IR-03-01

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ABSTRACT

METHODS TO IMPROVE THE EFFECTIVENESS OF ADVANCE WARNING SIGNS IN ALABAMA CONSTRUCTION WORK ZONES

Work zone safety has been and will continue to be of growing concern to both motorists and transportation officials alike. Part of the problem is the growing tendency of motorists to disregard advance warning signs in work zones. The purpose of this research is to identify methods to improve the impact the advance warning area of a work zone has on driver behavior.

The research performed was divided into six distinct tasks. These were: 1) perform a comprehensive literature review to determine what devices and methods have a positive impact on traffic control and driver behavior, 2) perform a review of current standards that affect Alabama work zone traffic control, 3) conduct on-site visits to Alabama Department of Transportation work zones to gain insight into the implementation of Traffic Control Plans, 4) survey engineers who are involved with the construction and maintenance of Alabama's roads and highways and analyze the results, 5) analyze the Critical Analysis Reporting Environment accident database to determine characteristics of work zone accidents and compare those characteristics with those for all accidents occurring within the same time frame, and 6) to recommend improvements in planning and operation of construction work zones. Conclusions and recommendations regarding effective traffic control methods and devices to reduce work zone accidents are made.

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# CHAPTER ONE

# INTRODUCTION

## Background

Traffic safety is a topic of growing concern to many Americans. Since the early 1980s the volume of traffic on our nation's highways has increased rapidly while the construction of new highways has increased only marginally. Alabama is no different from the rest of the nation. At any given time, there are numerous work zones on Alabama highways and roads that involve a disruption of normal traffic flow. In the past three years there have been over four hundred thousand traffic accidents just within the State of Alabama, with just under seven thousand five hundred of those occurring in work zones. That means that out of every 1000 accidents in Alabama, 18 of them occurred in a work zone. Another key problem with the growing number of work zones on our highways is the delay caused to the traveling public. Thus there is a need to both improve safety and congestion in work zones.

A key concern to people who work and transit work zones is that many people simply ignore the presence of construction or maintenance zones. This leads to a great speed disparity between those drivers who heed the advance warnings and those that do not. This in turn leads to accidents and thus more congestion. Why the drivers feel that they can ignore the signing of work zones is what led to this research.

**Objective**

The goal of this research is to define work zone safety problems and to identify methods of improving the effectiveness of the advance warning area of work zones. This goal will be achieved by structuring the research into six objectives. These objectives are defined as follows:

1. To review literature pertaining to work zone activities for the purpose of identifying effective traffic control devices and methods;
2. To identify the current standards of work zone traffic control that are applicable to work zones within the State of Alabama;
3. To conduct on-site field visits of work zones to gain insight into the Traffic Control Plan implementation process and field practices of inspecting and maintaining traffic control devices;
4. To survey Alabama public and private sector engineers about critical issues involving work zones;
5. To investigate the use of the Critical Analysis Reporting Environment (CARE) software, an accident database for the State of Alabama, to provide accident analysis data for work zones; and
6. To recommend improvements in the planning and operation of construction work zones.

**Methodology**

The Internet, through the Transportation Research Information Services (TRIS) website, was used to assist in conducting the literature review. Transportation Research Board (TRB) literature was obtained and reviewed in detail. Current specifications for work zone traffic control, of both national and state origin, were also reviewed. Project plans were reviewed to assist in the field visits that were conducted for work zone projects within Lee and Macon Counties, Alabama. A survey to assess opinions regarding work zone traffic control was prepared and sent to Alabama County engineers, Alabama Department of Transportation (ALDOT) District, Division, and Central Office engineers, and engineering consultants that work within Alabama. The CARE accident database system was used to conduct an analysis of work zone accidents and to compare the characteristics of work zone accidents to all accidents occurring in Alabama in a three year period. Finally, conclusions and recommendations to improve both the planning and construction phases of work zone operations were prepared.

# CHAPTER TWO

# LITERATURE REVIEW

## Methodology

There are several different areas of previous research that must be looked at for this study. Reports on crash statistics indicate which areas of work zones need improvements in traffic safety. Reports on the effectiveness of several different traffic control devices that are available show what options are viable and worthwhile and which are too expensive or not very effective or both. Last, large scale programs at improving work zone safety are important to determine methods of improving safety in all work zones.

## Literature on Accident Statistics

Nicholas Garber and Ming Zhao published an article in 2002 in the *Transportation Research Record* (TRR) series relating to the characteristics of work zone crashes in the state of Virginia (Garber and Zhao 2002). This data is confined only to work zone accidents and does not relate to normal driving conditions. However, the authors place each of the accidents that they analyze into one of the five primary areas of a work zone: Advance Warning, Transition, Longitudinal Buffer, Activity, and Termination. These authors conclude that of these five, "the activity area is the most prevalent accident location in a work zone, and the termination area is the safest area in a work zone" (p. 25). Figure 2.1 defines the five areas (Advance Warning, Transition, Buffer, Activity, and Termination) within a typical work zone.

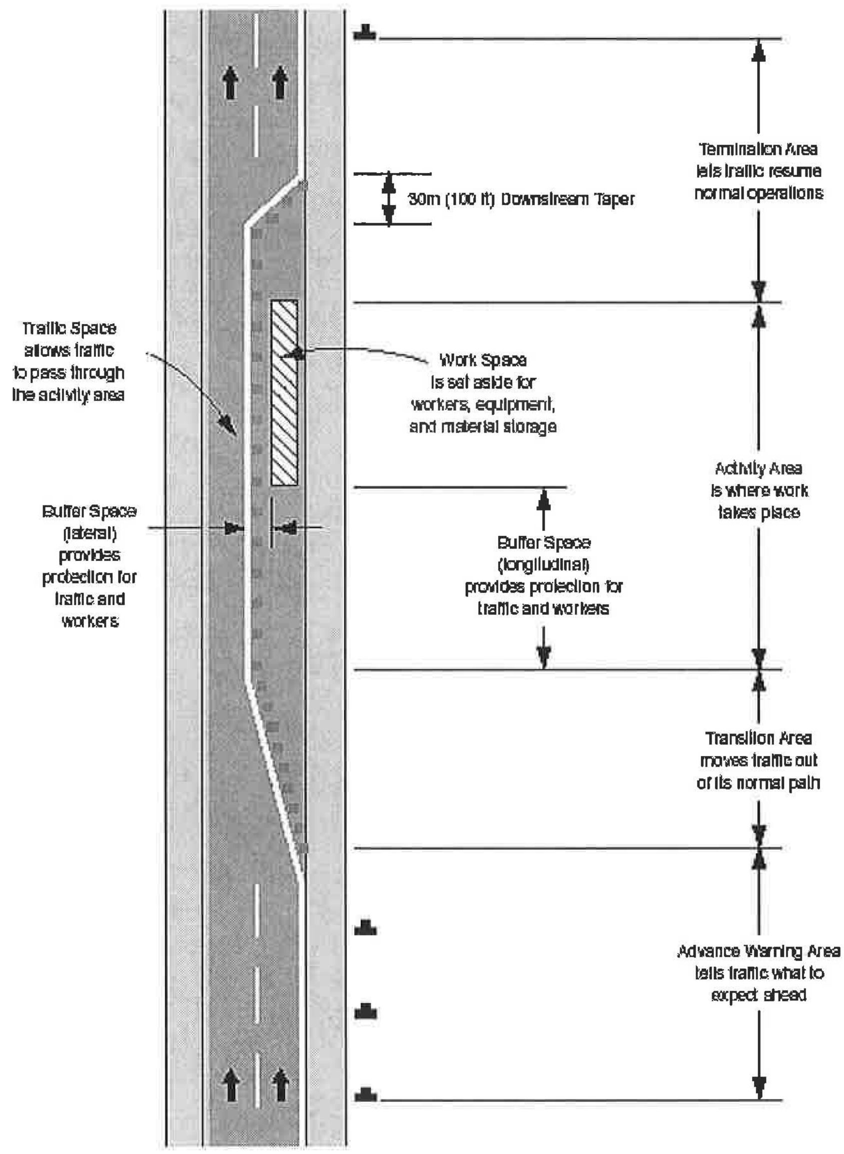


**Figure 2.1: Definition of the Five Areas of a Work Zone (MUTCD Figure 6C-1)**

Garber and Zhao looked at accident severity, collision type, type of highway, and time of day for all accidents in their data set to determine what effect these factors have on work zone accidents. These factors were obtained from police accident reports in the state of Virginia. In addition to finding that the activity area is the most dangerous in a work zone, the authors ranked the advance warning area third worst out of the five areas listed. With regard to the other factors, the authors found that Property Damage Only was the most prevalent type of crash and Rear End was the most common collision type. When the accidents in just the advance warning area were investigated, the authors found that 83% of the collisions occurring in this area were Rear End. The authors conclude that this high percentage of Rear End accidents in the advance warning area is explained by the high variation in speeds between the normal stretch of road and the work zone.

Jil Chambless, Adnan Ghadiali, Jay K. Lindly, and John McFadden published an article in the ITE Journal that looks at "typical work zone characteristics and the differences between work zone and nonwork zone crashes in order to identify some issues that are special or different about work zone crashes" (Chambless et al. 2002, p 46). To determine these characteristics, the authors utilized computerized work zone crash data from Alabama, Michigan, and Tennessee. The authors noted that discrepancies arise from the nature of accident reporting and the reliance of police officers' evaluations of whether or not an accident is work zone related. Work zone crashes were shown to be under 2% of the total crashes in the three states examined. Accident severity was similar in work zone and nonwork zone crashes. The authors also found that most work zone crashes occur in urban areas and the primary contributing circumstances were most often cited as misjudging stopping distance/ following too closely.

The crash characteristic analysis revealed that 25% of the work zone crashes studied involved an injury or fatality. Since the authors studied three disparate states' data, the results are taken loosely by the authors to represent national trends. The authors noted that "63% of work zone crashes take place on interstate, U.S., and state roads, as compared to only 37% of nonwork zone crashes" (p 49). This research hints that one of the greatest areas of traffic safety that needs improvement is in work zones.

A study of fatal crashes in Georgia work zones was performed by Janice Daniel, Karen Dixon, and David Jared with the results published in TRR series (Daniel, Dixon, and Jared 2000). These three authors noted that many studies are performed on work zone crashes, but

> few studies focus on fatal crashes within work zones, although a clear understanding of the driver, roadway, and work zone conditions associated with fatal crashes will facilitate the development of strategies aimed at improving safety and reducing fatal as well as nonfatal crashes (p 18).

The purpose of the study was to improve work zone safety by determining strategies for reducing speeds in work zones. The authors reviewed three years of data for Georgia work zones and looked in particular at several factors in the crashes. Some of these factors were construction activity, vehicle type, and roadway characteristics.

Daniel, Dixon, and Jared found that the majority of fatal crashes in work zones were in idle construction (versus maintenance) zones, and involved rear end accidents. The authors further found that more fatal accidents occur at night and "the primary contribution factors to fatal crashes in work zones are Driver Lost Control, Failed to

Yield, and Too Fast for Conditions" (p 22). The higher incidence of rear end collisions indicates that the drivers were not aware of conditions they were to encounter down the road. Addressing this lack of awareness is the primary function of the advance warning area of any work zone.

**Literature on Traffic Control Devices**

There are many traffic control devices that are available for use in work zones. The following group of studies looks at many of these devices. An article in the TRR series written by Helmut Zwahlen and Thomas Schnell deals with the daylight detection and recognition of fluorescent verses nonfluorescent signs (Zwahlen and Schnell 1997). The authors' goal in this study was to

> investigate the peripheral detection and recognition of fluorescent and nonfluorescent color targets against a multicolored (spring foliage, green, gray, brown) background as a function of the peripheral viewing angle and the target size (p 28).

The tests were conducted on a runway where the conditions of the sun could be controlled. The authors set up tests so that the sun would be behind the drivers and therefore have the most direct light available on the signs. The target size and distance from the traveled way were varied to obtain the desired data.

After an extensive presentation of their results, Zwahlen and Schnell stated that "on the basis of the results presented in this study, it may be concluded that fluorescent colors generally outperform their nonfluorescent counterparts for percentage of detection" (p 39). The authors further conclude that, with the exception of fluorescent yellow-green, fluorescent signs are not as easily recognized as their nonfluorescent counterparts. The authors note that correctly recognizing a color in the periphery depends largely on how well that color contrasts with the background. This study indicates that for any sign to be utilized to its greatest advantage it must be properly installed and inspected to maintain its functional capacity.

Joseph Hummer and Craig Scheffler published a similar study on the effectiveness of fluorescent orange versus standard orange signs in an article in the TRR series (Hummer and Scheffler 1999). These authors noted that "The objective of this research was to conduct a controlled comparison of safety-related operational measures found with standard versus fluorescent orange warning signs in work zones" (p 55). The two authors used the following five operational measures of effectiveness: "traffic conflicts, the percentage of all vehicles in the left lane (the lane to be closed), the percentage of trucks in the left lane, mean speed, and speed variance" (p 57). The authors used sites in North Carolina and conducted a before-and-after study with control to determine the measures of effectiveness before and after the standard signs were replaced with fluorescent signs.

Hummer and Scheffler found that the treatment sites experienced a lower conflict frequency, but the mean speed data led to inconclusive results as a result of the different geometrics of the two sites studied. The differences in speeds were observed to be lower for 13 of the 26 hours of data taken. Hummer and Scheffler conclude that "fluorescent orange signs caused some changes, primarily positive, in driver behavior" (p 60). The authors conclude by stating that even if the benefits are small, when dealing with human life those small benefits gained by using the fluorescent signs are worth the cost difference.

David Burns and Timothy Donahue published an article in the TRR series dealing with the field and laboratory measurements of color and brightness of the yellow and yellow green fluorescent signs (Burns and Donahue 2001). In this article the authors state that "to fulfill their role as safety devices, traffic signs must function effectively day and night in all driving environments and under all visibility conditions (p. 48). The authors also note that "a growing body of engineering research indicates that fluorescent-retroreflective signing does promote safer driver behavior on the road" (p. 49). The authors continue by citing several works on driver behavior when the ordinary signs are replaced by the fluorescent signs.

Burns and Donahue discuss the procedures that were used to determine the photometric properties of the standard test sign and the conditions under which the tests were to be conducted. The authors find that the results of laboratory testing conducted in accordance to ASTM standards and FHWA regulations are useful only as an estimate of performance under field conditions. These conclusions are important to advance warning sign research when looking at how drivers will see and react to the change from normal road to work zone conditions.

Thomas Schnell, Keith Bentley, Elizabeth Hayes, and Martin Rick are the authors of an article published in the TRR series that deals with the legibility of fluorescent signs (Schnell, Bentley, Hayes, and Rick 2001). The article is a comparison between fluorescent and non-fluorescent signs and the distances to which they are legible. The authors note that "Fluorescent colors in traffic sign sheeting materials represent a fairly new method for attracting driver attention and for enhancing legibility of text or recognition symbols" (p 31). Their literature review referenced numerous articles that indicated "fluorescent colors are far more attention getting than their normal color counterparts" (p 31). Research into fluorescent signs is important for determining driver behavior around work zones.

The authors chose to perform field work only to determine the legibility of six test signs. One side of each sign was normal color and the other side was the corresponding fluorescent color. The authors concluded that "adding the property of fluorescence to the colors used in this study did in fact statistically significantly increase the legibility distances" (p 37). It was also found that the legibility distance increased for all six test signs and that the increase was between 5.3 and 15.9 percent. The authors concluded by noting that their study was very limited in nature (daylight conditions only) and that the increase in legibility may be far greater during conditions with less natural light present. For the limited conditions studied the authors did find that in general the fluorescent signs improved the legibility distance of traffic signs.

Another article published in the TRR series is by Kristen Sanford Bernhardt, Mark Virkler, and Nawaz Shaik and deals with the effectiveness of three particular traffic control devices in improving work zone safety (Sanford Bernhardt, Virkler, and Shaik 2001). The three devices looked at were white lane-drop arrows, the citizens band (CB) wizard alert system, and orange rumble strips. The authors cite a wide range of sources that all show the need for improved work zone safety. To determine the effectiveness of these devices, the authors looked at the differences in speeds and the merging characteristics at four test sites when the three devices were implemented separately.

Three characteristics were looked at to determine the difference in speeds and merging characteristics: lane distribution, mean speed characteristics, and speed variance characteristics. The authors conclude that the lane-drop arrows and the rumble strips significantly affected the lane distribution and the mean speed, but had a very limited effect on the speed variance. For the CB system the authors concluded that the system had very limited effect on mean speed and lane distribution. Again, there was no noticeable effect on the speed variances. Overall the authors concluded that these three devices did not cause any accidents themselves and improved safety in work zones on a limited basis.

An article in the TRR series by Eric Meyer examines the effectiveness of the orange removable rumble strips (Meyer 2000). Meyer cites several applications of rumble strips, most notably before intersections and work zones. The goal of the study "was to evaluate a new type of rumble strip that is intended to increase safety through better visibility and reduce costs through shorter installation and removal times" (p 37). This new type of rumble strip is an adhesive tape that is colored orange. The author notes in his conclusions that the tape did not create a noticeable noise, but that there was a reduction in 85$^{th}$ percentile speeds because of the bright color used.

Melisa Finley, Gerald Ullman, and Conrad Dudek published an article in the TRR series dealing with a sequential warning-light system for use in work zone lane closures (Finley, Ullman, and Dudek 2001). The basis for the authors' work is summarized in their first sentence: "When a lane is closed for the maintenance and construction of a roadway, temporary traffic control devices must provide for the continuity of traffic flow and the safety of workers and motorists" (p. 39). The warning light system is a series of flashing lights placed on the top of channelizing devices that flash one at a time from one end to the other of the line of lights to indicate the direction the driver is to merge. The study by these authors was conducted for nighttime conditions on an old runway, and without the placement of advance warning signs "since the researchers wanted to focus strictly on the effect of the warning-light flash rates and approach speeds on motorists' reaction and preference to the warning-light system" (p 40). After testing 59 people on the new warning-light system, the authors concluded that the use of this system had a positive influence on driver behavior and is not confusing to the general public.

Michael Fontaine and Paul Carlson look at two devices that may be used in rural work zones in an article they published in the TRR series (Fontaine and Carlson 2001). The two devices studied were speed displays and rumble strips. The authors noted:

> The speed displays create speed reductions in two ways. First, drivers tend to slow once they see their speed shown on the display. Second, the radar unit in the display will activate radar detectors far in advance of the work zone. This may influence drivers to slow down because of the perceived presence of a police officer (p 28).

The authors noted that the "rumble strips provide an auditory and vibratory warning to the driver of the upcoming work zone" (p 28). After looking at field speed data collected at four sites, the authors found that the rumble strips had little effect on the speeds of passenger cars and had only a minimal effect on truck speeds. On the other hand, the speed displays were found to have a noticeable impact on both car and truck speeds.

