Determination of Traffic Control Device Selection for Nighttime Maintenance of Traffic

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ABSTRACT

Each year more than 700 fatalities occur nationally due to vehicular accidents within work zones. [1] New developments and technologies have paved the way for the creation of diamond grade sheeting, a new, more retroreflective sheeting. Research has shown that diamond grade sheeting is 6 to 14 times brighter then engineering grade sheeting and is already widely required for use on work zone signs. However, the diamond grade sheeting is not widely required for use on channelizing drums due to the increased cost and concern that the increased retroreflectivity of the sheeting may actually decrease the safety of the work zone when used on closely spaced construction drums. A comparative parallel study was conducted to compare the safety impacts of the diamond grade sheeting with high intensity sheeting, the current MUTCD standard. Driver behavior within the work zone was analyzed in terms of lane placement and traveled speed with respect to the posted speed limit. These data were collected and analyzed to determine the extent to which the behaviors different between the two traffic control treatments. A current practices survey was also distributed to each state department of transportation to determine the extent to which diamond grade sheeting is being used. Of the 80% of the states which responded to the current practices survey, approximately 66.7% of them do not require diamond grade sheeting for use in construction zones in their states with cost being the most widely selected reason. Those states that do require diamond grade sheeting for use on drums in their work zones listed safety, improved work zone delineation, and improved work zone visibility as outweighing the cost of the sheeting. Based on the lane placement and speed deviation data, drivers traveling through work zones with diamond grade sheeting position their vehicle further away from the work zone and abide closer to the posted speed limits when compared to those traveling through work zones with high intensity sheeting on the construction drums.

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1.0 INTRODUCTION

Each year more than 700 fatalities occur nationally due to vehicular accidents within work zones. [1] In order to guide motorists through work zones in a safe, efficient and smooth manner, various traffic control devices are used including temporary warning signs, pavement markings, channelizing devices such as drums, cones, markers, and barricades. In most work zones, numerous drums are used as traffic control devices to channelize traffic through the work zone. The drums have alternating orange and white retro-reflective stripes which make them highly visible, even during the nighttime. There are three types of retro-reflective strips or sheeting that can be utilized on the drums, engineer-grade, high-intensity sheeting and diamond-grade.

Engineer-grade sheeting is composed of very small glass beads that are enclosed in a translucent substrate with a product life of approximately seven years. High-intensity sheeting is composed of at least two layers, an outer translucent layer and an inner reflective layer that includes glass beads. The product life is generally ten years and costs approximately twice the cost for engineer-grade sheeting. Approximately 32 state's recommend the use of high-intensity sheeting on drums in work zones. Diamond-grade sheeting is micro-prismatic material with a diamond-shaped lattice separating the layers with either a course or fine grain. Diamond-grade sheeting ranges from six to 14 times brighter than engineer-grade sheeting and has a ten year product life. The cost for diamond-grade sheeting is nearly five times the cost for engineer-grade sheeting. Recently, a new full cube diamond-grade sheeting, (DG^3), has been introduced into the highway market that can reflect 60 percent more light back to vehicles than the traditional diamond-grade sheeting.

There have been concerns voiced by transportation engineers as well as local agencies that the retro-reflectivity of the diamond-grade sheeting may reflect too much light from the vehicle's headlights back to the driver, particularly for a string of devices several miles in length spaced at approximately twice the speed limit. Such reflections may cause glare and limit the ability of the driver to continue safely along their travel path. It has been shown in past research that higher retro-reflectivity improves driver visibility of signs in various weather conditions [2]. However, a study has not been conducted comparing the diamond-grade sheeting on drums with high-intensity sheeting on drums.

A comparative parallel study was performed to compare vehicle behavior in regards to lateral placement within the lane and deviation between travel speed and the posted work zone speed limit. A current practice survey was distributed to each state department of transportation in order to determine the extent to which diamond grade sheeting is currently being required. The departments were also asked to respond as to why they were or were not requiring diamond grade sheeting. The survey responses were collected and evaluated.

