A STUDY OF THE EFFECTIVENESS OF THE USE OF STEADY BURN WARNING LIGHTS ON DRUMS IN CONSTRUCTION WORK ZONES

Executive Summary

Prepared for:
Construction and Technology Division
Michigan Department of Transportation
8885 Ricks Road
Lansing, MI 48909

Prepared by:
Wayne State University
Transportation Research Group
Detroit, MI

Date: May 2005
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16. Abstract
The Wayne State University - Transportation Research Group performed a study to evaluate the effectiveness of drums as a delineation treatment in work zone traffic control with and without steady-burn warning lights mounted on them. Currently in Michigan, warning lights are used on drums in work zones. It should be noted that in the United States, only five other states (in addition to Michigan) have similar requirements. The purpose of this study was to evaluate driver behavior in terms of delineation and safety in work zones channelized by drums with and without steady-burn warning lights. As a part of this research, two methodologies were used including (1) field observations in actual highway work zone settings and (2) controlled laboratory experiments using a modern driving simulator. The study evaluated various driver performance measures including vehicular lateral placement, speed profile, steering reversals and traffic crash experiences. The statistical analysis performed in the field and driving simulator experiments did not indicate any difference in driver performance and safety measures between work zone traffic control with and without steady-burn warning lights on drums. The results of this study may be used in setting future policies in Michigan.
EXECUTIVE SUMMARY

INTRODUCTION

Since work zone fatalities have consistently risen over the past several decades in the United States, work zone safety has become a high priority for road agencies and the road building industry. Between 1997 and 2002, the nation has seen an increase in work zone fatalities of nearly 55% (1). Nationwide in 2002, there were 117,567 work zone crashes with 52,000 injuries and 1,181 fatalities (1). In Michigan, the total number of work zone crashes has declined between 1997 and 2003 by nearly 13 percent dropping from 6,638 crashes in 1997 to 5,800 crashes in 2003. The number of injuries has also decreased from 2,510 in 1997 to 1,636 in 2003, nearly a 35 percent decrease (2).

The safety gains in Michigan can be attributed to safety conscious decisions made by road agencies during the past decade. Increasing work zone safety can be achieved through the provision of clear and positive guidance. In a work zone, motorists are expected to travel along the roadway where their path of travel has changed due to lane closures or where they are constricted due to narrower lanes. In most cases, the available width of pavement may result in a decreased number of lanes or reduced lane widths which creates an unanticipated change in the path of travel. Also, the shoulders, which often provide a recovery area for motorists, may not be available in a work zone. Other sources of confusion for motorists include unfamiliar traffic control devices, a lack of visibility due to weather, poor lighting, deteriorated pavement markings and increased congestion. All of these factors lead to an increased demand on the driver, while reducing the acceptable margin of error for their navigation.

In order to guide motorists through work zones in a safe and efficient manner, various traffic control devices are used including temporary warning signs, pavement markings, and channelizing devices such as drums, cones, tubular markers and barricades. The National Manual on Uniform Traffic Control Devices (MUTCD) and the Michigan MUTCD both state that the primary function of temporary traffic control is to provide safe and smooth movement of motor vehicles while the normal function of the roadway is temporarily suspended (3, 4). The
National and Michigan MUTCDs also state that no one set of temporary traffic control devices in a project can satisfy all the conditions of safety including the motorist, workers, emergency personnel and equipment protection. The general safety principles for roadway work zones is to “…route road users through such zones using roadway geometrics, roadside features, and temporary traffic control devices as nearly as possible comparable to those for normal highway situations” (3).

In most work zones, numerous drums are used as traffic control devices to channelize traffic through the work zone. The drums have alternating orange and white retro-reflective stripes which make them highly visible, even during the nighttime. Warning lights may be mounted on the drums to “supplement the guidance function” of channelizing devices and alert the drivers’ attention to warning signs (4). The warning lights have been perceived as improving nighttime visibility. The warning lights may be flashing or steady burn warning lights. Flashing lights are commonly placed on drums and other channelizing devices used alone, or in a cluster, to warn motorists of a condition (3). The steady burn warning lights are most appropriate for use on channelizing devices, including drums placed in a series to channelize and guide motorists through the work zone (3). However, as per the MUTCD, the warning lights on drums are considered optional (3). As per the Michigan MUTCD, Type C steady burn warning lights “are intended to be used to delineate the edge of the traveled way on detour curves, on lane changes, on lane closures and on other similar conditions” (4).