Another key traffic control device in reducing driver speeds is the Changeable-Message Sign (CMS). Nicholas Garber and Srivatsan Srinivasan published an article in the TRR series stating:

> the purpose of this portion of the project was to evaluate the impact of duration of exposure to a CMS with radar, as well as the type of vehicle, on the effectiveness of this equipment to reduce speeds and other speed characteristics (e.g., variance, $85^{th}$ percentile speeds) of speeding drivers in work zones (Garber and Srinivasan 1998, p 62).

The larger project referred to dealt with the general effectiveness of a CMS. After installing the devices in pre-selected sites and taking data, the authors found that the CMS is a viable means of reducing speeds in work zones for any duration up to seven weeks. The authors further noted that the speed variances are generally positively affected, but the CMS has no appreciable effect on one vehicle type over another.

A more in-depth study of the CMS was published in the TRR series by Conrad L. Dudek and Gerald L. Ullman (Dudek and Ullman 2002). These two authors looked at the effectiveness of different ways of showing text on a CMS: flashing an entire one-frame message, flashing one line of a one frame message, and alternating text on one line of a three line CMS while keeping the other two lines of text the same (p 94). Each of the three methods was studied separately and all were conducted in a laboratory setting. Figure 2.2 contains examples given by the authors for each of the three methods tested (p. 97,99):

One Frame Example: Either the whole was flashed or the top line was flashed.

| |
|---|
| FREEWAY BLOCKED<br>AT [location]<br>USE OTHER ROUTES |

Two Frame Examples:

| | |
|---|---|
| CONSTRUCTION<br>AT [location]<br>ALL LANES CLOSED | CONSTRUCTION<br>AT [location]<br>USE OTHER ROUTES |
| First frame | Second frame (with redundancy) |

or

| | |
|---|---|
| CONSTRUCTION<br>AT [location]<br>ALL LANES CLOSED | USE<br>OTHER ROUTES |
| First frame | Second frame (without redundancy) |

**Figure 2.2: Examples of Flashing Lines on a Changeable Message Sign**

The authors found that "the results of this study indicate that flashing a one-frame, three-unit message on a CMS has no significant effect on motorist comprehension of the information being presented" (p 97). This indicates that the driver would comprehend the message whether or not it was flashing on a CMS. The second form showing the message was flashing one line of a one-frame message. The authors found that "the results of this study indicate that flashing one line of a one-frame CMS message containing three units of information reduces the ability of motorists to remember parts of the message that are not flashing" (p 98). The authors also found that the time needed to read the sign was greatly increased when flashing one line of the message. The authors found that for the third method of showing a message, the ability of motorists to remember parts of the message is not affected, but the reading time is "significantly increased" (p 101). Overall, the authors found that none of the three methods studied of showing a message on a CMS should be used. This recommendation was based on the reading times for the messages, which were increased for all three types of displaying messages studied here. This is not to say that CMS messages are not useful, only that the three methods of communicating those messages explained in the study should not be implemented.

Brent M. Turley looks at the effectiveness of the CMS when used as caution displays (in various forms) in an article in the *ITE Journal* (Turley 2002). Turley points out in the introduction to the literature review portion of his paper that "in past research, caution displays were appendages to broader research on directional displays" (p 35). To determine the effectiveness of the caution displays, the author conducted two different types of experiments. The first was a field study in which speed reduction and conflict characteristics were studied and analyzed. The second experiment was an opinion survey that was aimed at the general public.

Turley found that none of the various caution displays caused any dangerous conflicts in the traffic flow. While the Flashing Box display had no statistical influence on the speeds, the Dancing Diamond was shown to have a statistical significance on speed reduction. Lastly, the author notes that the free flow speed was not affected by the caution displays. The survey results showed that most people recognized any form of the caution display. Furthermore, the author found that of those surveyed, "54 percent thought that the Dancing Diamonds would best prompt safe driving, followed by the

Flashing Diamonds (43 percent) and the Flashing Box (3 percent)" (p 40). This research shows that the CMS is a viable resource for promoting safety in work zones.

Yet another application of the CMS is explored in an article in the TRR series by Patrick McCoy and Geza Pesti (McCoy and Pesti 2002). These two authors look at the CMS as applied in a condition-responsive system for work zones. The purpose of this system is to advise drivers in advance of a work zone of the actual speeds of drivers in a work zone. The purpose is to persuade drivers to slow down before the slower traffic is encountered. While the authors confine their study to rural interstate highways in the midwest, the implications of this research are far reaching. The authors found that

> Advisory speed messages displayed during periods of lower-density flow were not effective in reducing speeds. However, when traffic flow approached higher-density levels, these messages were effective in reducing speeds at locations where drivers were aware of the work zone ahead and likely to perceive the need to slow down (p 18).

The authors admit that their research is limited and that further research is needed to make the system more adaptable to all driving conditions. However, the idea of a system that allows drivers a glimpse into driving conditions further down their traveled way holds promise for the future of work zone safety.

Another device that was developed to improve work zone safety is the real-time Travel Time Prediction System (TIPS). This device was evaluated by Helmut T. Zwahlen and Andrew Russ, who published their findings in an article in the TRR series (Zwahlen and Russ 2002). After describing the system and the reasons that it was developed, the authors proceed to give the objective of their research as "to determine the accuracy of the predicted travel times compared with the actual travel times" through a work zone (p 88). The authors had three crews travel through a test work zone site for three days. After a total of 119 runs, the authors determined that "88% of the readings taken for any CMS or for all three CMSs were accurate within +/- 4 minutes, which is also the resolution of the system" (p 92). This indicates that the TIPS system provides accurate information and therefore is a viable tool to use in improving work zone safety.

**Literature on Wide-Scale Safety Programs**

There are many publications that deal with procedures for improving work zone safety on a large scale. James Bryden and Laurel Andrew published an article in the TRR series that deals with a quality assurance program implemented in New York to manage work zone traffic control (Bryden and Andrew 2001). The authors noted that work zone safety was a primary factor in starting a quality assurance program. The inspection procedures and sample selection procedures are described in the paper in ample detail. The importance of a quality assurance program in any work zone is to ensure that the project managers and construction contractors are implementing and maintaining all temporary traffic control for the work zone in which they are operating. Each work zone is rated by an inspection team to indicate how well the work zone meets the requirements found in the plans and specifications of the particular project.

Bryden and Andrew conclude "This work zone quality assurance process has been very successful in improving the quality of temporary traffic control in New York work zones and has led to numerous improvements in the overall temporary-traffic-control program on department projects" (p. 9). There are many specific benefits that these authors cite in the program. Since its inception, the program has improved the use of temporary traffic barriers, improved flagging, reduced sign conflicts, and improved the condition guidelines for all traffic control devices.

The National Cooperative Highway Research Program (NCHRP) published Report 475 in 2002 that describes research by James Bryden and Douglas Mace. Report 475 deals with nighttime highway construction and maintenance (Bryden and Mace 2002). This report is a systematic approach for determining the need for nighttime work, determining the different traffic control methods and devices available, and methods to improve safety during nighttime work. The importance of this work is the very inclusive approach to traffic control the research represents and the high importance that is placed on work zone safety.

A second NCHRP report (Report 476) was also published in 2002 (Bryden and Mace 2002). This report also describes research performed by James Bryden and Douglas Mace, but Report 476 looks at issues concerning nighttime work zone traffic control. This report is a step-by-step approach to designing and implementing traffic control in a nighttime work zone environment. The report contains options for traffic control, detailed information on the uses of particular devices needed for those options, and procedures for putting those options into use. The authors have published a comprehensive tool for nighttime work zones that includes many useful guidelines concerning safety in nighttime work.

Gerald Ullman, Paul Carlson, and Nada Trout have written an article published in the TRR series that deals with the Double-Fine law in Texas (Ullman, Carlson, and Trout

2000). The authors note that "This law doubles the minimum and maximum fines applicable for traffic violations that occur in a work zone where workers are present" (p 24). The author's goal was to evaluate the short-term effectiveness of the law. To do so the authors look at two measures of effectiveness: the speeds in the work zones, and the dispensation of traffic citations.

Ullman, Carlson, and Trout found that the double-fine law had little effect on the speeds in work zones. This conclusion is derived from on-site measuring of speeds and comparing the 85$^{th}$ percentile speeds with those obtained before the law was implemented. The authors also found that the citation rate was not appreciably affected by the new law. The work by these three authors indicates that simply passing a new law dealing with work zone speeds is not adequate to lower the speeds (and therefore accidents) in highway work zones.

Virginia Sisiopiku and Hitesh Patel reported on the effect of police enforcement on motorists' speeds in normal road conditions in an article in the TRR series (Sisiopiku and Patel 1999). This study looks at speed variance and the lasting effects of police presence on a roadway. While the study is limited to a few sites in Michigan where the speed limits were increased, the results as a whole indicate the effects of police presence in other areas, including work zones. The authors concluded that police presence is effective in slowing traffic down in the vicinity of a marked police vehicle. However, the lasting effects were found to be negligible as were the downstream effects of the police presence. The authors noted that

> given the findings from this study, and the many demands for service and limited resources of law enforcement agencies, police enforcement appears a more effective strategy for treating specific problem locations rather than as a method to reduce highway driving speeds in general (p 36).

This conclusion's referral to specific problem locations hints that police presence may be very effective in work zones. However, the authors did not study work zones as a part of their research.

**Closure**

The importance of all of the previously mentioned research is to determine what areas of work zones need improvement in safety, which devices are adequate tools to help in that improvement, and what wide scale programs can be implemented in order to ensure that the safety requirements placed on work zones are properly implemented. The overall goal is improving work zones for both the workers and the traveling public. By narrowing down the areas of a work zone that need to be improved and by identifying the devices that are best suited to the situation at hand, the respective agencies involved are saved both time and money, in addition to improving conditions on the roads for which those agencies are responsible.

The literature revealed that traffic control devices and measures that had a positive effect on work zone safety include fluorescent signs, lane drop arrows, orange rumble strips, a sequential warning light system, changeable message signs, the Travel Time Prediction System, a work zone quality assurance program, and a police presence. The double-fine law, CB wizard alert system, and flashing lines on a CMS (configured as cited in this review) were found to have limited effects on driver behavior. In addition, nighttime work zones were found to pose special problems in work zone traffic control and safety.

## CHAPTER THREE

## REVIEW OF CURRENT STANDARDS

### Methodology

There are currently four different sources of standards dealing with work zones in Alabama that are important to this research. They are the Federal Highway Administration's (FHWA) Manual on Uniform Traffic Control Devices Millennium Edition (MUTCD 2000), the Alabama Department of Transportation's (ALDOT) Standard Specifications for Highway Construction (SSHC 2001), ALDOT's Policy and Procedure (Policy and Procedure 2000), and ALDOT's "Traffic Control Plan Project Notes" (TCP Notes 2001). On January 1, 2003 the State of Alabama formally adopted the 2000 Edition of the MUTCD "as the official manual for a uniform system of traffic control devices for the State of Alabama" (Bowlin 2003). These four publications outline exactly what is required, permitted, and allowed in highway work zones in Alabama.

### Federal Standards

The objective of this research is to improve highway safety in construction work zones by exploring methods of making the driver more aware of advance warning signs. Not only does the advance warning area of a work zone warn the driver of an upcoming area in the road where delays might be expected, but it also informs drivers of the proper speeds to maintain, the closure of a lane, the presence of flaggers, and the existence of a detour in the traveled way. In the work zone itself, excessive speeds are a problem to both the safety of the driver and the safety of the workers on the job site. Such high speeds indicate that drivers are either not aware of changes in the speed limit or that they simply ignore the changes. The MUTCD makes note of this when it states "Temporary traffic control at work and incident sites should be designed on the assumption that drivers will only reduce their speeds if they clearly perceive a need to do so" (Section 6B.01).

One method of improving the advance warning area deals with the signs themselves. The MUTCD mandates that

> All temporary control devices shall be removed as soon as practical when they are no longer needed. When work is suspended for short periods of time, temporary traffic control devices that are no longer appropriate shall be removed or covered (Section 6B.01).

Inappropriate signs are required to be removed or covered so that drivers are not confused about upcoming conditions in the work zone. A specific example of this specifically deals with the Flagger sign, which the MUTCD states "shall be removed, covered, or turned away from road users when the flagging operations are not occurring" (Section 6F.29). The purpose of warning signs are to inform drivers of current conditions that may become dangerous. If the signs are left in place when the condition no longer exists, then there is the possibility of a situation similar to that of the boy who cried wolf.

To expound on the covering of useless signs, the MUTCD further notes that "Temporary traffic control devices inconsistent with intended travel paths through temporary traffic control zones should be removed or covered" (Section 6B.01). In addition "As the work progresses, temporary traffic controls and/or working conditions should be modified in order to provide safe and efficient road user movement and to promote worker safety" (Section 6B.01). This indicates that the advance warning area of any work zone is not static. Advance warning areas need to respond to changes in work zone conditions. Another standard found in the MUTCD states

> If a temporary traffic control zone requires regulatory measures different from those existing, the existing permanent regulatory devices shall be removed or covered and superseded by the appropriate temporary regulatory signs. This change shall be made in conformance with applicable ordinances or statutes of the jurisdiction (Section 6F.07).

Covering or removing current signs, such as speed limit signs, is important so the driver is aware of the proper response to the conditions in the work zone.

Another issue involved in the disregard of advance warning signs is the quality of the signs and their placement. The MUTCD states that "signs shall be properly maintained for cleanliness, visibility, and correct positioning" (Section 6F.04). To ensure that signs are properly cared for, the MUTCD notes

> Individuals who are knowledgeable [...] in the principles of proper temporary traffic control should be assigned responsibility for safety in temporary traffic control zones. The most important duty of these individuals should be to check that all temporary traffic control devices of the project are reasonably consistent with the temporary traffic control plan and are effective in providing safe conditions for drivers, bicyclists, pedestrians, and workers (Section 6B.01).

The MUTCD also states that "the individual responsible for temporary traffic control should have the authority to halt work until applicable or remedial safety measures are taken" (Section 6B.01). While both of the above passages are "guidance," they nevertheless indicate the importance the MUTCD places on safety.

**State Standards**

The MUTCD is a book of national standards that is published by the Federal Highway administration. The SSHC, Policy and Procedure, and TCP Notes are all published for use in Alabama and have application to Alabama work zones, in addition to the MUTCD and other national policies. The SSHC notes in Section 740 that "the traffic control devices covered by this section shall meet the requirements specified in the MUTCD and as detailed on the plans. In case of conflict or discrepancy, the plans shall govern over the MUTCD" (Section 740.01). This allows the usage of the national policy while at the same time allowing for on site conditions that may not be fully detailed in the MUTCD. The SSHC deals with the maintenance of temporary traffic control devices in much the same way the MUTCD does: "The Contractor shall designate or otherwise provide personnel to furnish continuous surveillance over his traffic control operations," and like the MUTCD, the SSHC states that "when work of a progressive nature is involved [...] the necessary signs shall be moved concurrently with advancing operation" (Section 740.03 a). These two clauses ensure that the proper signs should be in their proper places. In addition to inspecting the signs for proper position, the SSHC states that "during periods of non-use, construction signs and other devices shall be removed from the work area, covered with specified material or otherwise positioned so they do not convey their message to the traveling public" (Section 740.03 a). This passage is a restatement of the MUTCD phrase of similar meaning and shows the importance of invalidating unneeded signs.

Where the MUTCD states that the responsible party should have authority to halt work under unacceptable conditions, the SSHC states "if at any time the Engineer determines that proper provisions for safe traffic control are not being provided or maintained, he may order suspension of the work until the proper level is achieved" (Section 740.03 a). This clause places the overall responsibility for traffic safety on the Project Engineer and allows that Engineer the power to correct problems that arise in the traffic control plans. The Contractor, however, is not exempt from ensuring traffic safety. The SSHC states that "the Contractor shall assume full responsibility for the continuous and expeditious maintenance of all construction warning signs, barricades and other traffic control devices" (Section 740.03 c) and

> Although the Department will be designating and directing the placement of certain traffic control devices, the Contractor is not relieved of his responsibility to continuously review and maintain all traffic handling measures… (Section 740.03 d).

These two passages provide another means emphasizing the importance of inspecting the conditions of the signs on a job site. With two parties inspecting and correcting deficiencies in traffic control devices, there should be fewer misplaced or ill maintained signs. Whereas the SSHC does not give any specifics as to the frequency of the inspections to be performed, the Policy and Procedure does. The Policy states "before work begins on a project, the Project Engineer shall designate in writing a qualified person to be responsible for reviewing the traffic control items on the project" and that person "shall inspect the installation of the items and make routine inspections (at least once each workday) of the traffic control devices to determine if they are being properly maintained" (Section 2 Article P 2). The Policy further states that the inspector shall conduct "periodic nighttime inspections, at least one each month, to assure that proper maintenance is being performed on the traffic control devices," and also that "off project detour routes will not require daily inspections, but should be inspected at least once a week…" (Section 2 Article P 2). These inspections provide periodic documentations of the traffic control devices and their condition.

The pertinent TCP Notes are included in every highway construction project and provide explicit instructions to contractors and engineers alike in the maintenance of safe traffic flow through work zones. In Note 704 "the contractor is to remove, relocate or cover during construction and then reset or uncover upon completion of a particular section any conflicting in-place roadway signs and delineators, as directed by the Engineer." This instruction is derived directly from the MUTCD and SSHC and shows the importance of not confusing drivers by improper signs. Note 707 states that "The contractor shall place all advance warning signs before proceeding with his work," which ensures that drivers are aware of the existence of the work zone and the possibility of construction workers and vehicles in the immediate vicinity. Note 720 reads "All traffic control devices that are not applicable at any specific time shall be covered or removed as directed by the Engineer," while Note 729 says "Signs on temporary supports are to be removed or covered when no work is being performed or at the completion of the day's operation." Both of these Notes stress again the importance of not confusing the drivers in the work zone. One further instance of this is Note 712, which states "Flaggers are to be used when directed by the Engineer. Signs shall be placed at the appropriate time, and shall be covered or removed when flaggers are not on duty and during non-working hours." All of the Notes cited here are direct applications of the policies found in the MUTCD and the SSHC.

**Closure**

The standards and policies discussed above give important insight into the requirements placed on engineers and contractors when dealing with traffic control plans. The crucial factor in determining the usefulness of these standards and procedures is whether or not the requirements are being followed. If they are being followed and implemented, then the research into excessive speeds and other dangerous driving habits in work zones does not stem from improper action on the engineer's or contractor's behalf, and the problem of ignored signs would seem to lie elsewhere. In the next chapter, the on-site visits to two ALDOT projects is discussed, which provides a glimpse into current practices and helps answer the question of the engineers' and contractors' liability.