2.0 BACKGROUND

2.1 What is Retroreflectivity

Retroreflectivity refers to the ability of a specially engineered surface to reflect incoming light back in the direction from which it came [3]. It results from the conscious design and precise manufacturing of prismatic structures which comprise modern retroreflective sheeting [4]. This characteristic is essential for nighttime visibility of traffic signs and other traffic control devices and therefore is essential for safe nighttime motor vehicle operation [3]. It is imperative for safe driving conditions that drivers are able to see and read traffic signs or traffic control devices at a sufficient distance to be able to comprehend the meaning of the sign and have sufficient time to make appropriate decisions and adjustments. When geometric sight distance obstructions are not considered, the retroreflectivity, or the amount of light reflected back to the source of the incident light, of the sheeting used on the traffic control device or sign directly relates to a drivers ability to see and comprehend the device or sign, especially during nighttime driving conditions.

Retroreflection is achieved through the combination of specular reflection, as with light reflected from a mirror, refraction, or the change in path of a light source as it passes through a medium, and total internal reflection which occurs when light contacts a transparent material but still bounces off rather than passing through. In combination, these three principles lead to a beam of light being transmitted back towards its source in a path parallel to the incident light beam [5].

2.2 Types of Retroreflective Sheeting

The first generation of retroreflective sheeting was introduced by the 3M™ Corporation in the 1920's. However, the first wide use application of retroreflective sheeting was initiated in 1947 [5]. This sheeting, termed "Engineering Grade" sheeting, utilized spherical glass beads encased in a transparent polymer. This encasing of the class beads sealed the glass beads from the elements which would render their visibility lower than that of other materials used for signs at the time. The sealing of the glad beads in a transparent polymer made the Engineering Grade sheeting the brightest available at the time. This sheeting was the dominant traffic sign sheeting around the world for 25 yrs [5]. Though it set the standard as the most retroreflective material of its time, the use of fully encapsulated spherical beads only transmitted approximately eight percent of the incident light back to the source [5]. Advances in technology which transmit a larger percentage of the incident light back to the source have rendered this sheeting obsolete for use of work zone traffic control devices.

A second generation of retroreflective sheeting emerged from the 3M™ Corporation in 1971. This sheeting, termed "High Intensity" sheeting continues to use face film to be in contact with the glass beads, an air void was induced between the incident surface of the glass beads and the protective transparent film [5]. This, along with improvements in the reflective backing material, provided for a new retroreflective sheeting material which transmits approximately 16% of the incident light back to its source [5]. This increase in brightness quickly propelled the High Intensity sheeting into the forefront for use on highway signs.

Use of glass beads had its limitations for retroreflectivity. The spherical glass bead has only approximately 28% of its area which provides proper angle for retroreflection. The spherical design of the glass beads also inherently provided "dead spots" due to its shape and the lack of dense packing abilities of spheres. In order to significantly increase the amount of light transmitted back to the source a new technology, prismatic sheeting, was developed. As early as 1963 the Rowland Products Corporation, now Reflexite, was working to develop a prismatic retroreflective sheeting [5]. In 1970, Rowland Products Inc. patented a "microprismatic" sheeting which lead to the next generation of retroreflective sheeting, "Diamond Grade" sheeting. This prismatic sheeting incorporates the use of "high accuracy and high definition cube corners" rather than glass beads. This new generation of retroreflective sheeting transmits nearly 35% of incident light back to its source.

The new generation of retroreflective sheeting technology created by the 3M™ Corporation is based on 100% efficient optics [5, 6]. Previously the greatest efficiency achieved in sheeting material was 65%, and many signs and devices are utilizing sheeting with 28%

efficient optics [6]. The efficiency of the full cube prismatic reflective sheeting, 3M's DG^3 sheeting, returns almost 60% of the incident light back toward its source. When compared to the spherical glass lens bead optics, the 3M™ DG^3 sheeting provides for the reflection of nearly twice as much of the incident light [3, 5, 6, 7]. The 3M™ DG^3 sheeting is proposed as ASTM Type XI and has been designed as a replacement for all devices which utilize retroreflective sheeting [8].