This study will determine the effectiveness of drums, with and without steady burn warning lights, in work zones with regard to driver performance and safety during the nighttime driving hours.

**PROBLEM STATEMENT AND STUDY OBJECTIVE**

As requested by MDOT, research was conducted by the Wayne State University Transportation Research Group to evaluate the effectiveness of steady burn warning lights on drums in comparison to drums without such lights in highway work zones.
The major objectives of this study included:

- Performing a literature review on work zone channelizing devices.
- Conducting a current practices survey of the state departments of transportation (DOTs).
- Investigating crash trends in other states, where available, that have eliminated the steady burn warning lights from the drums in their work zones.
- Conducting controlled laboratory experiments with a driving simulator.
- Conducting a field experiment of driver behavior through work zones with drums, with and without steady burn warning lights, on Michigan freeways.
- Determining the relative effectiveness of the use of drums with and without steady burn warning lights.
- Conducting a Cost/Benefit Analysis if the effectiveness of the warning lights is statistically significant.
- Preparing a final report.

**BACKGROUND**

A comprehensive state-of-the-art literature review was performed in order to evaluate the effectiveness of drums with and without steady burn warning lights. Highlights of the main findings from the literature review are as follows:

- In general, traffic crashes typically increase during the construction period as compared to the pre-construction period, regardless of the type of project activity, work zone layout and temporary traffic control devices used.
- The predominant types of crashes that occur in construction work zones during the nighttime driving hours are fixed object and rear end crashes.
- A study performed for the American Traffic Safety Services Association in 1992 recommended the use of steady burn warning lights for left lane closures; however, it did not recommend the use of steady burn warning lights on drums for right lane closures.
- Studies performed for the Ohio Department of Transportation recommended that the use of steady burn warning lights be discontinued along tangent sections, curved, lighted, unlighted and tapered sections of roadways with ramps and crossovers.
• Another study found no statistical difference between using steady burn warning lights on all drums along the taper sections as compared to using warning lights on every or alternating drum (taper and tangent sections) in the construction zone. This study also found similar results between Type III (high intensity) reflectorized sheeting on drums and steady burn warning lights on drums in terms of lane change/merge locations at tapers associated with construction work zone located along tangent roadway segments.

• Driving simulators have been used to determine the effectiveness of work zone channelizing devices in terms of driver performance. Several studies have concluded that driver simulators can reasonably predict driver performance in terms of mean speeds and lateral placement.

**Current Practices**

A review of the current practices of state transportation departments was performed and viewed as one of the most important sources for determining the current state-of-the-practice with regard to the use of drums with and without steady burn warning lights in highway construction zones. It was found that five states (not including Michigan) currently require the use of steady burn warning lights on drums. Nine states require the use of steady burn warning lights on drums in tapers only and 30 states do not use steady burn warning lights on drums at all. In addition, two states did not require warning lights on drums yet they are generally utilized on curves and spot locations to emphasize potential hazards. Three states use warning lights on drums at the discretion of the engineer. Of the 30 states that do not use steady burn warning lights, 12 had predominately used steady burn warning lights in the past and have changed their policies to eliminate the use of the steady burn warning lights on drums in highway work zones.

A comparison of fatal crash rates was made as a part of this study between the states that use steady burn warning lights in all highway work zones and those that do not use the steady burn warning lights on drums. For states that use the steady burn warning lights (considered as the control), the crash rate (number of crashes per million vehicle miles of travel) between 1994 and 1998 was 0.65. The crash rate for states that do not use the steady burn warning lights
(considered as the test) was 0.70. It was found through statistical analysis that the crash rates were not significantly different at a 95 percent confidence level or alpha equal to 0.05, between the states that use and those states that do not use steady burn warning lights on drums.