# CHAPTER FOUR

# PROJECT SITE VISITS

## Methodology

The nature of this research project dictated that a couple of project site visits should be performed in order to identify actual field practices for the placement and maintenance of advance warning signs. Both projects were being conducted by the Alabama Department of Transportation. After meeting with the respective Project Engineers and examining the Traffic Control Plan (TCP) for each site, the actual placement of the signs was examined and noted. The first project was road improvement and relocation and the second was bridge replacement. Table 4.1 presents the distances between advance warning signs (MUTCD, p 6H-5). These distances are known as an A-B or A-B-C sequence of signs in this research. The MUTCD explains

> The A dimension is the distance from the transition or point of restriction to the first sign. The B dimension is the distance between the first and second signs. The C dimension is the distance between the second and third signs. (The third sign is the first one in a three-sign series encountered by a driver approaching a temporary traffic control zone (Notes to Table 6H-3).

**Table 4.1: Distance Between Signs (in feet)**
**(MUTCD 2000 Table 6H-3)**

| Road Type | A | B | C |
|---|---|---|---|
| Urban (low speed) | 100 | 100 | 100 |
| Urban (high speed) | 350 | 350 | 350 |
| Rural | 500 | 500 | 500 |
| Expressway / Freeway | 1,000 | 1,500 | 2,640 |

Figure 4.1 contains a diagram indicating the A-B-C distances as defined in Table 4.1.

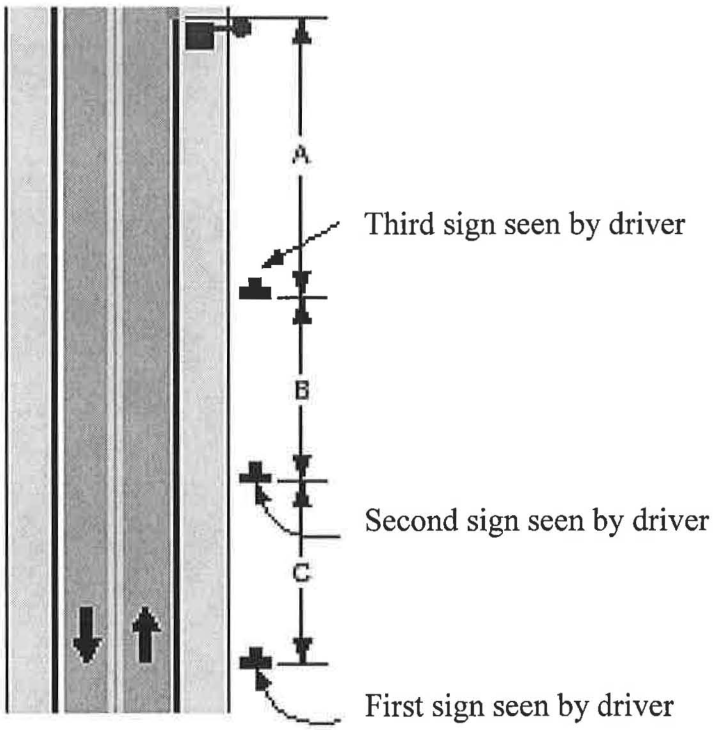


**Figure 4.1: A-B-C Distance Definition**

The speed category is determined by the highway agency. Some agencies may choose to use speed definitions consistent with the choice of taper length. For example, low speed could mean 40 miles per hour or less and high speed could mean 45 miles per hour or greater (MUTCD p. 6H-5).

**Project Visit One**

The first of the two projects was located in Opelika, Alabama (an urban setting) and was a road relocation project. The purpose of the visit was to become familiar with the placement of advance warning signs for a temporary traffic control zone and note the on-site placement of advance warning signs on all approaches for later comparison to the requirements of such placements in the project plans. The improvement and relocation project is ALDOT number STPOA-0925(4) and involves the partial relocation of Frederick Road from its current intersection with Long Street at a T intersection to the new connection with Long Street to connect with Morton Avenue. The researchers met with the ALDOT project engineer before inspecting the temporary traffic control zone. The project involved both new construction and tying that new construction in with the existing roads in the area. After meeting with the project engineer and inspecting the job site, several discrepancies were found between actual sign placements and what was called for in the Traffic Control Plan. A couple of advance warning signs were missing, but because of the nature of the area in which the project was located, these missing signs had little impact on the work zone. It was also found that in a couple of instances, more signs were used than were called for in the TCP. Again, the nature of the project area dictated that these extra signs be used.

The Traffic Control Plan dealt with Frederick Road and all of the side streets together. The plans called for a W20-1 (ROAD WORK AHEAD) on the approaches to the work zone on Tatum Ave, Wallace Ave, Alton Ct, Bulloch St, Francis St, Thompson St, and Alabama Ave. An A-B-C sequence of W20-1 (ROAD WORK 1500 FT, 1000 FT, and 500 FT) was called for in the plans on the approaches on Frederick Rd (both approaches), Society Hill Rd, Martin Luther King Jr. Boulevard, Long Rd, and Morton Ave. The approach of Martin Luther King Jr. Boulevard and Long Rd would each have two W20-1's (ROAD WORK 1500 FT and 1000 FT) and would use the same W20-1

(ROAD WORK 500 FT). Based on the above locations, the plans called for seven W20-1 (ROAD WORK AHEAD) signs, six W20-1 (ROAD WORK 1500 FT) signs, six W20-1 (ROAD WORK 1000 FT) signs, and five W20-1 (ROAD WORK 500FT) signs. These numbers differ from those found on page 50 of the project plans which call for one fewer than the above on the W20-1 (ROAD WORK 1000 FT).

Upon inspection of the site, it was noticed that Francis St is now a private entrance to a shopping center. The eastbound approach of Frederick Rd had an A-B-C series of W20-1 signs (ROAD WORK 1500 FT, 1000 FT, and 500 FT). Thompson St, Tatum Ave, Wallace Ave, Bulloch St, and Alabama Ave all had W20-1 signs (ROAD WORK AHEAD). The westbound approach on Frederick Rd had two W20-1 signs (ROAD WORK 1000 FT and 500 FT) and the approaches on Society Hill Rd, Long Rd, and Martin Luther King Jr. Blvd had a complete A-B-C sequence. The Morton Ave approach had an A-B sequence (ROAD WORK 1000 FT and 500 FT). Based on the above locations, the signs found were 5 W20-1 (ROAD WORK AHEAD) signs, 4 W20-1 (ROAD WORK 1500 FT) signs, 6 W20-1 (ROAD WORK 1000 FT) signs, and 6 W20-1 (ROAD WORK 500 FT) signs.

The difference of two less W20-1 (ROAD WORK AHEAD) signs than the plans called for is explained by the lack of a sign on the Alton Ct approach and the changing of Francis Rd to a private entrance. The project engineer stated that the owners of the private entrance did not want a sign placed on their property. The difference of two less W20-1 (ROAD WORK 1500 FT) than the plans call for is explained by the lack of that sign on the westbound Frederick Rd and the Morton Ave approaches. The Project

Engineer stated that the westbound approach on Frederick Rd was not long enough to place the entire A-B-C sequence, so the first W20-1 (Road Work 1500ft) was omitted. The same Engineer gave no reason for the lack of the sign on the Morton Ave approach. All of the required W20-1 (ROAD WORK 1000 FT) signs were found in their proper places. The difference of one more W20-1 (ROAD WORK 500 FT) than the plans call for is explained by the addition of one sign to the Martin Luther King Jr. Blvd approach. This was necessary to maintain the 500 ft that the sign states until the beginning of the road work.

The A-B-C distances used for the Traffic Control Plan are longer than necessary for the situation. The Plans called for the distances to all be 500 ft. The MUTCD states in Table 6H-3 that for Urban (low speed) roads the A-B-C distances are each 100 ft (MUTCD). Upon investigation of the temporary work zone, the posted speed limits on each road were not higher than 35 mph. Using the 100 ft distances, the approach on westbound Frederick Rd could have fit all three signs in the A-B-C sequence and the third sign would therefore not have to be eliminated due to lack of space. Also noted was that the A-B-C sequence on Society Hill Rd overlapped that on westbound Frederick Rd, so that even if the 500 ft distances were used, the third sign was not necessary.

Two other discrepancies that were noted are out of the advance warning area but are still noteworthy. The first is the closing of Center St. There was a Dead End sign placed on Alton Ct, but there was no Road Closed sign placed on the barricades that blocked the road. Second, the Project Engineer stated that an off-site detour had to be developed to allow utility work to be done on-site. This detour was developed by the

Engineer and approved by ALDOT. The detour signs used were M4-10 signs. In a couple of the placements these signs hung over the roadway and were therefore a hazard. The MUTCD notes that "The DETOUR (M4-9) sign should be used … for periods of short durations, or where, over relatively short distances, road users are guided along the detour and back to the desired highway without route markers" (MUTCD, section 6F.50). The MUTCD further notes in the same section that the "Detour Arrow (M4-10) sign should normally be mounted just below the ROAD CLOSED (R11-2, R11-3a, or R11-4) sign." For this project, the detour was of short duration and drivers were guided along residential streets and back to the original highway, therefore calling for the use of the M4-9 signs. It must also be noted that all of these detour signs were properly covered because the detour was not being utilized at the time of the researchers' visit.

During the discussion with the project engineer the MUTCD was discussed in relation to this project. The plans called for the 1988 version of the MUTCD to be used. The project engineer stated that if a discrepancy arose, she would refer to the 2000 edition. Table 4.1 which presents the A-B-C distances was also discussed with the project engineer.

**Project Visit Two**

The second project visit was to a rural bridge replacement work zone. The project has been done in metric units and involves the replacement of two bridges on US 29/US 80 east of Tuskegee, Alabama. As was the case with the first project visit, the purpose of the second visit was to become familiar with the placement of advance warning signs for a temporary traffic control zone of this type and to note the on-site placement of advance warning signs on all approaches for later comparison to the requirements of such placements in the project plans. The two researchers met with the ALDOT project engineer and his assistant project engineer before inspecting the temporary traffic control zone. Upon inspection, the Traffic Control Plan for the project was found to have significant omissions. The most noteworthy was the complete absence of any warning signs on one of the two major approaches to the project. The inspection of the work zone found that the missing signs had been added at the discretion of the project engineer.

The Traffic Control Plan deals with US 29/US 80 and four side roads. The side roads are AL 53, US forest road 931, and a local access road. The plans call for a W20-1 (ROAD WORK AHEAD) on the side roads. The plans also call for a sequence of W20-1 (ROAD WORK ½ MILE, 1500 FT, 1000 FT, and 500 FT) for the northbound approach to the work zone on US 29/US 80. The plans did not call for any signs for the southbound approach. The Engineer stated that the lack of placement for signs in the plans for the southbound approach to the work zone was not acceptable and he had a series of W20-1 signs (ROAD WORK ½ MILE, 1000 FT, and 500 FT) placed on that approach to the work zone. The engineer further noted that the ROAD WORK ½ MILE sign was indeed needed due to the presence of a crest vertical curve in the advance warning area.

Upon inspecting the site, it was noticed that all the signs called for in the plans were in place as well as those noted above that the engineer had ordered. One problem was encountered on AL 53. The W20-1 (ROAD WORK AHEAD) sign was found to be limiting the sight distance of the R1-1 (STOP) sign. Upon closer inspection the researchers found that the W20-1 sign was closer to the centerline of the intersecting road than the plans called for. The W20-1 was found to be 190 ft from the centerline of US 29/US 80 where the plans called for that sign to be 250 ft (76 m) from said centerline. There were two side roads that were located just outside of the job site, but within the advance warning area. When asked why these approaches did not have signs the engineer stated that each approach had a R1-1 (STOP) sign and that since the drivers were required to come to a complete stop then it is assumed that they would see at least one advance warning sign in place along US 29/US 80.

A few other items were noted during the visit. The engineer felt that speeds needed to be reduced in the work zone because of the presence of a detour and a reverse curve. The engineer used his judgment and had R2-1 (SPEED LIMIT 45) signs ordered and placed appropriately. The engineer did not let the lack of a series of advance warning signs in the plans prohibit him from placing a series of W20-1 signs for the southbound approach to the work zone, as noted above. The engineer noted that the contractors were having a recurring problem with signs being stolen from the job site and the need to inspect the sign placements daily. Last, the plans for this replacement project were in metric and called for Revision 3 of the 1988 MUTCD to be used

**Closure**

The two site visits performed for this research yielded valuable insight into the techniques used in placing advance warning signs. It was found that the project engineers often use their experience to correct omissions and oversights that those preparing the plans failed to recognize. These omissions indicate that perhaps there is a problem in the planning stage of some projects. The fact that the two project engineers for the two sites visited took the initiative to correct problems in the TCP indicates that the people in charge of the work zones have the safety of both the workers and travelers in mind.

# CHAPTER FIVE

# SURVEY DISCUSSION AND RESULTS

## Methodology

The research undertaken in this project entailed a survey of Alabama engineers concerning work zone safety. The purpose of the survey was to determine whether people working on Alabama's highways are aware of some perceived common problems with work zones. The survey was eight questions on a two page format and was color-coded and sent to five different groups of engineers: Alabama Department of Transportation (ALDOT) District Engineers (blue), ALDOT Division Engineers (green), ALDOT Central Office Engineers (yellow), Alabama County Engineers (white), and Consulting Engineers that work within Alabama (orange). A reformatted version of the survey appears in Appendix A (p. 72-75). Before analyzing the significance of the results of the survey, the results were analyzed statistically to determine if the responses of the five groups of engineers reflected a single population or different populations. Following this analysis, the results were studied and summarized.

## Statistical Analysis of Survey Responses

Before entering into a discussion of the results of the survey, it was desired to determine as near as possible if the responses of the five groups of engineers represent a single statistical population or more than one population. To determine this for Questions

1, 3, 5, and 7, the Kolmogorov-Smirnov Two-Sample Test was used. Sidney Siegel in Nonparametric Statistics for the Behavioral Sciences (Siegel 1956) describes this test as "a test of whether two independent samples have been drawn from the same population (or from populations with the same distribution)" (p 127). The test compares the largest difference between two cumulative distribution functions with a critical value that is based on the sample sizes. For this test the sample sizes do not have to be equal. Siegel explains further "If the two samples have in fact been drawn from the same population distribution, then the cumulative distributions of both samples may be expected to be fairly close to each other, inasmuch as they both should show only random deviations from the population distribution" (p 127). As stated before, this test could only be run on Questions 1, 3, 5, and 7 because these four questions had simple "yes," "maybe," or "no" answers. In addition, because the returns of the ALDOT Central Office and Consulting Engineers were so small, neither of these could be compared in any of the four mentioned questions. Also, the distributions of the answers of the ALDOT Division Engineers limited their use for comparison to Question 3.

To use the Kolmogorov-Smirnov Test, the null hypothesis was established that the two sample distributions are members of the same population and the alternative hypothesis was established that the two sample distributions are not members of the same population. Then the two sample distributions were put in a tabular form and the cumulative distributions were established. An example is presented in Table 5.1.

In Table 5.1 a comparison was made between the responses of the County Engineers and the District Engineers to Question 1 of the survey. In this question, the

Engineers are asked to indicate whether they are aware of the presence of six problems in Alabama work zones. The answers were recorded in a yes/no format. A summary of the yes responses to the six coded problem areas is shown in Table 5.1. The cumulative frequency distributions of the responses are defined.

**Table 5.1: Example Table for Kolmogorov-Smirnov Test**

| 1.) | County | | | ALDOT District | | | |
|---|---|---|---|---|---|---|---|
| | Freq. | Cum. Freq. | % | Freq. | Cum. Freq. | % | Difference |
| a | 17 | 17 | 14.5 | 4 | 4 | 5.9 | 8.6% - Max |
| b | 34 | 51 | 43.6 | 22 | 26 | 38.2 | 5.4% |
| c | 5 | 56 | 47.9 | 7 | 33 | 48.5 | 0.6% |
| d | 20 | 76 | 65.0 | 10 | 43 | 63.2 | 1.8% |
| e | 21 | 97 | 82.9 | 13 | 56 | 82.4 | 0.5% |
| f | 20 | 117 | 100.0 | 12 | 68 | 100.0 | 0.0% |
| | 117 | | | 68 | | | |

After the maximum difference in the two distributions is determined, that number is compared to a critical difference. For this research, a two-tailed test was used with alpha equal to 5% ($\alpha = 0.05$). Since the sample sizes are larger than 40, the equation to determine the critical difference is:

$$D_{CR} = 1.36[(n_1 + n_2)/(n_1 n_2)]^{1/2}$$

where $n_1$ and $n_2$ are the sample sizes and $D_{CR}$ is the critical value. Once the maximum difference and the critical value are determined, it is a simple task to compare the two. If the maximum difference is less than the critical value, the null hypothesis is accepted (cannot be rejected) and the alternative hypothesis is rejected. If the difference is greater than or equal to the critical value, then the null hypothesis is rejected and the alternative hypothesis is accepted.

In the example in the table above, the maximum difference was found to be 0.086 and the critical value was determined to be 0.207. Since the difference is less than the critical value, it can be stated that the null hypothesis is accepted and the two sample distributions come from the same population (or populations with the same distributions). The results of the test show that the two samples have no significant differences.

The results of Question 3 were examined using the same test. For this question, the results from the County, ALDOT District, and ALDOT Division Engineers were examined. Comparing these three groups by running the Kolmogorov-Smirnov Test three times determined that all three of these groups are not significantly different in their responses. Questions 5 and 7 resulted in similar findings, but only the County and District Engineers' results had sample sizes large enough to run the test. A complete summary of the Kolmogorov-Smirnov Test results is presented in Table 5.2. The results of the Kolmogorov-Smirnov Test for these four questions indicate that even though the surveys were sent to five different groups of engineers, the responses received from those engineers reflect the same population. Apparently, the engineers from different organizations and different levels of the same organization perceive the same types of problems in dealing with work zones. The complete tables and calculations for the statistical tests can be found in Appendix B.

**Table 5.2: Kolmogorov-Smirnov Test Results**

| Question | Comparison | D | $D_{CR}$ | Significant Difference |
|---|---|---|---|---|
| 1 | County vs. District | 0.086 | 0.207 | No |
| 3 | County vs. District | 0.043 | 0.139 | No |
| 3 | County vs. Division | 0.092 | 0.217 | No |
| 3 | District vs. Division | 0.054 | 0.226 | No |
| 5 | County vs. District | 0.038 | 0.170 | No |
| 7 | County vs. District | 0.106 | 0.225 | No |

As stated before, the Kolmogorov-Smirnov Test could not be applied to Questions 2, 4, and 8, but it was desirable to determine the correlation between the answers to these questions as well. Therefore, the Spearman Rank Correlation Coefficient was used. This test is used to determine to what extent two samples of ranked data are in agreement. For the purposes of this research, the rankings were based on the calculated means of the data for Question 2, and the raw frequency data for Questions 4 and 8. After obtaining the ranking of the sample sets, the differences in the two samples are determined and then squared. For example, Table 5.3 below summarizes the responses to the rankings of the three most dangerous problem areas in work zones from the choices provided in Question 2. This example looks at the ranking of AL County Engineers vs. ALDOT District Engineers. In the case of a "tie" in the rankings, as in the District data between "Travel Time Delay" and "Work Zone Not Needed," the average of the rank is taken, in this case 9.5. The difference between the two ranks is then determined and squared, again as shown in Table 5.3.