2.3 Previous Research on the Effects of Different Sheeting Types

A study performed by Gatscha et al. published and presented at the TRB 2008 conference studied the eye movement characteristics for Type-III, or Engineering Grade, and Type-XI, or Diamond Grade, sheeting on signs during nighttime driving conditions [9]. This study was performed with two groups of participants, a group of young drivers (20-25 yrs old) and a group of older drivers (50-55 yrs old). The study was performed using the IView-System of SensoMotoric Instruments. This system utilized a gaze tracking system with 2 cameras mounted on a bicycle helmet and connected to a PC in the test vehicle [9]. One camera, an infrared camera, records one of the participant's pupils while the second camera captures the same section of the environment that subjects see. The test included two tasks, an action task and a navigation task [9]. The action task consisted of signs which told the participant to look at various objects within the test car. A task was considered fulfilled only when the participant focused on the target corresponding to the signs instructions. The navigation task in this experiment required the participant navigate the test route using only traffic signs and vague instruction from a co-driver. The signs were all of equal size within each task and used capital letters [9].

Two types of sheeting were used on the signs in this research: Encapsulated glass bead retroreflective sheeting classified as ASTM Type-III and full cube microprismatic sheeting proposed as ASTM Type-XI [9]. Both of these types of sheeting are designed for permanent highway signing, construction zone devices and delineators. The test results indicated no significant differences between the sheeting types for first glance distances. Both sheeting types were easily detected by both age groups in the test [9]. The results of the action test showed significant differences with regard to the last glance distances however. The test results indicate that the Type-III sheeted signs were viewed an average of 0.3 second longer than the Type-XI sheeted signs [9]. The researchers concluded that the Type-XI sheeting allowed the drivers to read and perceive the displayed information at a greater distance. This would allow the drivers to potentially have more time to concentrate on other roadway stimuli [9].

The previous studies were performed comparing sheeting types used for roadway information, regulatory, and warning signs. Little research has been performed to determine the effects of using diamond grade sheeting on work zone traffic control devices. These devices are lower to the ground and in closer proximity to the light source. This changes incident angle of the incoming light and therefore may alter the amount of light being retroreflected and therefore may alter the effectiveness of the microprismatic sheeting for use on construction drums and other traffic control devices as compared to its use on traffic signs.

A study performed by the Wisconsin Department of Transportation, published in 2009, studied the effectiveness of Diamond Grade sheeting on flexible delineator posts as a secondary study objective in their overall evaluation of the use of the flexible delineators [10]. Their findings determined that the Diamond Grade sheeting was brighter than the High Intensity sheeting both in daytime and nighttime conditions but over the course of the year that they were installed no increased safety effects were noticed. The study estimated that the diamond grade sheeting cost approximately 60% more than the high intensity sheeting while only having an expected life of 2 years greater than that of the High Intensity sheeting [10]. Based on the greater expense and the lack of a noticeable increase in safety Bischoff et al. suggested that Diamond Grade sheeting not be used on the delineators.

This study utilized crash and incident reports to determine the safety effects of the flexible delineators [10]. However, crash and incident rates are not the sole indicator of increased or decreased safety of a roadway. The crash and incident rates were not reported in the study, but if they were sufficiently low prior to the installation of the Diamond Grade sheeting on the delineators the delineators themselves may have no effect at all on the crash occurrence. Other measures such as vehicle travel speed and lane placement can also be used as determinants of increased or decreased roadway safety attributed to the diamond grade sheeting.

2.4 Need for Work Zone Visibility

In recent years there has been a change in roadway work zone projects from mostly new roadway construction to maintenance and rehabilitation projects. This change in work zone activity has therefore changed the work zone locations from closed no traffic new roadways to existing roadways on which traffic flow must be kept. Operating work zones on existing roadways while maintaining traffic flow, while required in order to satisfy the driving public, has put construction workers at a higher exposure to the driving public as well as putting the driving public at a higher exposure to work zones. The result is a decrease in safety for both the work zone personnel and drivers. While roadway construction is still primarily performed during daylight hours, for reasons of driver safety and project efficiency, work zone lane closures often remain in place day and night. Nighttime lane closures place drivers at an even greater safety risk due to the combination of changed lane alignments because of a closed lane as well as the decreased in visual cues available to nighttime drivers as compared to during daytime hours [11].