Prior to 1995, the Iowa Department of Transportation utilized drums with Type C steady burn incandescent warning lights on work zone channelizing devices with engineering grade reflectorized sheeting. Since 1995, Iowa has only used high intensity grade sheeting on the drums and has eliminated the use of steady burn warning lights. Statistical analyses were performed to determine if there were any significant differences in the work zone crash frequencies before and after the steady burn warning lights were discontinued in the State of Iowa. The annual average crash frequencies for the years when Iowa used drums with steady burn warning lights (1989 to 1994) and when Iowa used drums without steady burn warning lights (1995 to 2000) were calculated. The total crash frequency during the years when Iowa used the steady burn warning lights was found to be 381.67 crashes per year with 23,894,200 vehicle miles of travel (VMT). During the years after Iowa discontinued the use of steady burn warning lights, the crash frequency decreased to 354.5 crashes per year while the average vehicle miles of travel increased to 28,058,800. A comparison was made of the Iowa state average crash data for fatal crashes, injury crashes, property damage only crashes and total crashes where drums with the steady burn warning lights and drums without the steady burn warning lights were used. Based upon a statistical analysis, it was found that the fatal and injury crashes were not significantly different at a 95 percent confidence level or alpha equal to 0.05. However, there was a significant difference for the property damage only and total crash comparisons. In both instances, the actual number of crashes observed for the period without steady burn warning lights was lower by 33 percent for the property damage only crashes and nearly 21 percent for total crashes. The period when steady burn warning lights were used with engineering grade reflectorized sheeting on drums had a significantly greater number of crashes. This reduction may be attributable to many factors. An important item to note is that the crashes did not increase due to the elimination of the steady burn warning lights in the work zone traffic control.
STUDY METHODOLOGY

Statistical Analysis of Effects of Drums With and Without Lights

The statistical significance of the safety and operational effectiveness of drums with and without steady burn warning lights was tested as a part of this study. The statistical analyses that were performed to test the effectiveness of drums with and without steady burn warning lights are as follows:

- Poisson test of significance – for traffic crash frequencies
- Chi-square test – for focus group sample for the driving simulator study to determine if the sample is representative of the population
- T-Test – for traffic crash rates, speed, lateral placement and steering reversal data (student’s t-test for ‘comparative parallel studies’)

Field Experiment

The WSU-TRG staff worked with MDOT’s Construction and Technology Division in order to select sites to perform the field experiment. The criteria for selection of work zone sites are as follows:

- Work zones that were located on MDOT roads and highways
- Work zones that were operational during the nighttime
- Work zones that were delineated through the use of drums, both with and without steady burn warning lights

The selected sites represented a variety of geographic, environmental, and traffic conditions in the State of Michigan. The selected sites encompassed urban and rural areas, locations with and without ambient street lighting, high and low traffic volume conditions and for different types of construction projects. A test site was considered a work zone where drums were being used without the steady burn warning lights. A control site was considered a location where drums with steady burn warning lights were being used.
Traffic operational and safety data was collected for each site including lateral placement of vehicles, speed through the work zone, traffic crash data and a physical inspection of the work zone including drums and lights. Driver behavior and vehicle placement within the lanes was recorded using video cameras. The video camera was mounted inside a survey vehicle and data was recorded for numerous runs through the advanced warning area and the work zone during the nighttime hours at all study sites, while following target vehicles. With this approach, the motorists were not aware that they were being monitored and thus, their driving behavior was unbiased. The video data was then analyzed in the laboratory in order to obtain quantifiable lateral placement data. When analyzing the video data, the lateral placement of vehicles was determined by locating the vehicle in the center of the lane, in the right third of the lane or in the left third of the lane. An acceptable lateral placement position of a vehicle meant when it was being driven in the center or left third of the open lane for drums located on the right side of the lane.

Spot speed data was collected for vehicles traveling through the work zones using portable radar detectors at all study sites. The speed data was collected at three locations in the work zone where a safe vantage location for speed measurements was available. In general, the speed data was collected: 1) at the beginning of the work zone, just before or immediately following the taper, 2) in the middle of the work zone, and 3) at the end of the work zone (prior to the beginning of the departure taper). All speed data was collected during nighttime hours only, since the warning lights can only be of value in darkness.