**Table 5.3: Example of Spearman Rank Correlation Coefficient Data**

| | County Rank | District Rank | $d_i$ | $d_i^2$ |
|---|---|---|---|---|
| Accidents | 5 | 6 | -1.0 | 1.00 |
| Crest Vertical Curves | 2 | 1 | 1.0 | 1.00 |
| Flagging Operations | 6 | 4 | 2.0 | 4.00 |
| Inadequate Information | 7 | 5 | 2.0 | 4.00 |
| Lack of Public Awareness | 4 | 3 | 1.0 | 1.00 |
| Speeds Too Fast For Conditions | 9 | 8 | 1.0 | 1.00 |
| Stop and Go Congestion | 3 | 2 | 1.0 | 1.00 |
| Travel Time Delay | 1 | 9.5 | -8.5 | 72.25 |
| Work Zone Not Needed | 10 | 9.5 | 0.5 | 0.25 |
| Other | 8 | 7 | 1.0 | 1.00 |
| $\sum =$ | 55 | 55 | 0.0 | 86.50 |

After the squares of the differences are calculated, the sum is determined. Then the sum is inserted into the equation:

$$r_s = 1 - [ ( 6 * \sum d_i^2 ) / ( n * (n^2 - 1) ) ]$$

where n is the sample size and $r_s$ is the Spearman Rank Correlation Coefficient. For the example presented in Table 4.3, the sum of the squares of the differences ( $\sum d_i^2$ ) is equal to 86.5 and the sample size is 10. Therefore, using the equation above, the rank correlation coefficient is equal to 0.476. Richard Scheaffer and James McClave give the following four properties for the Spearman Rank Correlation Coefficient: 1) The value of $r_s$ is always between -1 and 1, 2) if $r_s$ is positive: The ranks of the pairs of sample observations tend to increase together, 3) If $r_s = 0$: The ranks are not correlated, and 4) If $r_s$ is negative: The ranks of one variable tend to decrease as the other variable's rank increases (Scheaffer and McClave 1990). It can be further deduced that the closer to the extremes (1 and -1) that the coefficient lies, the stronger the data is either correlated or opposite. In other words, a value of 1 means that the data is ranked exactly the same and a value of -1 means that the data are ranked exactly opposite. Furthermore, 0.5 is used as a break point in this research for differentiating between "weak" and "strong" correlations. For the example above, the value of 0.476 can be used to describe the relationship between the two sample sets as being a weak positive correlation. This shows that there are some differences in the two rankings.

The responses of the AL County, the ALDOT District, and the ALDOT Division Engineers provided enough data for Question 2 to use the Spearman Rank Correlation Coefficient to compare the answers of the three groups. As with the Kolmogorov-Smirnov Test, the Consulting and ALDOT Central Office data was not adequate to apply the Spearman Coefficient because there simply were not enough responses to obtain a useful ranking. Comparing the County, District, and Division responses for Question 2 showed that there is a weak positive correlation in the County vs. District ($r_s = 0.476$) and the County vs. Division ($r_s = 0.185$) data, which indicates that there are some differences in the rankings. The District vs. Division ($r_s = 0.697$) comparison resulted in a strong positive correlation which indicates that there are similarities in the rankings.

Question 4 consisted of two parts, and the responses of the County and District Engineers were the only two that could be compared for this question. The comparison of the two groups for Question 4a resulted in a weak positive ($r_s = 0.420$) correlation for the two groups while the comparison for 4b showed a strong positive ($r_s = 0.689$) correlation in the rankings. The comparison of County and District responses for Question 8 showed a very strong positive ($r_s = 0.957$) correlation in the rankings. This indicates that the rankings are almost identical. The results of the Spearman Rank

Correlation Coefficient comparisons shows that while there are some differences in the data, all of the correlations are positive. This indicates that the data samples are in the "ballpark." All of the calculations for the Spearman Rank Correlation Coefficient comparisons can be found in Appendix B and a summary of the findings appear in Table 5.4.

**Table 5.4: Summary of Spearman Rank Correlation Coefficient Comparisons**

| Question | Comparison | $r_s$ | Correlation |
|---|---|---|---|
| 2 | County vs. District | 0.476 | Weak Positive |
| 2 | County vs. Division | 0.185 | Weak Positive |
| 2 | District vs. Division | 0.697 | Strong Positive |
| 4a | County vs. District | 0.420 | Weak Positive |
| 4b | County vs. District | 0.698 | Strong Positive |
| 8 | County vs. District | 0.957 | Strong Positive |

**Survey Results**

A total of 136 surveys mailed and 82 were returned. This is an overall return percentage of 60.3 percent. The complete survey and survey results can be found in Appendix A. Surveys were mailed to thirty-nine ALDOT District Engineers and twenty-six were returned for a return rate of 66.7 percent. Surveys were mailed to nine ALDOT Division Engineers and eight were returned for a return rate of 88.9 percent. Surveys were mailed to six ALDOT Central Office Engineers and three were returned for a return rate of 50.0 percent. Surveys were mailed to sixty-seven Alabama County Engineers and forty were returned for a return rate of 59.7 percent. Lastly, surveys were mailed to fifteen Consulting Engineers and five were returned for a return rate of 33.3 percent

The first question of the survey was “Are you aware of any of the following items as being problems in Alabama work zones?,” which was followed by six items with yes or no answers. These six were: a) Work zone signs placed too early, b) Work zone signs left in place too long, c) Too many signs are used, d) Too few signs are used, e) Signs are not appropriate for the current situation, and f) Signs that are improperly located. Table 5.5 contains the overall distribution of answers for all six parts of Question 1. The District, Central Office, and County Engineers on average felt that signs placed too early was not a problem while the Division and Consulting Engineers felt that they were. Overall 35.4 percent of the Engineers surveyed felt that signs placed too early are a problem in work zones while 61.0 percent felt that this is not a problem (3.6 percent did not answer). All five groups of Engineers felt that work zone signs left in place too long is a problem. 86.6 percent of all Engineers surveyed agreed that this is a problem and 13.4 percent felt that signs left in place too long was not a problem. None of the five groups surveyed felt that too many signs are used in work zones. Overall, 18.3 percent of all Engineers surveyed felt that this is a problem and 75.6 percent felt that it is not (6.1% did not answer).

Only the County Engineers felt that too few signs used is a problem. The District, Central Office, and Consulting Engineers felt that too few signs used is not a problem, and the Division Engineers were split down the middle on the question. Overall, 42.7 percent of all Engineers surveyed felt that too few signs used in work zones is a problem while 52.4 percent felt that it is not (4.9 percent did not answer). All five groups felt that signs not appropriate for the current situation was a problem. 58.6 percent of all

Engineers surveyed felt that this is a problem and 39.0 percent felt that it is not a problem (2.4 percent did not answer). The Division and Central Office Engineers felt that signs that are improperly located is a problem in work zones while the District, County, and Consulting Engineers were split fifty-fifty on the question. Overall, 52.4 percent of all Engineers surveyed felt that improperly located signs are a problem and 43.9 percent did not (3.7 percent did not answer). The Kolmogorov-Smirnov Test shows that there is no significant difference in the responses of the County and District Engineers for this question.

**Table 5.5: Frequencies and Percentages for Survey Question 1.**

| Are you aware of the following as being Problems in Alabama Work Zones? | Yes | No | No Answer |
|---|---|---|---|
| Work zone signs placed too early | 29 (35.4%) | 50 (61.0%) | 3 (3.6%) |
| Work zone signs left in place too long | 71 (86.6%) | 11 (13.4%) | 0 (0.0%) |
| Too many signs are used | 15 (18.3%) | 62 (75.6%) | 5 (6.1%) |
| Too few signs are used | 35 (42.7%) | 43 (52.4%) | 4 (4.8%) |
| Signs are not appropriate for the current situation | 48 (58.4%) | 32 (39.0%) | 2 (2.4%) |
| Signs that are improperly located | 43 (52.4%) | 36 (43.9%) | 3 (3.7%) |

Question 2 of the survey was: "Rank the three most dangerous problem areas in work zones with 1 being the most dangerous." The choices given were Accidents, Crest Vertical Curves, Flagging Operations, Inadequate Information, Lack of Public Awareness, Speeds Too Fast For Conditions, Stop and Go Congestion, Travel Time Delay, Work Zone Not Needed, and Other (where space was provided for what that other might be). The responses are shown in Table 6. Exactly half of those surveyed felt that the most dangerous problem in work zones was Speeds Too Fast For Conditions. The second most common number 1 ranking was Accidents, followed closely by Lack of

Public Awareness. The number 2 and 3 rankings were a little more disparate. The overall results of Question 2 can be found in Table 5.6. There were several people who ranked Other as one of their categories. Some of the expressions the participants wrote under were "Lack of Public Concern," "Inattention of Drivers," "Lack of Driver Patience," and "Lack of Contractor's Knowledge of Traffic Control." The results of Question 2 broken down by group surveyed can be found in Appendix A. The Spearman Rank Correlation Coefficient comparison showed a weak positive correlation in the rankings of the County vs. District and the County vs. Division responses and a strong positive correlation in the rankings of the District vs. Division responses.

**Table 5.6: Frequencies for Survey Question 2.**

| Rank the 3 most dangerous problem areas in work zones. | 1's | 2's | 3's | Total |
|---|---|---|---|---|
| Accidents | 11 | 8 | 11 | 30 |
| Crest Vertical Curves | 2 | 7 | 12 | 21 |
| Flagging Operations | 9 | 12 | 17 | 38 |
| Inadequate Information | 3 | 4 | 2 | 9 |
| Lack of Public Awareness | 10 | 14 | 16 | 40 |
| Speeds Too Fast For Conditions | 41 | 18 | 7 | 66 |
| Stop and Go Congestion | 1 | 12 | 5 | 18 |
| Travel Time Delay | 0 | 3 | 8 | 11 |
| Work Zone Not Needed | 0 | 1 | 0 | 1 |
| Other | 3 | 1 | 1 | 5 |
| Missing | 2 | 2 | 3 | 7 |
| Total | 82 | 82 | 82 | 246 |

Question 3 of the survey asked the participants to look at several methods of stressing the importance of a work zone and tell whether or not those methods were effective. The question states: "Do you think the following methods will improve the effectiveness of advance warning areas in work zones?" The options for each answer were Yes, Maybe, and No. A complete list of the methods questioned can be found in

Appendix A, along with the complete listing of frequencies of answers. The method that had the most "yes" votes is "The use of police to monitor traffic." Of the 82 people who participated in the survey, 74 thought this was effective. The next most common yes answer was "The use of signs in the proper locations," while the third most common yes answer was "The use of standard MUTCD signs." On the other end of the spectrum, 38 of the Engineers felt that "The use of a unique sign shape" was not effective. 31 felt that "The use of public relation signing, i.e. Pardon Our Progress: Working For You" was not effective and 28 Engineers felt that "The use of flags to supplement signs" was not effective. Table 5.7 contains the frequencies of answers for all of the Engineers surveyed. The Kolmogorov-Smirnov Test determined that there is no significant difference in the responses of the County, District, and Division Engineers.

**Table 5.7: Frequencies and Percentages for Survey Question 3.**

| Are the following methods effective? | Yes | Maybe | No | No Answer |
|---|---|---|---|---|
| Contractor pay item to remove or cover signs | 48 (58.5%) | 21 (25.6%) | 13 (15.9%) | 0 (0.0%) |
| Police | 74 (90.2%) | 5 (6.1%) | 3 (3.7%) | 0 (0.0%) |
| Portable speed displays | 39 (47.6%) | 30 (36.6%) | 13 (15.8%) | 0 (0.0%) |
| Standard MUTCD signs | 57 (69.5%) | 18 (22.0%) | 6 (7.3%) | 1 1.2%) |
| Signs in the proper locations | 67 (81.7%) | 10 (12.2%) | 3 (3.7%) | 2 (2.4%) |
| Flashing lights to supplement signs | 43 (52.4%) | 29 (35.4%) | 10 (12.2%) | 0 (0.0%) |
| Flags to supplement signs | 21 (25.6%) | 33 (40.2%) | 28 (34.2%) | 0 (0.0%) |
| A unique sign color | 26 (31.7%) | 33 (40.2%) | 23 (28.1%) | 0 (0.0%) |
| A unique sign shape | 14 (17.1%) | 30 (36.6%) | 38 (46.3%) | 0 (0.0%) |
| An advisory speed on the first advance warning sign | 29 (35.4%) | 26 (31.7%) | 27 (32.9%) | 0 (0.0%) |
| Enforcement signing | 49 (59.8%) | 28 (34.1%) | 5 (6.1%) | 0 (0.0%) |
| Public relation signing | 16 (19.5%) | 35 (42.7%) | 31 (37.8%) | 0 (0.0%) |

The purpose of Question 4 was for the Engineers to rate what they felt was the most and least effective of the twelve methods presented in Question 3. Overwhelmingly the Engineers felt that "The use of police to monitor traffic" was the most effective. The most common answer for the least effective method was "The use of a unique sign shape." Overall there were 89 total answers for both 4a and 4b because several of the Engineers who took the survey chose to identify more than one answer for each part of the question. The overall tally of the frequency of answers for both parts of Question 4 can be found in Table 5.8 while the complete tally of responses can be found in Appendix A. The Spearman Rank Correlation Coefficient comparisons for the County vs. District responses showed a weak positive correlation in the rankings for 4a and a strong positive correlation in the rankings for 4b.

**Table 5.8: Frequency of Answers for Survey Question 4.**

| Which method is the most/least effective? | 4a (most) | 4b (least) |
|---|---|---|
| Contractor pay item to remove or cover signs | 6 | 3 |
| Police | 66 | 1 |
| Portable speed displays | 3 | 1 |
| Standard MUTCD signs | 3 | 0 |
| Signs in the proper locations | 3 | 1 |
| Flashing lights to supplement signs | 5 | 1 |
| Flags to supplement signs | 0 | 11 |
| A unique sign color | 1 | 4 |
| A unique sign shape | 0 | 29 |
| An advisory speed on the first advance warning sign | 1 | 12 |
| Enforcement signing | 1 | 4 |
| Public relation signing | 0 | 22 |
| Total | 89 | 89 |

Question 5 stated "What is your experience with Traffic Control Plans?" Following the question were five items with yes or no answers. The majority of all Engineers who participated in the survey felt that Traffic Control Plans are "properly designed," "properly sequenced," "properly detailed," and "properly installed" to use the wording of the survey. However, the majority of those same Engineers felt that the

Traffic Control Plans are not "properly removed." In addition, even though the majority felt that the Plans were "properly installed," just over 20% felt that they are not. Appendix A contains the complete listing of answers. Table 5.9 contains the frequency of answers for Question 5. The Kolmogorov-Smirnov Test determined that there was no significant differences in the answers of the County and District Engineers' responses for this question.

**Table 5.9: Frequencies and Percentages for Survey Question 5.**

| Are Traffic Control Plans | Yes | No | No Answer | Maybe |
|---|---|---|---|---|
| Properly designed? | 77 (93.9%) | 1 (1.2%) | 3 (3.7%) | 1 (1.2%) |
| Properly sequenced? | 76 (92.6%) | 3 (3.7%) | 3 (3.7%) | 0 (0.0%) |
| Properly detailed? | 71 (86.6%) | 7 (8.5%) | 3 (3.7%) | 1 (1.2%) |
| Properly installed? | 61 (74.4%) | 17 (20.7%) | 3 (3.7%) | 1 (1.2%) |
| Properly removed? | 35 (42.7%) | 42 (51.2%) | 4 (4.9%) | 1 (1.2%) |

As noted in the Review of Current Standards chapter of this report, the MUTCD states that signs that are no longer appropriate shall be turned, removed, or covered (1). Question 6 was written to find out if this standard is complied with. The question reads "What is your experience with traffic control devices in work zones: a.) Are the devices properly removed, covered, or turned when no longer needed? and b.) Are damaged devices promptly identified and repaired or replaced?" Over half of all Engineers that participated in the survey felt that the devices are not removed, covered, or turned and that damaged devices are not promptly replaced. The overall frequencies for Question 6 can be found in Table 5.10, and the complete tally can be found in Appendix A. The responses were not adequate to run any statistical tests on this data.

**Table 5.10: Frequencies and Percentages for Survey Question 6.**

| What is your experience with Traffic Control Devices in work zones: | Yes | No | No Answer | Maybe |
|---|---|---|---|---|
| Are they properly removed, covered, or turned when no longer needed? | 23 (28.1%) | 55 (67.1%) | 2 (2.4%) | 2 (2.4%) |
| Are damaged devices promptly identified and repaired or replaced? | 29 (35.4%) | 48 (58.5%) | 1 (1.2%) | 4 (4.9%) |

Question 7 focused on the frequency of inspections of traffic control devices by the Project Manager and the reaction of the contractor to deficiencies found in those inspections. The three sub-items to the first part of the question come directly from ALDOT's Policy and Procedure. Part (a) asks "Are inspection procedures performed according to the following schedules? i.) At least once each workday, ii.) At least once each month at night, and iii.) At least once each week on off project detours." Part (b) asks "Does the contractor respond to deficiencies in a timely manner?" The majority of the Engineers felt that all three schedules were met. However, the Engineers felt that contractors do not respond well to deficiencies found during those inspections. The overall frequency of answers for Question 7 can be found in Table 5.11. The Kolmogorov-Smirnov Test determined that there was no significant difference in the responses of the County and District Engineers for this question.

**Table 5.11: Frequencies and Percentages for Survey Question 7.**

| Are inspections performed: | Yes | No | No Answer | Maybe |
|---|---|---|---|---|
| At least once each workday? | 57 (69.5%) | 20 (24.4%) | 5 (6.1%) | 0 (0.0%) |
| At least once each month at night? | 49 (59.8%) | 26 (31.7%) | 7 (8.5%) | 0 (0.0%) |
| At least once each week on off Project detours? | 55 (67.1%) | 18 (21.9%) | 9 (11.0%) | 0 (0.0%) |
| Does the contractor respond to problems in a timely manner? | 29 (35.4%) | 43 (52.4%) | 6 (7.3%) | 4 (4.9%) |

Question 8 asked the Engineers to choose which area of a work zone they felt was the most dangerous. Over half of all those who participated felt that the Transition Area was the most dangerous. The second most common response was the Activity Area and the third was the Buffer Area. The Advanced Warning Area ranked fourth in this survey with the Termination Area being ranked last. The frequency of answers for Question 8 can be found in Table 5.12 while the complete tallies can be found in Appendix A. The Spearman Rank Correlation Coefficient comparison showed a very strong positive correlation in the rankings of the County and District Engineers' responses for this question.