The usage of reflective sheeting on traffic control devices was first introduced more than 60 years ago [6]. In recent years however, motor vehicles have tended toward the usage of Visually Optically Aim able (VOA) headlamps. According to a study performed at the University of Michigan Transportation Institute by Sivak et al., the overall emitted luminous intensities directed toward typical sign locations by VOA headlamps is 53% less on a right mounted sign, 28% less on an overhead sign, and 42% less on a left mounted sign versus conventional US headlamps [9, 12]. In order to attain the same "brightness" of a sign and therefore the same distance for noticing and comprehending traffic signs and traffic control devices the retroreflectivity of the sheeting used must be increased [4]. This required increase in retroreflectivity has been made possible through innovations in microprismatic retroreflective sheeting technology [3]. The biggest change made with the VOA head lights is the amount of light emitted above the head light. Work zone traffic control drums or barrels are much lower than post or overhead mounted signs and therefore may not be affected by the change to VOA headlights however little research has been done to date to determine this effect.

The NCHRP Report No. 627 identified four main strategies for the safety improvement of work zones [6]. One of those four strategies was to improve the visibility of work zone traffic control devices [7]. The 3M™ DG^3 full cube prismatic sheeting has been designed to reflect nearly twice as much incident light toward the light source [6]. This sheeting is a proposed ASTM Type-XI and is designed to replace all types of reflective sheeting in use today [8]. This sheeting is designed to perform efficiently at short and medium sight distances and where signs are placed in non-ideal locations such as overhead or on the left shoulder [6]. The sheeting's design enables it to reflect nearly twice as much light toward the driver to increase the devices "brightness." Theoretically this increased brightness will increase the distance at which the driver notices the construction barrels and therefore allows more time for the drivers to comprehend and take action accordingly. The effect of this increased brightness improves the visibility of solitary traffic signs. It is unknown what effect the increased brightness will have when the barrels are placed close together and in line along a highway work zone.

An increasing demographic that must be considered and planned for in transportation safety is the older driver demographic. According to the US Census the number of drivers over the age of 65 years old in the United States will be approximately 50 million, or 20% of the total driving population [11]. This group of drivers shows reduced sensitivity to contrast and lesser response times then their younger counterparts [13]. Olson (1988) stated that a major problem for traffic safety is the reduced contrast sensitivity experienced during nighttime driving conditions. Objects become hard to see when because they cannot be distinguished from their background. The brightness of a traffic control device is the main factor in its attention-getting capability [13]. The brightness of the traffic control device increases its contrast in relation to its surroundings allowing it to more easily be seen, especially during nighttime driving conditions. The brightness or contrast of traffic control devices could, however, have the effect of distracting some driver groups. During a study performed to assess the benefits of using reflectors on lane markings, the older driver group indicated that the reflectors were beneficial. The younger focus group in the experiment however found the reflectors to be excessively bright and even distracting [14].

3.0 SITE DISCRIPTIONS

The work zone locations chosen for data collection were based on several general criteria. Criteria included: freeway/highway designation with a normal travel speed of 55 mph or greater, closure of at least one travel lane, a lane closure of one mile or greater, a lane closure using construction drums along the tangent sections of the closure, and a lane closure which remained in place overnight. Based on this criteria and with the help of the Ohio Department of Transportation three sites were selected for data collection for drums with high intensity sheeting, and with the cooperation of the Illinois Department of Transportation one site was selected for data collection for drums using diamond grade sheeting.

3.1 High Intensity Data Collection Sites

The first site selected for data collection was along US-50 near Athens, Ohio in Athens County. The work zone began approximately 0.25 miles east of the SR-682 interchange with US-33/SR-32 and continued for approximately 4.60 miles, ending at the interchange of US-50 and East State Street. The terrain along the corridor is rolling/hilly terrain with five access points for traffic to enter the corridor. The ADT throughout this corridor is 18,370 vpd.