Traffic crash data (UD-10 forms) was collected from the Michigan State Police database for each of the study sites. The dates and locations of the traffic crashes were analyzed in order to determine where the crash occurred within the work zone, and whether or not the steady burn warning lights were present on the drums.

A survey of the current work zone configuration and the condition of the drums and the surrounding traffic control devices was also performed. The drums were surveyed in terms of their approximate location and condition assessment in order to establish the baseline reference. For the control site, details regarding the type of warning lights used, as well as the operational and physical characteristics of the steady burn warning lights (burn out, and orientation being turned and not properly visible, etc.) were collected.
The study sites were subdivided into two groups, those with drums with and those without steady burn warning lights. Statistical tests were performed to test the difference between these two groups. The sites were further subdivided by roadway functional classification and rural and urban settings as shown in Table ES-1. The sites were also subdivided by the availability of ambient lighting in the work zone. Statistical tests were performed for subcategories where appropriate.

### Table ES-1. Test and Control Site Categorization

<table>
<thead>
<tr>
<th>Category</th>
<th>Location</th>
<th>Site Type</th>
<th>Urban / Rural Setting</th>
<th>Lighting Available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interstate</td>
<td>I-75 at M-57</td>
<td>Control</td>
<td>Urban</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>I-94</td>
<td>Test</td>
<td>Urban</td>
<td>Mix</td>
</tr>
<tr>
<td></td>
<td>I-96</td>
<td>Control</td>
<td>Urban</td>
<td>Ambient</td>
</tr>
<tr>
<td></td>
<td>I-75 at US-10</td>
<td>Test</td>
<td>Urban</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>I-69</td>
<td>Test</td>
<td>Rural</td>
<td>None</td>
</tr>
<tr>
<td>Other Freeway</td>
<td>US-23</td>
<td>Control</td>
<td>Urban</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>M-10</td>
<td>Control</td>
<td>Urban</td>
<td>Ambient</td>
</tr>
<tr>
<td></td>
<td>US-131; M-43 to M-89</td>
<td>Test</td>
<td>Rural</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>US-131; US-10 to Luther</td>
<td>Test</td>
<td>Rural</td>
<td>None</td>
</tr>
<tr>
<td>Principal Arterial / Major Collector</td>
<td>US-10</td>
<td>Test</td>
<td>Rural</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Grand River Avenue</td>
<td>Test</td>
<td>Urban</td>
<td>Ambient</td>
</tr>
<tr>
<td></td>
<td>Telegraph Road</td>
<td>Test</td>
<td>Urban</td>
<td>Ambient</td>
</tr>
<tr>
<td></td>
<td>Bus. US-10 (Main St.)</td>
<td>Test</td>
<td>Rural</td>
<td>Ambient</td>
</tr>
<tr>
<td></td>
<td>US-12 (Michigan Avenue)</td>
<td>Control</td>
<td>Urban</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>M-39 (Southfield Road)</td>
<td>Control</td>
<td>Urban</td>
<td>Ambient</td>
</tr>
</tbody>
</table>

**Simulator Experiment**

The WSU-TRG utilized the driving simulator owned by Wayne State University’s Department of Occupational Therapy for the controlled laboratory experiment portion of this project. The simulator was used to conduct a controlled laboratory experiment of driver performance through work zones that used drums with and without warning lights. A sample focus group of motorists (89 individuals) participated in the driving simulator experiment.
The driving simulator that was used in this experiment is shown in Photographs ES-1, ES-2 and ES-3.