**Table 5.12: Frequency of Answers for Survey Question 8.**

| Where in a work zone to most accidents occur? | Frequency |
|---|---|
| Advance warning area | 3 (3.7%) |
| Transition area | 46 (56.1%) |
| Buffer zone | 4 (4.9%) |
| Activity area | 26 (31.7%) |
| Termination area | 0 (0.0%) |
| No answer | 3 (3.7%) |

**Closure**

As stated previously, the purpose of the survey was to determine whether Alabama engineers with responsibilities for highway safety are familiar with some perceived common problems with work zones. This research determined that there was little difference in the responses of those groups who were able to be statistically compared, whether they were County, District, Division, or Central Office engineers or consultants. The overall return rate of 60.3 % shows that work zone safety is important to those engineers who are responsible for the construction and maintenance of Alabama's roads and highways. Looking at the survey responses, a majority of those engineers felt that work zone signs left in place too long posed a problem. Additionally, half of the engineers felt that speeding was the most dangerous problem in work zones. The three most popular positive responses to the question looking at methods to improve the effectiveness of advance warning signs were the use of police to monitor traffic, the use of signs in their proper locations, and the use of standard MUTCD signs. The vast majority of the engineers felt that the use of police is the most effective, while the least effective was felt to be the use of a unique sign shape or the use of public relations signing. While the majority of engineers surveyed felt that traffic control plans are properly designed, sequenced, detailed, and installed, most felt that the traffic control plans were not properly removed. Along the same line, the majority of the engineers felt that signs that are no longer needed are not properly removed, turned, or covered. The engineers felt that damaged signs are not promptly identified and repaired or replaced. While most engineers felt that the inspection schedules are met, the same engineers felt that the contractor usually does not respond in a timely manner to correct any deficiencies. Lastly, the majority of the engineers surveyed felt that the most dangerous area of a work zone is the transition area.

## CHAPTER SIX

## ACCIDENT DATA ANALYSIS

### Methodology

The nature of this research was such that an analysis of work zone accidents in Alabama was desired. The goal of this analysis was to identify characteristics of work zone accidents that may indicate some safety problems in those work zones. The data were obtained and analyzed through the use of computer software. The pertinent data for work zone accident analysis were then summarized and is presented later in this chapter.

The data and filtering of the data were obtained using the Critical Analysis Reporting Environment (CARE) software, version 6.1.1, developed by David B. Brown at the University of Alabama, Tuscaloosa. The objective of CARE is to improve traffic safety in Alabama by maintaining a database of traffic accident data for the State of Alabama. The software allows the user to analyze traffic data sets (usually based on the year or years in question) by filtering out certain factors in a given accident. These factors are derived directly from the Alabama Uniform Traffic Accident Report (AUTAR). Some examples of filters include ages of the drivers involved, types of vehicles involved, and injuries or fatalities resulting from the accident. The software also allows the user to single out specific items to filter out. For example, instead of looking at all of the counties in Alabama, the software allows the user to look at data pertaining to

Lee County. The software also allows the user to combine filters. Combining allows for specific examination of the data.

For this research the patterns of accidents within work zones were compared to the patterns of all accidents. To this end, the filter "Workzone" was used. This filter is a combination of the variables for type of vehicle. By sorting out only accidents that involved a construction vehicle, the resulting data dealt only with accidents occurring within a work zone. Since CARE is based on the standard accident reports, this limits the software to what is on that form. In this case, there is an item on the form that specifically categorizes an accident as occurring within a work zone. However, the only way this software sorts out work zone accidents is by the type of vehicle involved. This is one limitation to the CARE data. Determining the limitations of the CARE software is one of the major goals of this section. However, the data that CARE generates is still adequate to show general trends in work zone accident data.

**Accident Frequency Data**

Three years of accident data were analyzed for this research. These were the years 1999 through 2001. In those three years, there were a total of 404,088 traffic accidents within the State of Alabama. Of those, 1.8% (7,435) occurred within work zones, according to the CARE software. The least number of accidents occurred in February (7.6% of all accidents) while the month with the most accidents was March (8.8% of all accidents). However, the month of December had the fewest accidents (6.1%) of the year within work zones while August had the most (9.8%). The 87 fatal accidents occurring in work zones in those three years accounts for 3.1% of the 2,804 fatal accidents in that same time frame. Table6.1 contains the complete listing by month of all accidents and work zone accidents for the three years mentioned above. Table 6.2 contains the same accident data separated by the severity of the accidents and also by all accidents vs. work zone accidents.

Another indicator of the problem of work zone accidents is the frequency with which flaggers are involved in accidents. To determine this, the work zone filter used before was combined with the subset value of "flagger" from the variables for "Traffic Control Unit." After this is done, a frequency analysis can be performed. For the three years examined for this research, there were a total of 67 accidents involving flaggers. This represents 0.9 % of work zone accidents.

**Table 6.1: Frequency Data by Month for All Accidents and Work Zone Accidents**

| | All Accidents (1999-2001) | | | Work Zone Accidents (1999-2001) | |
|---|---|---|---|---|---|
| Month | Frequency | % of Total | | Frequency | % of Total |
| January | 32,881 | 8.14 | | 480 | 6.45 |
| February | 30,643 | 7.58 | | 524 | 7.05 |
| March | 35,489 | 8.78 | | 596 | 8.02 |
| April | 34,287 | 8.49 | | 632 | 8.50 |
| May | 35,169 | 8.70 | | 706 | 9.50 |
| June | 34,221 | 8.47 | | 644 | 8.67 |
| July | 31,778 | 7.86 | | 699 | 9.40 |
| August | 32,913 | 8.15 | | 732 | 9.84 |
| September | 32,642 | 8.08 | | 633 | 8.51 |
| October | 34,580 | 8.56 | | 695 | 9.35 |
| November | 34,481 | 8.53 | | 641 | 8.62 |
| December | 35,004 | 8.66 | | 453 | 6.09 |
| Total | 404,088 | 100.00 | | 7,435 | 100.00 |

**Table 6.2: Accident Severity for All Accidents and Work Zone Accidents**

| | All Accidents (1999-2001) | | | Work Zone Accidents (1999-2001) | |
|---|---|---|---|---|---|
| Severity | Frequency | % of Total | | Frequency | % of Total |
| Property Damage Only | 309,481 | 76.59 | | 5,643 | 75.90 |
| Injury | 91,803 | 22.72 | | 1,705 | 22.93 |
| Fatality | 2,804 | 0.69 | | 87 | 1.17 |
| Total | 404,088 | 100.00 | | 7,435 | 100.00 |

There are several other characteristics of work zone accidents that should be examined. Table 6.3 contains the split of those accidents occurring in rural or urban areas. For work zones, the split is about fifty-fifty while the rural/urban split for all accidents is closer to thirty-seventy. The accident rate split for all accidents is not surprising since common sense says there will be more accidents where the roads are both more congested and more traveled. However, the fifty-fifty split for work zone accidents indicates that there is a need to improve the safety of work zones in rural areas.

**Table 6.3: Accident Location for All Accidents and Work Zone Accidents**

| | All Accidents (1999-2001) | | | Work Zone Accidents (1999-2001) | |
|---|---|---|---|---|---|
| Location | Frequency | % of Total | | Frequency | % of Total |
| Rural | 117,534 | 29.09 | | 3,700 | 49.76 |
| Urban | 286,554 | 70.91 | | 3,735 | 50.24 |
| Total | 404,088 | 100.00 | | 7,435 | 100.00 |

Looking at the types of roads, the greatest number of all accidents (34.4 %) occurs on municipal streets. Near the bottom of that list, accidents on Interstate highways account for only 8.5 % of all accidents. The greatest number of work zone accidents occur on Interstate highways (32.1 %) while accidents in work zones on municipal streets account for 13.5 %. This shows that while there may be fewer accidents overall on the Interstate highways, there is a disproportionately higher rate of those accidents occurring within work zones. The breakdown of accident frequency by type of road can be found in Table 6.4.

**Table 6.4: Road Class for All Accidents and Work Zone Accidents**

| | All Accidents (1999-2001) | | | Work Zone Accidents (1999-2001) | |
|---|---|---|---|---|---|
| Road Class | Frequency | % of Total | | Frequency | % of Total |
| Interstate | 34,339 | 8.49 | | 2,385 | 32.08 |
| Federal | 74,022 | 18.32 | | 1,532 | 20.61 |
| State | 87,124 | 21.56 | | 1,800 | 24.21 |
| County | 69,528 | 17.21 | | 712 | 9.58 |
| Municipal | 138,924 | 34.38 | | 1,005 | 13.52 |
| Private Property | 0 | 0.00 | | 0 | 0.00 |
| Other | 151 | 0.04 | | 1 | 0.00 |
| Total | 404,088 | 100.00 | | 7,435 | 100.00 |

Another important consideration besides whether the road was in an urban or rural setting and what type of road the accident occurred on is what the area surrounding the accident location is like. When looking at all accidents for the three years studied, the most accidents occurred in a shopping or business district (43.7 %) or in open country (28.8 %). In work zones, the most accidents occur in the same two locales, but in the opposite order of frequency: open country accidents accounted for 52.9% while the shopping or business category accounted for 30.5 %. The complete listing of accident locale can be found in Table 6.5.

**Table 6.5: Accident Locale for All Accidents and Work Zone Accidents**

| | All Accidents (1999-2001) | | | Work Zone Accidents (1999-2001) | |
|---|---|---|---|---|---|
| Locale | Frequency | % of Total | | Frequency | % of Total |
| Open Country | 116,268 | 28.77 | | 3,935 | 52.92 |
| Residential | 88,074 | 21.80 | | 858 | 11.54 |
| Shopping or Business | 176,657 | 43.72 | | 2,269 | 30.52 |
| Manufacturing or Industrial | 6,617 | 1.63 | | 107 | 1.44 |
| School | 7,259 | 1.80 | | 60 | 0.81 |
| Playground | 258 | 0.06 | | 3 | 0.04 |
| Other | 8,955 | 2.22 | | 203 | 2.73 |
| Total | 404,088 | 100.00 | | 7,435 | 100.00 |

Weather is also important when looking at accident frequencies. However, most accidents occur in daylight during clear weather conditions. This is equally true when looking at work zone accident frequencies. These data indicate that weather cannot be singled out as a primary causal factor for work zone accidents. Table 6.6 contains the frequency of accidents based on lighting conditions while Table 6.7 looks at accident frequency based on weather conditions.

**Table 6.6: Light Conditions for All Accidents and Work Zone Accidents**

| | All Accidents (1999-2001) | | | Work Zone Accidents (1999-2001) | |
|---|---|---|---|---|---|
| Light Condition | Frequency | % of Total | | Frequency | % of Total |
| Daylight | 296,397 | 73.34 | | 5,781 | 77.76 |
| Dawn | 3,945 | 0.98 | | 82 | 1.10 |
| Dusk | 9,248 | 2.29 | | 117 | 1.57 |
| Darkness, Not Lit | 48,451 | 11.99 | | 948 | 12.75 |
| Darkness, Lighted | 45,119 | 11.17 | | 496 | 6.67 |
| Not Specified | 928 | 0.23 | | 11 | 0.15 |
| Total | 404,088 | 100.00 | | 7,435 | 100.00 |

**Table 6.7: Weather Conditions for All Accidents and Work Zone Accidents**

| Weather Condition | All Accidents (1999-2001) Frequency | % of Total | | Work Zone Accidents (1999-2001) Frequency | % of Total |
|---|---|---|---|---|---|
| Clear | 257,210 | 63.66 | | 5,054 | 67.97 |
| Cloudy | 86,081 | 21.30 | | 1,571 | 21.13 |
| Rain | 55,707 | 13.79 | | 739 | 9.94 |
| Snow | 905 | 0.22 | | 8 | 0.11 |
| Sleet / Hail | 418 | 0.10 | | 10 | 0.13 |
| Crosswind | 55 | 0.01 | | 2 | 0.03 |
| Fog | 2,259 | 0.56 | | 34 | 0.46 |
| Other | 111 | 0.03 | | 0 | 0.00 |
| Not Specified | 1,342 | 0.33 | | 17 | 0.23 |
| Total | 404,088 | 100.00 | | 7,435 | 100.00 |

The data presented above indicates that there are some differences in the characteristics of accidents occurring within work zones when compared to the characteristics of all accidents occurring in the State of Alabama. One of the most notable differences is the higher frequency of fatal accidents occurring within work zones and the almost even split of rural versus urban accidents in work zones. These two statistics indicate that much work needs to be done to improve work zone safety. Also noteworthy is the data that indicates that work zones on Interstate highways suffer a disproportionate number of accidents. This shows that not only does work zone safety need to be improved, but also that work zones on interstates need drastic improvements. Lastly, it can be accurately stated that weather and lighting conditions have a minimal effect on the frequency of any accident because the vast majority of accidents occur in clear, daylight conditions.

The CARE program does have its limitations, mainly that it is based on the Alabama Uniform Traffic Accident Report. According to the Alabama Uniform Traffic Accident Report Instruction Manual (AUTAR 1994), there is a block on the back of the accident form that specifically asks "Accident In Or Related To Road Construction Zone" but the CARE software only differentiates between work zone and non-work zone accidents by the use of the vehicle(s) involved. This is a severe shortcoming for this research, and thus the data presented above is reduced in its accuracy regarding work zone accidents. Another limitation to this research is the Uniform Traffic Accident Report itself. The report, while asking whether or not the accident occurred in a work zone, does not differentiate between the areas of a work zone, or whether or not there were workers present at the time of the accident. These two items could make a significant difference in future work zone research.

**Closure**

The limitations of the CARE software are the difficulties with obtaining accurate work zone accident data because of the nature of the work zone filter used and the complete dependence on the AUTAR for its input data. The filter problem can be solved by adding the question on the AUTAR about whether or not the accident is work zone related, however the dependence on the AUTAR for input data cannot be altered. Taking these limitations into consideration, the CARE system can only provide general trends in work zone accident data. The CARE analysis of accident data for the State of Alabama showed that work zone accidents account for about 1.8 % of all accidents occurring in

Alabama for the years 1999, 2000, and 2001. However, the frequency of fatal work zone accidents was found to be almost double that of non-work zone accidents. In addition, while only 8.5% of all accidents in those three years occurred on Interstate highways, over 32% of work zone accidents occurred on those same Interstates. 53% of all work zone accidents occurred in open country, while only 29% of all accidents were in the same type area. Not surprising was the fact that the vast majority of all accidents and work zone accidents occurred during clear and daylight conditions. All of this data indicates that there is still much that needs to be done to improve work zone safety, especially in rural areas on Interstate highways.

# CHAPTER SEVEN

# CONCLUSIONS AND RECOMMENDATIONS

## Conclusions

The objective of this research was to identify methods to improve the effectiveness of the advance warning area of a work zone. The literature review indicated that there are several traffic control devices that do have a positive effect on work zone safety. The devices identified as such are fluorescent signs, lane drop arrows, orange rumble strips, a sequential warning light system, changeable message signs, and the Travel Time Prediction System. While many of these devices are already being utilized (i.e. changeable message signs), some of them are seeing only limited deployments (i.e. a sequential warning light system). The double-fine law, CB wizard alert system, and flashing lines on a changeable message sign (CMS) (configured as cited in the review) were found to have limited effect on driver behavior. In addition, nighttime work zones were found to pose special problems in work zone traffic control and safety. The literature further showed that wide-scale programs aimed at improving work zone safety can be quite effective when properly implemented. The review of current standards provided important insight into the requirements placed on contractors and engineers alike. These standards show that safety is very important and the proper implementation of Traffic Control Plans is crucial.

The project site visits yielded valuable insight into the field practices of implementing Traffic Control Plans (TCP). It was found that project engineers are familiar with the provisions in both the MUTCD and the TCP Notes and often use their experience and judgment to correct omissions and oversights that those preparing the plans failed to recognize. These omissions indicate that perhaps there is a lack of accurate information in the planning stage of some projects. The fact that the two project engineers for the two sites visited took the initiative to correct problems in the TCP indicates that the people in charge of the work zones on a daily basis have the safety of both the workers and travelers in mind.

The survey of engineers that work on Alabama's roads and highways indicated that problems within work zones are well known to the people involved in the constructing and maintaining those roads and highways. It was determined that there was little statistical difference in the responses of the five groups of engineers surveyed: Alabama County Engineers, Alabama Department of Transportation (ALDOT) District Engineers, ALDOT Division Engineers, ALDOT Central Office Engineers, and Consulting Engineers that work in Alabama. The majority of Engineers surveyed felt that advance warning signs are left in place too long and are often improperly located and not appropriate for the current situation. The Engineers also felt that speeding, lack of public awareness, and flagging operations are the most dangerous elements of a work zone. Using standard MUTCD signs, signs in their proper location, and using police to monitor traffic were all seen as ways to improve safety in work zones. While the Engineers felt that using police to monitor is the best means of improving safety, some of the items that were not felt to be useful were using a unique sign shape, using flags to supplement signs, and using public relations signing (i.e. Pardon Our Progress: Working for You). The only problem the majority of the engineers had with Traffic Control Plans were that they are oftentimes not properly removed. The Engineers felt that traffic control devices in work zones are not properly removed, turned, or covered when not needed and that damaged devices are not promptly identified and repaired or replaced. The Engineers did feel that the inspection requirements for work zone signs are being met, but contractors often do not respond in a timely manner. The Engineers felt that the two most dangerous areas of a work zone are the transition area and the activity area. In summary, some common areas of concern expressed by the engineers are speeding in work zones, traffic control signs that are left in place too long, and the inadequacy of contractors to uphold their responsibilities concerning work zone traffic control.

The accident data analysis, utilizing the CARE software, indicates that there is much work that needs to be done concerning work zone safety. The three years of Alabama accident data studied revealed that the frequency of fatal accidents compared to all other accidents in work zones is twice the same measurement for non-work zone accidents. The software itself is limited to the data contained on the Alabama Uniform Traffic Accident Report that is filed for traffic accidents within the State of Alabama. Also, the lack of exposure data leaves the user with only limited results.