Photograph ES-1. Driving Simulator- Close Up View of the Virtual Driving Environment

Photograph ES-2. View of the Driving Simulator Configuration

Photograph ES-3. Sample Driver Using the Driving Simulator

As shown in the noted photographs, the driving simulator consists of five viewing screens, steering wheel, gas and brake pedals, starting ignition, rear view mirror with simulated views, headlights, high beam lights, and turn signals, as well as other features. The simulator is equipped with software programs to simulate typical driving scenarios, which include visual images of a highway/roadway environment, as well as audible information to simulate sounds of a running vehicle.
The focus group was comprised of a sample of the general driver population, selected from residents of the metropolitan Detroit area with experience in driving on the region’s freeway and arterial roadway systems to commute to work or school. The gender breakdown of the subjects was 42.5 percent male and 57.5 percent female, with varied ages and educational levels. In a pre-test survey form, the subjects were asked about their driving experiences in terms of commuting through work zones, involvement in work zone crashes, and speeding violations over the past five years. The pre-test survey was performed in order to obtain demographic information regarding the test subjects in order for correlations to be made with their performance in the driving simulator and to determine if the focus group consisted of a representative sample of drivers in the State of Michigan. In order to generalize the data and results of the driver simulator experiment, comparisons must be made between the sample population used in the laboratory experiment and the population in the State of Michigan. The sample of drivers in the focus group was found to be representative of drivers in the State of Michigan; however, the age group of 16-24 was slightly over-represented in the focus group sample.

Traffic crash data was extracted from the driving simulator video data. For each scenario, drums with lights and drums without lights, the number of traffic crashes occurring was totaled for all human subjects. In addition, the location of the crash was noted and summarized. A traffic crash occurred when the driver of the simulator veered from the travel lane and hit a barrel. Upon hitting a barrel, the simulation experiment for that driver ended. In reality, upon hitting a barrel, a driver could continue along the roadway or respond with evasive maneuvers to correct the vehicle’s lane position.

Comparisons of the travel speed were also made at specific data points along the work zone configuration: at the beginning of the work zone lane closure taper, half the distance into the work activity area and at the end of the lane closure. These points are representative of the data point locations for the field experiment work zone speed measurement done as a part of this study.
The lateral placement of vehicles through the work zone was quantified in order to assess the ability of drums with and without lights in guiding the motorists’ travel path through the work zone. Driver behavior and vehicle placement within the lanes was recorded using video cameras. The video data was analyzed in the laboratory in order to obtain quantifiable lateral placement data. When analyzing the video data, the lateral placement of vehicles was to be determined by superimposing a calibrated grid system on the television monitor during the viewing process. Similar to the field experiment, lateral placement was determined by locating the vehicle in the center of the lane, in the right third of the lane or in the left third of the lane. For the simulator experiment, the drums were placed along both sides of the lane lines indicating an acceptable lateral placement would be the center of the lane. Therefore, any deviation from the center of the lane to either the right third of the lane or the left third of the lane was considered as an unacceptable lateral placement condition.

The steering reversal of vehicles through the work zone was captured in order to assess the ability of drums with and without lights in guiding motorists through the work zone. The video data was then analyzed in the laboratory in order to obtain quantifiable steering reversal data. When analyzing the video data, the steering reversal data was determined by observing the number of times the driver shifted from one lane position to a second lane position due to movement of the steering wheel.

**RESULTS**

**Field Tests’ Traffic Crash Data and Analysis**

Tables ES-2 and ES-3 summarize the number of nighttime (9 p.m. to 6 a.m.) crashes that occurred during the construction period as shown for each site location in 2004 and for the same monthly period one-year prior (2003) without the presence of construction. The total number of crashes remained the same during the construction and for the same period in the year prior for both the control and test sites.
### Table ES-2 Control Site (Drums with Steady Burn Warning Lights)
#### Work Zone Crash Data Summary

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>I-75 at M-57 (April-November)</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>I-96 (April-December)</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>US-23 (April-November)</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>M-10 (April-November)</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>US-12 (Michigan Avenue) (April-November)</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>M-39 (Southfield Road) (April-November)</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>Total</td>
<td>38</td>
<td>38</td>
</tr>
</tbody>
</table>

### Table ES-3 Test Site (Drums Without Steady Burn Warning Lights)
#### Work Zone Crash Data Summary

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>I-94 (April-November)</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>I-75 at US-10 (May-September)</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>I-69 (April-November)</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>US-131; M-43 to M-89 (June-October)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>US-131; US-10 to Luther (May-August)</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>US-10 (April-August)</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Grand River Avenue (April-November)</td>
<td>14</td>
<td>9</td>
</tr>
<tr>
<td>Telegraph Road (April-November)</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>Bus. US-10 (Main St.) (April-November)</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>29</td>
<td>29</td>
</tr>
</tbody>
</table>
A comparison was made of the crash data for the control and test sites for all sites combined, the interstate only comparison, the other freeway comparison and the arterial comparison using the Poisson Test of significance. The procedure involves the calculation of the estimated expected ‘after’ crashes of the ‘test’ sites by multiplying the before crashes for the ‘test’ sites by the quantity of the after crashes of the control sites divided by the before crashes of the control sites. This calculation yields the estimated expected ‘after’ crashes per year for the ‘test’ sites. The percent change was then calculated by subtracting the actual crashes per year from the estimated expected crashes per year for the ‘test’ sites and then dividing by the estimated crashes per year. The calculations can be shown as follows:

- Expected ‘After’ Crashes of ‘Test’ = \( \frac{\text{Before’ Crashes of ‘Test’} \times \text{‘After’ Crashes of ‘Control’}}{\text{‘Before’ Crashes of ‘Control’}} \)

- % Change = \( \frac{\text{Expected Crashes – ‘After’ Crashes}}{\text{Expected Crashes}} \)

Based upon the noted calculations, crashes at all the sites, at the interstates, freeways and arterial test sites were not significantly different from the control sites at a 95 percent confidence level or alpha equal to 0.05.

**Simulator Experiment Traffic Crash Data and Analysis**

Significant differences between the various types of crashes, at the test and control groups, were tested for significance using the Poisson Test at a 95 percent confidence level or alpha equal to 0.05.

Table ES-4 summarizes the number crashes that occurred during the simulator scenarios for the control and test sites. The total number of crashes was higher for the control site scenario than for the test site scenario.
Based upon the calculations, it was found that the actual number of crashes per subject for the test scenario was lower than expected by slightly more than 71 percent than the control scenario. Therefore, a significant difference was found between the control and test scenarios in terms of crashes. The control scenario (drums with steady burn warning lights) had a significantly greater number of crashes than the test scenario.

### Field and Simulator Speed Data and Analysis

The calculated 85th percentile speed results for the field experiment are shown in Table ES-5.

<table>
<thead>
<tr>
<th>LOCATION (FIELD STUDY)</th>
<th>TEST SITE 85TH PERCENTILE SPEED (MPH)</th>
<th>CONTROL SITE 85TH PERCENTILE SPEED (MPH)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BEGINNING OF WORK ZONE</td>
<td>MIDDLE OF WORK ZONE</td>
</tr>
<tr>
<td>All Sites</td>
<td>53</td>
<td>51</td>
</tr>
<tr>
<td>Interstate Sites</td>
<td>64</td>
<td>66</td>
</tr>
<tr>
<td>Freeway Sites</td>
<td>63</td>
<td>57</td>
</tr>
<tr>
<td>Arterial Sites</td>
<td>47</td>
<td>40</td>
</tr>
</tbody>
</table>
**Field Speed Data Analysis**

In order to test the effectiveness of the drums with and without steady burn warning lights on operating speed, the student’s t-test was used to determine if the differences are significant. The student’s t-test was used when comparing the mean or 85\textsuperscript{th} percentile speed for a group of test sites with a group of control sites using the ‘comparative parallel’ evaluation plan. The data used in the statistical analysis is based on the individual observations measured from the data taken in the field. Several comparisons were made to evaluate if the differences in 85\textsuperscript{th} percentile speed were significant between the control and the test sites. The comparisons made include the following: all test and all control sites, interstate test sites and interstate control sites, freeway test sites and freeway control sites, and arterial test sites and arterial control sites. When selecting locations for a comparative parallel study, roadways were selected as pairs based upon similar roadway category, average daily traffic, and posted speed limits. Individual site comparisons were also made including I-75 at M-57 and I-75 at US-10, I-96 and I-94, US-23 and US-131, M-43 to M-89, US-23 and US131, US-10 to Luther, US-12 and Grand River Avenue, and M-39 and Telegraph Road.