**Recommendations**

This research indicates that there are many areas of work zone safety concerning the effectiveness of the advance warning area that can be improved. First, the use of those devices that are shown to have a positive effect on motorists is advised where each is applicable. Specifically, the literature and the survey of engineers indicate that the use of police to monitor work zones is very effective. Also, the literature and the survey indicate that a quality assurance program, similar to that initiated in New York State can solve the problems with poor contractor involvement in work zone traffic control procedures. Furthermore, the project site visits indicated that the sequences of signs in the advance warning area and the distances required between the signs need to be understood better by both design and project engineers. Also, signs in work zones should not be placed in such a manner that they block other signs. The survey indicated that a specific pay item for contractors to remove or cover signs as needed would also have a worthwhile effect on safety. Along this line, the contractors' responsibilities should be made more clear, and the project engineers given the authority to correct deficiencies found on their job site concerning all areas of safety. Last, the data collected from work zones needs to be improved. Data collection improvements can occur in two ways: perform a detailed study on work zone accidents with exposure data included and change the Alabama Uniform Traffic Accident Report to include more precise data concerning work zone accidents. One more note, the CARE software should be updated to include the work zone question and thus make the filters for work zone accidents more usable.

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## APPENDIX A

### Survey and Survey Results

**Questionnaire Regarding the Effectiveness of Advance Warning Signs in Alabama Work Zones**

1. Are you aware of any of the following items as being problems in Alabama work zones?

| | Yes | No |
|---|---|---|
| a. Work zone signs placed too early | ___ | ___ |
| b. Work zone signs left in place too long | ___ | ___ |
| c. Too many signs are used | ___ | ___ |
| d. Too few signs are used | ___ | ___ |
| e. Signs are not appropriate for the current situation | ___ | ___ |
| f. Signs that are improperly located | ___ | ___ |

2. Rank the three most dangerous problem areas in work zones with 1 being the most dangerous.

_____ Accidents	_____ Speeds Too Fast for Conditions

_____ Travel Time Delay	_____ Inadequate Information

_____ Stop and Go Congestion	_____ Work Zone not Needed

_____ Lack of Public Awareness	_____ Other_________________________

______________________________________________________________________

______________________________________________________________________

3. Do you think the following methods will improve the effectiveness of advance warning areas in work zones?

| | Yes | Maybe | No |
|---|---|---|---|
| a. Require contractor to install and remove signs as needed with a corresponding pay item | ___ | ___ | ___ |
| b. The use of police to monitor traffic | ___ | ___ | ___ |
| c. The use of portable speed displays | ___ | ___ | ___ |
| d. The use of standard MUTCD signs | ___ | ___ | ___ |
| e. The use of signs in the proper locations | ___ | ___ | ___ |
| f. The use of flashing lights to supplement signs | ___ | ___ | ___ |
| g. The use of flags to supplement signs | ___ | ___ | ___ |
| h. The use of a unique sign color | ___ | ___ | ___ |
| i. The use of a unique sign shape | ___ | ___ | ___ |
| j. The use of an advisory speed on the first advance warning sign | ___ | ___ | ___ |
| k. The use of enforcement signing, i.e. WORKERS PRESENT: SPEEDING FINES DOUBLED | ___ | ___ | ___ |
| l. The use of public relation signing, i.e. My Parents Work Here; Slow Down, Give Them A Brake; Pardon Our Progress: Working For You | ___ | ___ | ___ |

4a. Which one of the twelve items in question 3 do you think would be the most effective? ______

4b. Which one of the twelve items in question 3 do you think would be the least effective? ______

5. What is your experience with Traffic Control Plans? Are they:

| | Yes | No |
|---|---|---|
| a. Properly designed? | ___ | ___ |
| b. Properly sequenced? | ___ | ___ |
| c. Properly detailed? | ___ | ___ |
| d. Properly installed? | ___ | ___ |
| e. Properly removed? | ___ | ___ |

6. What is your experience with traffic control devices in work zones:

| | Yes | No |
|---|---|---|
| a. Are the devices properly removed, covered, or turned when no longer needed? | ___ | ___ |
| b. Are damaged devices promptly identified and repaired or replaced? | ___ | ___ |

7a. Are inspection procedures performed according to the following schedules?

| Yes No | | |
|---|---|---|
| i. At least once each workday. | ___ | ___ |
| ii. At least once each month at night | ___ | ___ |
| iii. At least once each week on off project detours | ___ | ___ |

| | Yes | No |
|---|---|---|
| 7b. Does the contractor respond to deficiencies in a timely manner? | ___ | ___ |

8. Where in a work zone do you think most accidents occur? (Check only one).

_____ Advance Warning Area

_____ Transition Area

_____ Buffer Space

_____ Activity Area

_____ Termination Area

Prepared by: ______________________________

Job Title: ______________________________

Agency: ______________________________

Date: ______________________________

Note: The survey that was mailed to the engineers was a two page format. The format has been expanded here for uniformity of formatting.

**Responses to Survey of Consulting Engineers**

Mailed: 15 Returned: 5 Return Rate: 33.3%

Question 1: Are you aware of any of the following items as being problems in Alabama work zones?

| Frequency of Answers | Yes | No | No Answer |
|---|---|---|---|
| a. Work zone signs placed too early | 3 | 1 | 1 |
| b. Work zone signs left in place too long | 5 | | |
| c. Too many signs are used | | 4 | 1 |
| d. Too few signs are used | 1 | 3 | 1 |
| e. Signs are not appropriate for the current situation | 4 | 1 | |
| f. Signs that are improperly located | 2 | 2 | 1 |

Question 2: Rank the three most dangerous problem areas in work zones with 1 being the most dangerous.

| Summary of Frequencies of Answers | 1's | 2's | 3's |
|---|---|---|---|
| Accidents | 1 | | 1 |
| Crest Vertical Curves | | 1 | 1 |
| Flagging Operations | | | |
| Inadequate Information | | 1 | |
| Lack of Public Awareness | 3 | | |
| Speeds Too Fast For Conditions | 1 | | 1 |
| Stop and Go Congestion | | 1 | 1 |
| Travel Time Delay | | 1 | 1 |
| Work Zone Not Needed | | 1 | |
| Other | | | |
| Missing | | | |

Question 3: Do you think the following methods will improve the effectiveness of advance warning areas in work zones?

| Frequency of Answers | Yes | Maybe | No | No Answer |
|---|---|---|---|---|
| a. Require contractor to install and remove or cover signs as needed with a corresponding pay item | 3 | 2 | | |
| b. The use of police to monitor traffic | 4 | | 1 | |
| c. The use of portable speed displays | 2 | 1 | 2 | |
| d. The use of standard MUTCD signs | 2 | 3 | | |
| e. The use of signs in the proper locations | 3 | 2 | | |
| f. The use of flashing lights to supplement signs | 1 | 3 | 1 | |
| g. The use of flags to supplement signs | 1 | 1 | 3 | |
| h. The use of a unique sign color | 1 | 1 | 3 | |
| i. The use of a unique sign shape | | 1 | 4 | |
| j. The use of an advisory speed on the first advance warning sign | | 1 | 4 | |
| k. The use of enforcement signing, i.e. WORKERS PRESENT: SPEEDING FINES DOUBLED | 4 | | 1 | |
| l. The use of public relation signing, i.e. My Parents Work Here; Slow Down, Give Them A Brake; Pardon Our Progress, Working For You | 2 | 1 | 2 | |

Question 4a/b: Which one of the twelve items in question 3 do you think would be the most/least effective?

| Summary of Frequencies of Answers | 4a (most) | 4b (least) |
|---|---|---|
| a. Require contractor to install and remove or cover signs as needed with a corresponding pay item | 1 | |
| b. The use of police to monitor traffic | 4 | |
| c. The use of portable speed displays | | |
| d. The use of standard MUTCD signs | | |
| e. The use of signs in the proper locations | | |
| f. The use of flashing lights to supplement signs | | |
| g. The use of flags to supplement signs | | |
| h. The use of a unique sign color | | |
| i. The use of a unique sign shape | | 2 |
| j. The use of an advisory speed on the first advance warning sign | | 2 |
| k. The use of enforcement signing, i.e. WORKERS PRESENT: SPEEDING FINES DOUBLED | | |
| l. The use of public relation signing, i.e. My Parents Work Here; Slow Down, Give Them A Brake; Pardon Our Progress, Working For You | | 1 |

Question 5: What is your experience with Traffic Control Plans? Are they:

| Frequency of Answers | Yes | No | No Answer | Maybe |
|---|---|---|---|---|
| a. Properly designed? | 4 | | 1 | |
| b. Properly sequenced? | 4 | | 1 | |
| c. Properly detailed? | 3 | 1 | 1 | |
| d. Properly installed? | 2 | 2 | 1 | |
| e. Properly removed? | 1 | 3 | 1 | |

Question 6: What is your experience with traffic control devices in work zones:

| Frequency of Answers | Yes | No | No Answer | Maybe |
|---|---|---|---|---|
| a. Are the devices properly removed, covered, or turned when no longer needed? | | 5 | | |
| b. Are damaged devices promptly identified and repaired or replaced? | 1 | 4 | | |

Question 7a: Are inspection procedures performed according to the following schedules?

| Frequency of Answers | Yes | No | No Answer | Maybe |
|---|---|---|---|---|
| 7a. i. At least once each workday | | 3 | 2 | |
| ii. At least once each month at night | 1 | 1 | 3 | |
| iii. At least once each week on off project detours | | 2 | 3 | |
| 7b. Does the contractor respond to deficiencies in a timely manner? | | 4 | 1 | |

Question 8: Where in a work zone do you think most accidents occur?

| | Frequency |
|---|---|
| Advance Warning Area | |
| Transition Area | 4 |
| Buffer Space | |
| Activity Area | 1 |
| Termination Area | |
| Other (more than one answer given) | |

**Responses to Survey of ALDOT Central Office Engineers**

Mailed: 6 Returned: 3 Return Rate: 50.0%

Question 1: Are you aware of any of the following items as being problems in Alabama work zones?

| Frequency of Answers | Yes | No | No Answer |
|---|---|---|---|
| a. Work zone signs placed too early | | 2 | 1 |
| b. Work zone signs left in place too long | 2 | 1 | |
| c. Too many signs are used | | 2 | 1 |
| d. Too few signs are used | | 2 | 1 |
| e. Signs are not appropriate for the current situation | 2 | 1 | |
| f. Signs that are improperly located | 2 | 1 | |

Question 2: Rank the three most dangerous problem areas in work zones with 1 being the most dangerous.

| Summary of Frequencies of Answers | 1's | 2's | 3's |
|---|---|---|---|
| Accidents | | | 1 |
| Crest Vertical Curves | | | 1 |
| Flagging Operations | | | 1 |
| Inadequate Information | 1 | | |
| Lack of Public Awareness | 1 | 1 | |
| Speeds Too Fast For Conditions | 1 | 1 | |
| Stop and Go Congestion | | 1 | |
| Travel Time Delay | | | |
| Work Zone Not Needed | | | |
| Other | | | |
| Missing | | | |

Question 3: Do you think the following methods will improve the effectiveness of advance warning areas in work zones?

| Frequency of Answers | Yes | Maybe | No | No Answer |
|---|---|---|---|---|
| a. Require contractor to install and remove or cover signs as needed with a corresponding pay item | 3 | | | |
| b. The use of police to monitor traffic | 2 | | 1 | |
| c. The use of portable speed displays | 2 | 1 | | |
| d. The use of standard MUTCD signs | 2 | | | 1 |
| e. The use of signs in the proper locations | 2 | | | 1 |
| f. The use of flashing lights to supplement signs | | 1 | 2 | |
| g. The use of flags to supplement signs | | 1 | 2 | |
| h. The use of a unique sign color | | 1 | 2 | |
| i. The use of a unique sign shape | | 1 | 2 | |
| j. The use of an advisory speed on the first advance warning sign | 1 | 1 | 1 | |
| k. The use of enforcement signing, i.e. WORKERS PRESENT: SPEEDING FINES DOUBLED | 2 | 1 | | |
| l. The use of public relation signing, i.e. My Parents Work Here; Slow Down, Give Them A Brake; Pardon Our Progress, Working For You | | 2 | 1 | |

Question 4a/b: Which one of the twelve items in question 3 do you think would be the most/least effective?

| Summary of Frequencies of Answers | 4a (most) | 4b (least) |
|---|---|---|
| a. Require contractor to install and remove or cover signs as needed with a corresponding pay item | 1 | |
| b. The use of police to monitor traffic | 2 | |
| c. The use of portable speed displays | | |
| d. The use of standard MUTCD signs | | |
| e. The use of signs in the proper locations | | |
| f. The use of flashing lights to supplement signs | | |
| g. The use of flags to supplement signs | | 2 |
| h. The use of a unique sign color | | |
| i. The use of a unique sign shape | | 1 |
| j. The use of an advisory speed on the first advance warning sign | | |
| k. The use of enforcement signing, i.e. WORKERS PRESENT: SPEEDING FINES DOUBLED | | |
| l. The use of public relation signing, i.e. My Parents Work Here; Slow Down, Give Them A Brake; Pardon Our Progress, Working For You | | |

Question 5: What is your experience with Traffic Control Plans? Are they:

| Frequency of Answers | Yes | No | No Answer | Maybe |
|---|---|---|---|---|
| a. Properly designed? | 3 | | | |
| b. Properly sequenced? | 2 | 1 | | |
| c. Properly detailed? | 2 | 1 | | |
| d. Properly installed? | 2 | 1 | | |
| e. Properly removed? | 1 | 2 | | |

Question 6: What is your experience with traffic control devices in work zones:

| Frequency of Answers | Yes | No | No Answer | Maybe |
|---|---|---|---|---|
| a. Are the devices properly removed, covered, or turned when no longer needed? | | 3 | | |
| b. Are damaged devices promptly identified and repaired or replaced? | 1 | 2 | | |

Question 7a: Are inspection procedures performed according to the following schedules?

| Frequency of Answers | Yes | No | No Answer | Maybe |
|---|---|---|---|---|
| 7a. i. At least once each workday | 1 | 1 | 1 | |
| ii. At least once each month at night | 1 | 1 | 1 | |
| iii. At least once each week on off project detours | 1 | 1 | 1 | |
| 7b. Does the contractor respond to deficiencies in a timely manner? | 1 | 1 | 1 | |

Question 8: Where in a work zone do you think most accidents occur?

| | Frequency |
|---|---|
| Advance Warning Area | |
| Transition Area | 2 |
| Buffer Space | |
| Activity Area | 1 |
| Termination Area | |
| Other (more than one answer given) | |

**Responses to Survey of ALDOT Division Engineers**

Mailed: 9 Returned: 8 Return Rate: 88.9%

Question 1: Are you aware of any of the following items as being problems in Alabama work zones?

| Frequency of Answers | Yes | No | No Answer |
|---|---|---|---|
| a. Work zone signs placed too early | 5 | 3 | |
| b. Work zone signs left in place too long | 8 | | |
| c. Too many signs are used | 3 | 5 | |
| d. Too few signs are used | 4 | 4 | |
| e. Signs are not appropriate for the current situation | 8 | | |
| f. Signs that are improperly located | 7 | 1 | |

Question 2: Rank the three most dangerous problem areas in work zones with 1 being the most dangerous.

| Summary of Frequencies of Answers | 1's | 2's | 3's |
|---|---|---|---|
| Accidents | 3 | | 2 |
| Crest Vertical Curves | | 2 | 1 |
| Flagging Operations | | | 2 |
| Inadequate Information | | | 1 |
| Lack of Public Awareness | | 1 | 2 |
| Speeds Too Fast For Conditions | 4 | 2 | |
| Stop and Go Congestion | 1 | 3 | |
| Travel Time Delay | | | |
| Work Zone Not Needed | | | |
| Other | | | |
| Missing | | | |

Question 3: Do you think the following methods will improve the effectiveness of advance warning areas in work zones?

| Frequency of Answers | Yes | Maybe | No | No Answer |
|---|---|---|---|---|
| a. Require contractor to install and remove or cover signs as needed with a corresponding pay item | 5 | 2 | 1 | |
| b. The use of police to monitor traffic | 8 | | | |
| c. The use of portable speed displays | 5 | 2 | 1 | |
| d. The use of standard MUTCD signs | 6 | 1 | 1 | |
| e. The use of signs in the proper locations | 6 | 1 | 1 | |
| f. The use of flashing lights to supplement signs | 2 | 3 | 3 | |
| g. The use of flags to supplement signs | 2 | 2 | 4 | |
| h. The use of a unique sign color | 2 | 5 | 1 | |
| i. The use of a unique sign shape | 2 | 1 | 5 | |
| j. The use of an advisory speed on the first advance warning sign | 3 | 2 | 3 | |
| k. The use of enforcement signing, i.e. WORKERS PRESENT: SPEEDING FINES DOUBLED | 6 | 2 | | |
| l. The use of public relation signing, i.e. My Parents Work Here; Slow Down, Give Them A Brake; Pardon Our Progress, Working For You | | 4 | 4 | |

Question 4a/b: Which one of the twelve items in question 3 do you think would be the most/least effective?

| Summary of Frequencies of Answers | 4a (most) | 4b (least) |
|---|---|---|
| a. Require contractor to install and remove or cover signs as needed with a corresponding pay item | 1 | |
| b. The use of police to monitor traffic | 7 | |
| c. The use of portable speed displays | | |
| d. The use of standard MUTCD signs | | |
| e. The use of signs in the proper locations | | |
| f. The use of flashing lights to supplement signs | | 1 |
| g. The use of flags to supplement signs | | |
| h. The use of a unique sign color | | 1 |
| i. The use of a unique sign shape | | 1 |
| j. The use of an advisory speed on the first advance warning sign | | 2 |
| k. The use of enforcement signing, i.e. WORKERS PRESENT: SPEEDING FINES DOUBLED | | 2 |
| l. The use of public relation signing, i.e. My Parents Work Here; Slow Down, Give Them A Brake; Pardon Our Progress, Working For You | | 2 |

Question 5: What is your experience with Traffic Control Plans? Are they:

| Frequency of Answers | Yes | No | No Answer | Maybe |
|---|---|---|---|---|
| a. Properly designed? | 6 | | 1 | 1 |
| b. Properly sequenced? | 6 | 1 | 1 | |
| c. Properly detailed? | 5 | 1 | 1 | 1 |
| d. Properly installed? | 5 | 2 | 1 | |
| e. Properly removed? | 3 | 4 | 1 | |

Question 6: What is your experience with traffic control devices in work zones:

| Frequency of Answers | Yes | No | No Answer | Maybe |
|---|---|---|---|---|
| a. Are the devices properly removed, covered, or turned when no longer needed? | 2 | 5 | | 1 |
| b. Are damaged devices promptly identified and repaired or replaced? | 1 | 6 | | 1 |

Question 7a: Are inspection procedures performed according to the following schedules?