The statistical analysis of the speed data analysis for the field experiment showed no difference between 85\textsuperscript{th} percentile speed at the control and test sites for all the sites except for the comparison between the control site US-23 and the test site US-131 in Kalamazoo.

**Simulator Speed Data Analysis**

The 85\textsuperscript{th} percentile speeds of the subjects using the driving simulator were consistently higher than the field experiment 85\textsuperscript{th} percentile speeds. The posted speed limit for the simulator was 70 mph prior to the construction zone and 60 mph in the construction zone. In a controlled laboratory experiment, as found also in Tornros study (5), when all elements of the driving task such as conflicting traffic, congestion, visual obstructions, and adverse weather are removed, the driver is able to concentrate on only the driving task, thereby increasing their speed. Although the 85\textsuperscript{th} percentile speed was higher in the simulator experiment as compared to the field experiment, the patterns were similar to those found in the field experiment.
In order to test the effectiveness of the drums with and without steady burn warning lights for the simulator speed data, the student’s t-test was used to determine if the differences were significant. The student’s t-test was used to compare the mean speed for the test site scenario with the control site scenario using the ‘comparative parallel’ evaluation plan.

The statistical analysis of the speed data for the simulator experiment showed no difference between 85th percentile speed at the control and test sites.

Field and Simulator Lateral Placement Data and Analysis

The lateral placement data for the field experiment is summarized in Table ES-6.

Table ES-6. Lateral Placement Data Summary

<table>
<thead>
<tr>
<th>LOCATION (FIELD STUDY)</th>
<th>CONTROL SITE PERCENTAGE IN ACCEPTABLE LANE POSITION</th>
<th>TEST SITE PERCENTAGE IN ACCEPTABLE LANE POSITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Sites</td>
<td>92%</td>
<td>94%</td>
</tr>
<tr>
<td>Interstate Sites</td>
<td>94%</td>
<td>92%</td>
</tr>
<tr>
<td>Freeway Sites</td>
<td>91%</td>
<td>99%</td>
</tr>
<tr>
<td>Arterial Sites</td>
<td>95%</td>
<td>97%</td>
</tr>
</tbody>
</table>

Field Lateral Placement Data Analysis

For the analysis of the lateral placement data for the field experiment, no significant difference between the lateral placement of vehicles while driving through the control and test site scenarios was found for the following comparisons:

- Arterial Control Sites vs. Arterial Test Sites
- Control Site I-75 at M-57 vs. Test Site I-75 at US-10
- Control Site I-96 vs. Test Site I-94
- Control Site US-12 vs. Test Site Grand River Avenue
- Control Site M-39 vs. Test Site Telegraph Road
A significant difference was found in the lateral placement data for the field experiment between control and test sites for the following comparisons:

- Total Control Sites vs. Total Test Sites
- Interstate Control Sites vs. Interstate Test Sites
- Freeway Control Sites vs. Freeway Test Sites
- Control Site US-23 vs. Test Site US-131, Kalamazoo
- Control Site US-23 vs. Test Site US-131, Cadillac

**Simulator Lateral Placement Data Analysis**

The percentages in the acceptable lane position for the driving simulator experiment were lower than the field experiment. This was due to the fact that the acceptable lane positions for the field experiment included the two furthest one-third lane positions from the drums, while the acceptable lane position for the simulator was only the center of the lane position as the drums were placed on both sides of the traveled lane.

In this analysis, comparisons between the field and simulator experiments were not performed. The purpose of the simulator experiment was to assess the relative differences in driver performance due to the presence/absence of warning lights on drums. It is assumed that the driver performance measures from the simulator experiment will not match the field experiment; rather, the relative differences between the field experiment will follow similar trends as the simulator experiment.

For the analysis of the lateral placement data for the simulator experiment, no significant difference between the lateral placement of vehicles while driving through the control and test site scenarios was found.