| Frequency of Answers | Yes | No | No Answer | Maybe |
|---|---|---|---|---|
| 7a. i. At least once each workday | 8 | | | |
| ii. At least once each month at night | 8 | | | |
| iii. At least once each week on off project detours | 8 | | | |
| 7b. Does the contractor respond to deficiencies in a timely manner? | 4 | 4 | | |

Question 8: Where in a work zone do you think most accidents occur?

| | Frequency |
|---|---|
| Advance Warning Area | |
| Transition Area | 6 |
| Buffer Space | |
| Activity Area | 2 |
| Termination Area | |
| Other (more than one answer given) | |

**Responses to Survey of ALDOT District Engineers**

Mailed: 39 Returned: 26 Return Rate: 66.7%

Question 1: Are you aware of any of the following items as being problems in Alabama work zones?

| Frequency of Answers | Yes | No | No Answer |
|---|---|---|---|
| a. Work zone signs placed too early | 4 | 21 | 1 |
| b. Work zone signs left in place too long | 22 | 4 | |
| c. Too many signs are used | 7 | 17 | 2 |
| d. Too few signs are used | 10 | 15 | 1 |
| e. Signs are not appropriate for the current situation | 13 | 11 | 2 |
| f. Signs that are improperly located | 12 | 12 | 2 |

Question 2: Rank the three most dangerous problem areas in work zones with 1 being the most dangerous.

| Summary of Frequencies of Answers | 1's | 2's | 3's |
|---|---|---|---|
| Accidents | 4 | 7 | 3 |
| Crest Vertical Curves | | 1 | 2 |
| Flagging Operations | 4 | 3 | 7 |
| Inadequate Information | | 1 | |
| Lack of Public Awareness | 2 | 4 | 6 |
| Speeds Too Fast For Conditions | 13 | 6 | 3 |
| Stop and Go Congestion | | 3 | 2 |
| Travel Time Delay | | | |
| Work Zone Not Needed | | | |
| Other* | 2 | | 1 |
| Missing | 1 | 1 | 2 |

* These responses were written in for the "Other" Category, the number in parenthesis is the ranking attributed to "Other":

"Lack of Public Concern" (1)
"Lack of Contractor's Knowledge of traffic control" (1)
"Inattention of Drivers" (3)

Question 3: Do you think the following methods will improve the effectiveness of advance warning areas in work zones?

| Frequency of Answers | Yes | Maybe | No | No Answer |
|---|---|---|---|---|
| a. Require contractor to install and remove or cover signs as needed with a corresponding pay item | 15 | 6 | 5 | |
| b. The use of police to monitor traffic | 25 | 1 | | |
| c. The use of portable speed displays | 12 | 8 | 6 | |
| d. The use of standard MUTCD signs | 21 | 3 | 2 | |
| e. The use of signs in the proper locations | 22 | 1 | 2 | 1 |
| f. The use of flashing lights to supplement signs | 13 | 10 | 3 | |
| g. The use of flags to supplement signs | 8 | 12 | 6 | |
| h. The use of a unique sign color | 8 | 9 | 9 | |
| i. The use of a unique sign shape | 2 | 12 | 12 | |
| j. The use of an advisory speed on the first advance warning sign | 10 | 6 | 10 | |
| k. The use of enforcement signing, i.e. WORKERS PRESENT: SPEEDING FINES DOUBLED | 16 | 7 | 3 | |
| l. The use of public relation signing, i.e. My Parents Work Here; Slow Down, Give Them A Brake; Pardon Our Progress, Working For You | 6 | 9 | 11 | |

Question 4a/b: Which one of the twelve items in question 3 do you think would be the most/least effective?

| Summary of Frequencies of Answers | 4a (most) | 4b (least) |
|---|---|---|
| a. Require contractor to install and remove or cover signs as needed with a corresponding pay item | | |
| b. The use of police to monitor traffic | 23 | |
| c. The use of portable speed displays | 3 | 1 |
| d. The use of standard MUTCD signs | 2 | |
| e. The use of signs in the proper locations | | 1 |
| f. The use of flashing lights to supplement signs | 2 | |
| g. The use of flags to supplement signs | | 3 |
| h. The use of a unique sign color | | 2 |
| i. The use of a unique sign shape | | 11 |
| j. The use of an advisory speed on the first advance warning sign | | 2 |
| k. The use of enforcement signing, i.e. WORKERS PRESENT: SPEEDING FINES DOUBLED | | 2 |
| l. The use of public relation signing, i.e. My Parents Work Here; Slow Down, Give Them A Brake; Pardon Our Progress, Working For You | | 7 |

Question 5: What is your experience with Traffic Control Plans? Are they:

| Frequency of Answers | Yes | No | No Answer | Maybe |
|---|---|---|---|---|
| a. Properly designed? | 25 | 1 | | |
| b. Properly sequenced? | 25 | 1 | | |
| c. Properly detailed? | 24 | 2 | | |
| d. Properly installed? | 20 | 6 | | |
| e. Properly removed? | 9 | 16 | 1 | |

Question 6: What is your experience with traffic control devices in work zones:

| Frequency of Answers | Yes | No | No Answer | Maybe |
|---|---|---|---|---|
| a. Are the devices properly removed, covered, or turned when no longer needed? | 6 | 18 | 2 | |
| b. Are damaged devices promptly identified and repaired or replaced? | 6 | 17 | 1 | 2 |

Question 7a: Are inspection procedures performed according to the following schedules?

| Frequency of Answers | Yes | No | No Answer | Maybe |
|---|---|---|---|---|
| 7a. i. At least once each workday | 19 | 5 | 2 | |
| ii. At least once each month at night | 16 | 8 | 2 | |
| iii. At least once each week on off project detours | 18 | 4 | 4 | |
| 7b. Does the contractor respond to deficiencies in a timely manner? | 5 | 16 | 2 | 3 |

Question 8: Where in a work zone do you think most accidents occur?

| | Frequency |
|---|---|
| Advance Warning Area | 1 |
| Transition Area | 12 |
| Buffer Space | 1 |
| Activity Area | 11 |
| Termination Area | |
| Other (more than one answer given) | 1 |

**Responses to Survey of AL County Engineers**

Mailed: 67 Returned: 40 Return Rate: 59.7%

Question 1: Are you aware of any of the following items as being problems in Alabama work zones?

| Frequency of Answers | Yes | No | No Answer |
|---|---|---|---|
| a. Work zone signs placed too early | 17 | 23 | |
| b. Work zone signs left in place too long | 34 | 6 | |
| c. Too many signs are used | 5 | 34 | 1 |
| d. Too few signs are used | 20 | 19 | 1 |
| e. Signs are not appropriate for the current situation | 21 | 19 | |
| f. Signs that are improperly located | 20 | 20 | |

Question 2: Rank the three most dangerous problem areas in work zones with 1 being the most dangerous.

| Summary of Frequencies of Answers | 1's | 2's | 3's |
|---|---|---|---|
| Accidents | 3 | 1 | 4 |
| Crest Vertical Curves | 2 | 3 | 7 |
| Flagging Operations | 5 | 9 | 7 |
| Inadequate Information | 2 | 2 | 1 |
| Lack of Public Awareness | 4 | 8 | 8 |
| Speeds Too Fast For Conditions | 22 | 9 | 3 |
| Stop and Go Congestion | | 4 | 2 |
| Travel Time Delay | | 2 | 7 |
| Work Zone Not Needed | | | |
| Other* | 1 | 1 | |
| Missing | 1 | 1 | 1 |

* These responses were written in for the "Other" Category, the number in parenthesis is the ranking attributed to "Other":

"Traffic backing up behind flagger beyond advance warning signs" (1)

"Lack of Driver Patience" (2)

Question 3: Do you think the following methods will improve the effectiveness of advance warning areas in work zones?

| Frequency of Answers | Yes | Maybe | No | No Answer |
|---|---|---|---|---|
| a. Require contractor to install and remove or cover signs as needed with a corresponding pay item | 22 | 11 | 7 | |
| b. The use of police to monitor traffic | 35 | 4 | 1 | |
| c. The use of portable speed displays | 18 | 18 | 4 | |
| d. The use of standard MUTCD signs | 26 | 11 | 3 | |
| e. The use of signs in the proper locations | 34 | 6 | | |
| f. The use of flashing lights to supplement signs | 27 | 12 | 1 | |
| g. The use of flags to supplement signs | 10 | 17 | 13 | |
| h. The use of a unique sign color | 15 | 17 | 8 | |
| i. The use of a unique sign shape | 10 | 15 | 15 | |
| j. The use of an advisory speed on the first advance warning sign | 15 | 16 | 9 | |
| k. The use of enforcement signing, i.e. WORKERS PRESENT: SPEEDING FINES DOUBLED | 21 | 18 | 1 | |
| l. The use of public relation signing, i.e. My Parents Work Here; Slow Down, Give Them A Brake; Pardon Our Progress, Working For You | 8 | 19 | 13 | |

Question 4a/b: Which one of the twelve items in question 3 do you think would be the most/least effective?

| Summary of Frequencies of Answers | 4a (most) | 4b (least) |
|---|---|---|
| a. Require contractor to install and remove or cover signs as needed with a corresponding pay item | 3 | 3 |
| b. The use of police to monitor traffic | 30 | 1 |
| c. The use of portable speed displays | | |
| d. The use of standard MUTCD signs | 1 | |
| e. The use of signs in the proper locations | 3 | |
| f. The use of flashing lights to supplement signs | 3 | |
| g. The use of flags to supplement signs | | 6 |
| h. The use of a unique sign color | 1 | 1 |
| i. The use of a unique sign shape | | 14 |
| j. The use of an advisory speed on the first advance warning sign | 1 | 6 |
| k. The use of enforcement signing, i.e. WORKERS PRESENT: SPEEDING FINES DOUBLED | 1 | |
| l. The use of public relation signing, i.e. My Parents Work Here; Slow Down, Give Them A Brake; Pardon Our Progress, Working For You | | 12 |

Question 5: What is your experience with Traffic Control Plans? Are they:

| Frequency of Answers | Yes | No | No Answer | Maybe |
|---|---|---|---|---|
| a. Properly designed? | 39 | | 1 | |
| b. Properly sequenced? | 39 | | 1 | |
| c. Properly detailed? | 37 | 2 | 1 | |
| d. Properly installed? | 32 | 6 | 1 | 1 |
| e. Properly removed? | 21 | 17 | 1 | 1 |

Question 6: What is your experience with traffic control devices in work zones:

| Frequency of Answers | Yes | No | No Answer | Maybe |
|---|---|---|---|---|
| a. Are the devices properly removed, covered, or turned when no longer needed? | 15 | 24 | | 1 |
| b. Are damaged devices promptly identified and repaired or replaced? | 20 | 19 | | 1 |

Question 7a: Are inspection procedures performed according to the following schedules?

| Frequency of Answers | Yes | No | No Answer | Maybe |
|---|---|---|---|---|
| 7a. i. At least once each workday | 29 | 11 | | |
| ii. At least once each month at night | 23 | 16 | 1 | |
| iii. At least once each week on off project detours | 28 | 11 | 1 | |
| 7b. Does the contractor respond to deficiencies in a timely manner? | 19 | 18 | 2 | 1 |

Question 8: Where in a work zone do you think most accidents occur?

| | Frequency |
|---|---|
| Advance Warning Area | 2 |
| Transition Area | 22 |
| Buffer Space | 3 |
| Activity Area | 11 |
| Termination Area | |
| Other (more than one answer given) | 2 |

**Responses to Survey of All Engineers**

Mailed: 136 Returned: 82 Return Rate: 60.3%

Question 1: Are you aware of any of the following items as being problems in Alabama work zones?

| Frequency of Answers | Yes | No | No Answer |
|---|---|---|---|
| a. Work zone signs placed too early | 29 | 50 | 3 |
| b. Work zone signs left in place too long | 71 | 11 | |
| c. Too many signs are used | 15 | 62 | 5 |
| d. Too few signs are used | 35 | 43 | 4 |
| e. Signs are not appropriate for the current situation | 48 | 32 | 2 |
| f. Signs that are improperly located | 43 | 36 | 3 |

Question 2: Rank the three most dangerous problem areas in work zones with 1 being the most dangerous.

| Summary of Frequencies of Answers | 1's | 2's | 3's |
|---|---|---|---|
| Accidents | 11 | 8 | 11 |
| Crest Vertical Curves | 2 | 7 | 12 |
| Flagging Operations | 9 | 12 | 17 |
| Inadequate Information | 3 | 4 | 2 |
| Lack of Public Awareness | 10 | 14 | 16 |
| Speeds Too Fast For Conditions | 41 | 18 | 7 |
| Stop and Go Congestion | 1 | 12 | 5 |
| Travel Time Delay | | 3 | 8 |
| Work Zone Not Needed | | 1 | |
| Other | 3 | 1 | 1 |
| Missing | 2 | 2 | 3 |

Question 3: Do you think the following methods will improve the effectiveness of advance warning areas in work zones?

| Frequency of Answers | Yes | Maybe | No | No Answer |
|---|---|---|---|---|
| a. Require contractor to install and remove or cover signs as needed with a corresponding pay item | 48 | 21 | 13 | |
| b. The use of police to monitor traffic | 74 | 5 | 3 | |
| c. The use of portable speed displays | 39 | 30 | 13 | |
| d. The use of standard MUTCD signs | 57 | 18 | 6 | 1 |
| e. The use of signs in the proper locations | 67 | 10 | 3 | 2 |
| f. The use of flashing lights to supplement signs | 43 | 29 | 10 | |
| g. The use of flags to supplement signs | 21 | 33 | 28 | |
| h. The use of a unique sign color | 26 | 33 | 23 | |
| i. The use of a unique sign shape | 14 | 30 | 38 | |
| j. The use of an advisory speed on the first advance warning sign | 29 | 26 | 27 | |
| k. The use of enforcement signing, i.e. WORKERS PRESENT: SPEEDING FINES DOUBLED | 49 | 28 | 5 | |
| l. The use of public relation signing, i.e. My Parents Work Here; Slow Down, Give Them A Brake; Pardon Our Progress, Working For You | 16 | 35 | 31 | |

Question 4a/b: Which one of the twelve items in question 3 do you think would be the most/least effective?

| Summary of Frequencies of Answers | 4a (most) | 4b (least) |
|---|---|---|
| a. Require contractor to install and remove or cover signs as needed with a corresponding pay item | 6 | 3 |
| b. The use of police to monitor traffic | 66 | 1 |
| c. The use of portable speed displays | 3 | 1 |
| d. The use of standard MUTCD signs | 3 | |
| e. The use of signs in the proper locations | 3 | 1 |
| f. The use of flashing lights to supplement signs | 5 | 1 |
| g. The use of flags to supplement signs | | 11 |
| h. The use of a unique sign color | 1 | 4 |
| i. The use of a unique sign shape | | 29 |
| j. The use of an advisory speed on the first advance warning sign | 1 | 12 |
| k. The use of enforcement signing, i.e. WORKERS PRESENT: SPEEDING FINES DOUBLED | 1 | 4 |
| l. The use of public relation signing, i.e. My Parents Work Here; Slow Down, Give Them A Brake; Pardon Our Progress, Working For You | | 22 |

Question 5: What is your experience with Traffic Control Plans? Are they:

| Frequency of Answers | Yes | No | No Answer | Maybe |
|---|---|---|---|---|
| a. Properly designed? | 77 | 1 | 3 | 1 |
| b. Properly sequenced? | 76 | 3 | 3 | |
| c. Properly detailed? | 71 | 7 | 3 | 1 |
| d. Properly installed? | 61 | 17 | 3 | 1 |
| e. Properly removed? | 35 | 42 | 4 | 1 |

Question 6: What is your experience with traffic control devices in work zones:

| Frequency of Answers | Yes | No | No Answer | Maybe |
|---|---|---|---|---|
| a. Are the devices properly removed, covered, or turned when no longer needed? | 23 | 55 | 2 | 2 |
| b. Are damaged devices promptly identified and repaired or replaced? | 29 | 48 | 1 | 4 |

Question 7a: Are inspection procedures performed according to the following schedules?

| Frequency of Answers | Yes | No | No Answer | Maybe |
|---|---|---|---|---|
| 7a. i. At least once each workday | 57 | 20 | 5 | |
| ii. At least once each month at night | 49 | 26 | 7 | |
| iii. At least once each week on off project detours | 55 | 18 | 9 | |
| 7b. Does the contractor respond to deficiencies in a timely manner? | 29 | 43 | 6 | 4 |

Question 8: Where in a work zone do you think most accidents occur?

| | Frequency |
|---|---|
| Advance Warning Area | 3 |
| Transition Area | 46 |
| Buffer Space | 4 |
| Activity Area | 26 |
| Termination Area | |
| Other (more than one answer given) | 3 |

# APPENDIX B

## Statistical Analysis of Survey Results

Question 1: Analyzed using the Kolmogorov-Smirnov Two-Sample Test
Responses of the AL County and the ALDOT District Engineers.

$H_0$: The two sample distributions are members of the same population.

$H_1$: The two sample distributions are not members of the same population.

Two-tailed test, $\alpha = 0.05$

| | County Freq. | Cum. Freq. | % | District Freq. | Cum. Freq. | % | Difference |
|---|---|---|---|---|---|---|---|
| a | 17 | 17 | 14.5 | 4 | 4 | 5.9 | 8.6% - max |
| b | 34 | 51 | 43.6 | 22 | 26 | 38.2 | 5.4 |
| c | 5 | 56 | 47.9 | 7 | 33 | 48.5 | 0.6 |
| d | 20 | 76 | 65.0 | 10 | 43 | 63.2 | 1.8 |
| e | 21 | 97 | 82.9 | 13 | 56 | 82.4 | 0.5 |
| f | 20 | 117 | 100.0 | 12 | 68 | 100.0 | 0.0 |
| | 117 | | | 68 | | | |

D = maximum difference in cumulative distribution functions
= 0.086

$D_{CR} = 1.36[(n_1 + n_2)/(n_1n_2)]^{1/2} = 1.36[(117+68)/(117*68)]^{1/2}$
$= 0.207$

$D < D_{CR} \rightarrow$ Accept $H_0$
Conclusion: There is no significant difference in the distributions.

Question 2: Analyzed using Spearman Rank Correlation Coefficient.

Responses of the AL County vs. ALDOT District Engineers

| Frequencies for AL County Engineers | 1's | 2's | 3's | Mean | Rank |
|---|---|---|---|---|---|
| Accidents | 3 | 1 | 4 | 2.125 | 5 |
| Crest Vertical Curves | 2 | 3 | 7 | 2.417 | 2 |
| Flagging Operations | 5 | 9 | 7 | 2.095 | 6 |
| Inadequate Information | 2 | 2 | 1 | 1.800 | 7 |
| Lack of Public Awareness | 4 | 8 | 8 | 2.200 | 4 |
| Speeds Too Fast For Conditions | 22 | 9 | 3 | 1.441 | 9 |
| Stop and Go Congestion | 0 | 4 | 2 | 2.333 | 3 |
| Travel Time Delay | 0 | 2 | 7 | 2.278 | 1 |
| Work Zone Not Needed | 0 | 0 | 0 | 0.000 | 10 |
| Other | 1 | 1 | 0 | 1.500 | 8 |

| Frequencies for ALDOT District Engineers | 1's | 2's | 3's | Mean | Rank |
|---|---|---|---|---|---|
| Accidents | 4 | 7 | 3 | 1.929 | 6 |
| Crest Vertical Curves | 0 | 1 | 2 | 2.667 | 1 |
| Flagging Operations | 4 | 3 | 7 | 2.214 | 4 |
| Inadequate Information | 0 | 1 | 0 | 2.000 | 5 |
| Lack of Public Awareness | 2 | 4 | 6 | 2.333 | 3 |
| Speeds Too Fast For Conditions | 13 | 6 | 3 | 1.545 | 8 |
| Stop and Go Congestion | 0 | 3 | 2 | 2.400 | 2 |
| Travel Time Delay | 0 | 0 | 0 | 0.000 | 9.5 |
| Work Zone Not Needed | 0 | 0 | 0 | 0.000 | 9.5 |
| Other | 2 | 0 | 1 | 1.667 | 7 |

| | County Rank | District Rank | $d_i$ | $d_i^2$ |
|---|---|---|---|---|
| Accidents | 5 | 6 | -1.0 | 1.00 |
| Crest Vertical Curves | 2 | 1 | 1.0 | 1.00 |
| Flagging Operations | 6 | 4 | 2.0 | 4.00 |
| Inadequate Information | 7 | 5 | 2.0 | 4.00 |
| Lack of Public Awareness | 4 | 3 | 1.0 | 1.00 |
| Speeds Too Fast For Conditions | 9 | 8 | 1.0 | 1.00 |
| Stop and Go Congestion | 3 | 2 | 1.0 | 1.00 |
| Travel Time Delay | 1 | 9.5 | -8.5 | 72.25 |
| Work Zone Not Needed | 10 | 9.5 | 0.5 | 0.25 |
| Other | 8 | 7 | 1.0 | 1.00 |
| $\sum =$ | 55 | 55 | 0.0 | 86.50 |

$r_s = 1 - [ ( 6 * \sum d_i^2 ) / ( n * (n^2 - 1) ) ] = 1 - [ ( 6 * 86.5 ) / ( 10 * ( 10^2 - 1 ) ) ]$

$r_s = 0.476$

Conclusions: Weak positive correlation between responses.
Therefore some differences are apparent.

Question 2: Analyzed using Spearman Rank Correlation Coefficient.

Responses of the AL County vs. ALDOT Division Engineers

Frequencies, means , and rankings for AL County Engineers can be found on page 95.

| Frequencies for ALDOT Division Engineers | 1's | 2's | 3's | Mean | Rank |
|---|---|---|---|---|---|
| Accidents | 3 | 0 | 2 | 1.800 | 5 |
| Crest Vertical Curves | 0 | 2 | 1 | 2.333 | 4 |
| Flagging Operations | 0 | 0 | 2 | 3.000 | 1.5 |
| Inadequate Information | 0 | 0 | 1 | 3.000 | 1.5 |
| Lack of Public Awareness | 0 | 1 | 2 | 2.667 | 3 |
| Speeds Too Fast For Conditions | 4 | 2 | 0 | 1.333 | 7 |
| Stop and Go Congestion | 1 | 3 | 0 | 1.750 | 6 |
| Travel Time Delay | 0 | 0 | 0 | 0.000 | 9 |
| Work Zone Not Needed | 0 | 0 | 0 | 0.000 | 9 |
| Other | 0 | 0 | 0 | 0.000 | 9 |

| | County Rank | Division Rank | $d_i$ | $d_i^2$ |
|---|---|---|---|---|
| Accidents | 5 | 5 | 0.0 | 0.00 |
| Crest Vertical Curves | 2 | 4 | -2.0 | 4.00 |
| Flagging Operations | 6 | 1.5 | 4.5 | 20.25 |
| Inadequate Information | 7 | 1.5 | 5.5 | 30.25 |
| Lack of Public Awareness | 4 | 3 | 1.0 | 1.00 |
| Speeds Too Fast For Conditions | 9 | 7 | 2.0 | 4.00 |
| Stop and Go Congestion | 3 | 6 | -3.0 | 9.00 |
| Travel Time Delay | 1 | 9 | -8.0 | 64.00 |
| Work Zone Not Needed | 10 | 9 | 1.0 | 1.00 |
| Other | 8 | 9 | -1.0 | 1.00 |
| $\sum =$ | 55 | 55 | 0.0 | 134.50 |

$$r_s = 1 - [\,(6 * \sum d_i^2\,) / (\,n * (n^2 - 1)\,)\,] = 1 - [\,(6 * 134.5) / (\,10 * (\,10^2 - 1\,)\,)\,]$$

$r_s = 0.185$

Conclusions: Weak positive correlation between responses.
Therefore some differences are apparent.

Question 2: Analyzed using Spearman Rank Correlation Coefficient.

Responses of the ALDOT District vs. ALDOT Division Engineers

Frequencies, means, and rankings for both ALDOT District and ALDOT Division Engineers can be found on pages 95 and 97, respectively.

| | District Rank | Division Rank | $d_i$ | $d_i^2$ |
|---|---|---|---|---|
| Accidents | 6 | 5 | 1.0 | 1.00 |
| Crest Vertical Curves | 1 | 4 | -3.0 | 9.00 |
| Flagging Operations | 4 | 1.5 | 2.5 | 6.25 |
| Inadequate Information | 5 | 1.5 | 3.5 | 12.25 |
| Lack of Public Awareness | 3 | 3 | 0.0 | 0.00 |
| Speeds Too Fast For Conditions | 8 | 7 | 1.0 | 1.00 |
| Stop and Go Congestion | 2 | 6 | -4.0 | 16.00 |
| Travel Time Delay | 9.5 | 9 | 0.5 | 0.25 |
| Work Zone Not Needed | 9.5 | 9 | 0.5 | 0.25 |
| Other | 7 | 9 | -2.0 | 4.00 |
| $\sum =$ | 55 | 55 | 0.0 | 50.00 |

$$r_s = 1 - [ ( 6 * \sum d_i^2 ) / ( n * (n^2 - 1) ) ] = 1 - [ ( 6 * 50 / ( 10 * ( 10^2 - 1 ) ) ]$$

$$r_s = 0.697$$

Conclusions: Strong positive correlation between responses.
Therefore good agreement in the responses.

Question 3: Analyzed using the Kolmogorov-Smirnov Two-Sample Test
Responses of the AL County and the ALDOT District Engineers.

$H_0$: The two sample distributions are members of the same population.

$H_1$: The two sample distributions are not members of the same population.

Two-tailed test, $\alpha = 0.05$

| | County Freq. | Cum. Freq. | % | District Freq. | Cum. Freq. | % | Difference |
|---|---|---|---|---|---|---|---|
| a | 22 | 22 | 9.1 | 15 | 15 | 9.5 | 0.4% |
| b | 35 | 57 | 23.7 | 25 | 40 | 25.3 | 1.6 |
| c | 18 | 75 | 31.1 | 12 | 52 | 32.9 | 1.8 |
| d | 26 | 101 | 41.9 | 21 | 73 | 46.2 | 4.3 – max |
| e | 34 | 135 | 56.0 | 22 | 95 | 60.1 | 4.1 |
| f | 27 | 162 | 67.2 | 13 | 108 | 68.4 | 1.2 |
| g | 10 | 172 | 71.4 | 8 | 116 | 73.4 | 2.0 |
| h | 15 | 187 | 77.6 | 8 | 124 | 78.5 | 0.9 |
| i | 10 | 197 | 81.7 | 2 | 126 | 79.7 | 2.0 |
| j | 15 | 212 | 88.0 | 10 | 136 | 86.1 | 1.9 |
| k | 21 | 233 | 96.7 | 16 | 152 | 96.2 | 0.5 |
| l | 8 | 241 | 100.0 | 6 | 158 | 100.0 | 0.0 |
| | 241 | | | 158 | | | |

D = maximum difference in cumulative distribution functions
= 0.043

$D_{CR} = 1.36[(n_1 + n_2)/(n_1n_2)]^{1/2} = 1.36[(241+158)/(241*158)]^{1/2}$
= 0.139

$D < D_{CR} \rightarrow$ Accept $H_0$

Conclusion: There is no significant difference in the distributions.

Question 3: Analyzed using the Kolmogorov-Smirnov Two-Sample Test
Responses of the AL County and the ALDOT Division Engineers.

$H_0$: The two sample distributions are members of the same population.

$H_1$: The two sample distributions are not members of the same population.

Two-tailed test, $\alpha = 0.05$

| | County Freq. | Cum. Freq. | % | Division Freq. | Cum. Freq. | % | Difference |
|---|---|---|---|---|---|---|---|
| a | 22 | 22 | 9.1 | 5 | 5 | 10.6 | 1.5% |
| b | 35 | 57 | 23.7 | 8 | 13 | 27.7 | 4.0 |
| c | 18 | 75 | 31.1 | 5 | 18 | 38.3 | 6.6 |
| d | 26 | 101 | 41.9 | 6 | 24 | 51.1 | 9.2 – max |
| e | 34 | 135 | 56.0 | 6 | 30 | 63.8 | 7.8 |
| f | 27 | 162 | 67.2 | 2 | 32 | 68.1 | 0.9 |
| g | 10 | 172 | 71.4 | 2 | 34 | 72.3 | 0.9 |
| h | 15 | 187 | 77.6 | 2 | 36 | 76.6 | 1.0 |
| i | 10 | 197 | 81.7 | 2 | 38 | 80.9 | 0.8 |
| j | 15 | 212 | 88.0 | 3 | 41 | 87.2 | 0.8 |
| k | 21 | 233 | 96.7 | 6 | 47 | 100.0 | 3.3 |
| l | 8 | 241 | 100.0 | 0 | 47 | 100.0 | 0.0 |
| | 241 | | | 47 | | | |

D = maximum difference in cumulative distribution functions
= 0.092

$D_{CR} = 1.36[(n_1 + n_2)/(n_1n_2)]^{1/2} = 1.36[(241+47)/(241*47)]^{1/2}$
$= 0.217$

$D < D_{CR} \rightarrow$ Accept $H_0$
Conclusion: There is no significant difference in the distributions.

Question 3: Analyzed using the Kolmogorov-Smirnov Two-Sample Test
Responses of the ALDOT District and the ALDOT Division Engineers.

$H_0$: The two sample distributions are members of the same population.

$H_1$: The two sample distributions are not members of the same population.

Two-tailed test, $\alpha = 0.05$

| | District Freq. | Cum. Freq. | % | Division Freq. | Cum. Freq. | % | Difference |
|---|---|---|---|---|---|---|---|
| a | 15 | 15 | 9.5 | 5 | 5 | 10.6 | 1.1% |
| b | 25 | 40 | 25.3 | 8 | 13 | 27.7 | 2.4 |
| c | 12 | 52 | 32.9 | 5 | 18 | 38.3 | 5.4 – max |
| d | 21 | 73 | 46.2 | 6 | 24 | 51.1 | 4.9 |
| e | 22 | 95 | 60.1 | 6 | 30 | 63.8 | 3.7 |
| f | 13 | 108 | 68.4 | 2 | 32 | 68.1 | 0.3 |
| g | 8 | 116 | 73.4 | 2 | 34 | 72.3 | 1.1 |
| h | 8 | 124 | 78.5 | 2 | 36 | 76.6 | 1.9 |
| i | 2 | 126 | 79.7 | 2 | 38 | 80.9 | 1.2 |
| j | 10 | 136 | 86.1 | 3 | 41 | 87.2 | 1.1 |
| k | 16 | 152 | 96.2 | 6 | 47 | 100.0 | 3.8 |
| l | 6 | 158 | 100.0 | 0 | 47 | 100.0 | 0.0 |
| | 158 | | | 47 | | | |

D = maximum difference in cumulative distribution functions
= 0.054

$D_{CR} = 1.36[(n_1 + n_2)/(n_1 n_2)]^{1/2} = 1.36[(158+47)/(158*47)]^{1/2}$
= 0.226

$D < D_{CR} \rightarrow$ Accept $H_0$

Conclusion: There is no significant difference in the distributions.

Question 4a: Analyzed using Spearman Rank Correlation Coefficient.

Responses of the AL County vs. ALDOT District Engineers

| | County Rank | District Rank | $d_i$ | $d_i^2$ |
|---|---|---|---|---|
| A | 3 | 8.5 | -5.5 | 30.25 |
| B | 1 | 1 | 0.0 | 0.00 |
| C | 10.5 | 2 | 8.5 | 72.25 |
| D | 6.5 | 3.5 | 3.0 | 9.00 |
| E | 3 | 8.5 | -5.5 | 30.25 |
| F | 3 | 3.5 | -0.5 | 0.25 |
| G | 10.5 | 8.5 | 2.0 | 4.00 |
| H | 6.5 | 8.5 | -2.0 | 4.00 |
| I | 10.5 | 8.5 | 2.0 | 4.00 |
| J | 6.5 | 8.5 | -2.0 | 4.00 |
| K | 6.5 | 8.5 | -2.0 | 4.00 |
| L | 10.5 | 8.5 | 2.0 | 4.00 |
| $\sum =$ | 78 | 78 | 0.0 | 166.00 |

$$r_s = 1 - [ ( 6 * \sum d_i^2 ) / ( n * (n^2 - 1) ) ] = 1 - [ ( 6 * 166 / ( 12 * ( 12^2 - 1 ) ) ]$$

$r_s = 0.420$

Conclusions: Weak positive correlation between responses.
Therefore some differences are apparent.

Question 4b: Analyzed using Spearman Rank Correlation Coefficient.

Responses of the AL County vs. ALDOT District Engineers

| | County Rank | District Rank | $d_i$ | $d_i^2$ |
|---|---|---|---|---|
| A | 5 | 10.5 | -5.5 | 30.25 |
| B | 6.5 | 10.5 | -4.0 | 16.00 |
| C | 10 | 7.5 | 2.5 | 6.25 |
| D | 10 | 10.5 | -0.5 | 0.25 |
| E | 10 | 7.5 | 2.5 | 6.25 |
| F | 10 | 10.5 | -0.5 | 0.25 |
| G | 3.5 | 3 | 0.5 | 0.25 |
| H | 6.5 | 5 | 1.5 | 2.25 |
| I | 1 | 1 | 0.0 | 0.00 |
| J | 3.5 | 5 | -1.5 | 2.25 |
| K | 10 | 5 | 5.0 | 25.00 |
| L | 2 | 2 | 0.0 | 0.00 |
| $\sum =$ | 78 | 78 | 0.0 | 89.00 |

$r_s = 1 - [ ( 6 * \sum d_i^2 ) / ( n * (n^2 - 1) ) ] = 1 - [ ( 6 * 89 / ( 12 * ( 12^2 - 1 ) ) ]$

$r_s = 0.689$

Conclusions: Strong positive correlation between responses.
Therefore good agreement in the responses.

Question 5: Analyzed using the Kolmogorov-Smirnov Two-Sample Test
Responses of the AL County and the ALDOT District Engineers.

$H_0$: The two sample distributions are members of the same population.

$H_1$: The two sample distributions are not members of the same population.

Two-tailed test, $\alpha = 0.05$

| | County Freq. | Cum. Freq. | % | District Freq. | Cum. Freq. | % | Difference |
|---|---|---|---|---|---|---|---|
| a | 39 | 39 | 23.2 | 25 | 25 | 24.3 | 1.1% |
| b | 39 | 78 | 46.4 | 25 | 50 | 48.5 | 2.1 |
| c | 37 | 115 | 68.5 | 24 | 74 | 71.8 | 3.3 |
| d | 32 | 147 | 87.5 | 20 | 94 | 91.3 | 3.8 – max |
| e | 21 | 168 | 100.0 | 9 | 103 | 100.0 | 0.0 |
| | 168 | | | 103 | | | |

D = maximum difference in cumulative distribution functions
= 0.038

$D_{CR} = 1.36[(n_1 + n_2)/(n_1n_2)]^{1/2} = 1.36[(168+103)/(168*103)]^{1/2}$
$= 0.170$

$D < D_{CR} \rightarrow$ Accept $H_0$

Conclusion: There is no significant difference in the distributions.

Question 7: Analyzed using the Kolmogorov-Smirnov Two-Sample Test
Responses of the AL County and the ALDOT District Engineers.

$H_0$: The two sample distributions are members of the same population.

$H_1$: The two sample distributions are not members of the same population.

Two-tailed test, $\alpha = 0.05$

| | County Freq. | Cum. Freq. | % | District Freq. | Cum. Freq. | % | Difference |
|---|---|---|---|---|---|---|---|
| a i | 29 | 29 | 29.3 | 19 | 19 | 32.8 | 3.5% |
| ii | 23 | 52 | 52.5 | 16 | 35 | 60.3 | 7.8 |
| iii | 28 | 80 | 80.8 | 18 | 53 | 91.4 | 10.6 – max |
| b | 19 | 99 | 100.0 | 5 | 58 | 100.0 | 0.0 |
| | 99 | | | 58 | | | |

D = maximum difference in cumulative distribution functions
= 0.106

$D_{CR} = 1.36[(n_1 + n_2)/(n_1n_2)]^{1/2} = 1.36[(99+58)/(99*58)]^{1/2}$
= 0.225

$D < D_{CR} \rightarrow$ Accept $H_0$
Conclusion: There is no significant difference in the distributions.

Question 8: Analyzed using Spearman Rank Correlation Coefficient.

Responses of the AL County vs. ALDOT District Engineers

| | County Rank | District Rank | $d_i$ | $d_i^2$ |
|---|---|---|---|---|
| Advance Warning Area | 4.5 | 4 | 0.5 | 0.25 |
| Transition Area | 1 | 1 | 0.0 | 0.00 |
| Buffer Zone | 3 | 4 | -1.0 | 1.00 |
| Activity Area | 2 | 2 | 0.0 | 0.00 |
| Termination Area | 6 | 6 | 0.0 | 0.00 |
| Other | 4.5 | 4 | 0.5 | 0.25 |
| $\sum =$ | 21 | 21 | 0.0 | 1.50 |

$r_s = 1 - [ ( 6 * \sum d_i^2 ) / ( n * (n^2 - 1) ) ] = 1 - [ ( 6 * 1.5 / ( 12 * ( 12^2 - 1 ) ) ]$

$r_s = 0.957$

Conclusions: Very strong positive correlation between responses.
Therefore excellent agreement in the responses.