**Field and Simulator Steering Reversal Data and Analysis**

The steering reversal data for the field and simulator experiments is summarized in Table ES-7.
**Table ES-7 Steering Reversal Data Summary**

<table>
<thead>
<tr>
<th>LOCATION (FIELD STUDY)</th>
<th>CONTROL SITE MEAN NUMBER OF STEERING REVERSALS PER VEHICLE PER MINUTE</th>
<th>TEST SITE MEAN NUMBER OF STEERING REVERSALS PER VEHICLE PER MINUTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Sites</td>
<td>2.54</td>
<td>1.84</td>
</tr>
<tr>
<td>Interstate Sites</td>
<td>3.08</td>
<td>2.34</td>
</tr>
<tr>
<td>Freeway Sites</td>
<td>2.72</td>
<td>1.35</td>
</tr>
<tr>
<td>Arterial Sites</td>
<td>1.64</td>
<td>1.47</td>
</tr>
</tbody>
</table>

**Field Steering Reversal Data Analysis**

The statistical analysis of the steering reversal data for the field experiment showed no significant difference between the control and test sites for the following comparisons:

- Interstate Control Sites vs. Interstate Test Sites
- Arterial Control Sites vs. Arterial Test Sites
- Control Site I-75 at M-57 vs. Test Site I-75 at US-10
- Control Site I-96 vs. Test Site I-94
- Control Site US-12 vs. Test Site Grand River Avenue
- Control Site M-39 and Test Site Telegraph Road

A significant difference was found in the steering reversal data analysis for the field experiment between control and test sites for the following comparisons:

- Total Control Sites vs. Total Test Sites
- Freeway Control Sites vs. Freeway Test Sites
- Control Site US-23 vs. Test Site US-131, Kalamazoo
- Control Site US-23 vs. Test Site US-131, Cadillac
**Simulator Steering Reversal Data Analysis**

The number of steering reversals experienced in the driving simulator experiment were higher than those in the field experiment. This was due to a combination of the higher speeds found in the simulator experiment as well as the restriction on the acceptable lateral position to only the center of the traveled lane.

The statistical analysis of the steering reversal data for the simulator experiment showed no difference between the control and test scenarios.

**CONCLUSIONS**

The intent of this study was to determine the effectiveness of drums with and without steady burn warning lights in work zones with regard to delineation and safety. A field experiment as well as a driving simulator laboratory experiment was conducted to assist in this determination of effectiveness. Traffic operational and safety data was collected for each site and each simulator scenario, including traffic crash data, speed through the work zone, lateral placement of vehicles and the steering reversal frequencies. The statistical significance of the effectiveness of the drums with and without steady burn warning lights was tested in order to better understand whether the changes observed in the measures of effectiveness of crash data, speed, lateral placement, and steering reversals are attributable to the presence of steady burn warning lights on the drums. Several hypotheses were tested for significance.

Based upon the field and driving simulator experiment’s statistical analysis presented in this report, overall there was no significant difference in delineation and safety between drums with steady burn warning lights and drums without steady burn warning lights. These findings are consistent with the study by Pant and Park (6) which found that steady burn warning lights had little impact on driver’s speed, lateral placement, or weaving along tangential sections of rural four-lane divided roadways. Pant performed a second study (7) which determined that steady burn warning lights had little impact on driver’s speed, lateral placement, weaving and traffic conflict along divided and undivided highways at horizontal and vertical curves, with and
without ambient lighting, ramps, tapers and crossovers. Although the study performed by the WSU-TRG did not specifically address horizontal or vertical curves due to the lack of field conditions to collect an adequate sample size, the findings of such a study may parallel the Pant study (7) as this study performed by the WSU-TRG paralleled the Pant and Park study (6).

Although the simulator experiment produced different values for the 85th percentile speed, average lateral placement and average number of steering reversals, it was assumed that the drivers would behave similarly in a simulator as in a real-world scenario. This was supported in a study performed by Godley et al. (8) which found when comparing a total of forty-four drivers in a real-world scenario to a simulator scenario, the motorists acted similarly in a simulator as compared to an instrumented car.

The results of this study indicated there is no significant difference in delineation and safety between drums with steady burn lights and without steady burn lights. The study outcome may be used to set future policies and directions toward work zone safety and delineation.

REFERENCES