Figure 1: High intensity data collection site 1

This portion of roadway is a 4-lane freeway with a speed limit of 55 mph. Lane placement data was collected while the right lane was closed with drums prior to the placement of concrete barriers. This site was a long term construction project and concrete barriers were installed shortly after the initial lane closure rendering the site unsuitable for data collection for this project. Only daytime data was collected from this site. A work zone speed limit was set at 45 mph throughout the work zone.

The second data collection was along SR-32 approximately 13 miles east of Peebles, Ohio in Pike County. This work zone began at County Road 87 on the east and continued west approximately 3.20 miles ending just prior to County Road 16. The terrain along the corridor is hilly/mountainous terrain. The ADT for this corridor is 4,270 vpd.

Figure 2: High intensity data collection site 2

SR-32 is a 4-lane freeway with a speed limit of 60 mph in this portion of the route. The work zone utilized for data collection consisted of a right lane closure in both directions of travel and included a speed limit reduction to 50 mph through the work zone. Daytime and nighttime lane placement data was collected at this location. No overhead roadway lighting was present along the route which made vehicle headlights the only illumination of the work zone during nighttime driving conditions.

The third work zone utilized to collect data from high intensity sheeting was a repaving project located on SR-32 approximately 5 miles west of Jackson, Ohio in Jackson County. The work zone began just east of SR-776 and continued approximately 2.50 miles to Cove Rd. The terrain along this corridor can be considered level/rolling terrain. The ADT along this section of SR-32 is 6,640 vpd.

Figure 3: High intensity data collection site 3

This section of SR-32 is a 4-lane divided freeway. The posted speed limit is 60 mph. The work zone utilized for lane placement data collection consisted of a left lane closure in both directions of travel with a posted work zone speed limit of 50 mph. No overhead roadway lighting was present along the route which made vehicle headlights the only illumination of the work zone during nighttime driving conditions. The terrain at this site was level/rolling and therefore it was used for speed data collection as well as the lane placement data. Speed data was collected at the east end of the work zone using vehicles traveling west for "entering" speed data and vehicles traveling east for "exiting" speed data. Speed data was also collected at the approximate midpoint of the work zone. Data was collected in the same approximate locations and manner for both daytime and nighttime conditions.

3.2 Diamond Grade Sheeting Data Collection Site

Lane placement and speed data collection from a work zone utilizing diamond grade sheeting was performed on Interstate 72 west of Champaign, Illinois. Data collection was performed on a mill and repave project being performed along the interstate. The interstate is a 4-lane corridor of which the right lane in each travel direction was closed at the time of data collection. The work zone began approximately halfway between mile marker 75 and mile marker 74 on the east end and continued west approximately 3.5 miles ending near mile marker 70. The terrain along the corridor was fairly level with one access point within the work zone. The ADT for this section of I-72 is 12,000 vpd.

Figure 4: Diamond grade data collection site 1

This section of I-72 was a 4-lane corridor with a speed limit of 65 mph. The work zone closed the right travel lane in each direction and had a posted speed limit of 55 mph when no work was being performed within the work zone and 45 mph when workers were present. Daytime and nighttime lane placement data along with speed data was collected at this site utilizing diamond grade sheeting on the construction drums used along the tangent sections of the lane closures. This section of the interstate was outside of the city limits and had overhead lights located only at the one access point within the work zone. Because of this it can be considered that the only illumination of the work zone was that from a vehicle's headlights during nighttime driving conditions. The speed data was collected at the east end of the work zone collecting data from westbound vehicles for speed entering the work zone and vehicles traveling eastbound for speed exiting the work zone. For the speed data collected within the work zone an overpass was utilized. The same approximate locations and collection practices were used for both daytime and nighttime speed data collection.

4.0 DATA COLLECTION

4.1 Current Practices

In this research an evaluation of the current state of practices of the state departments of transportation was deemed important in determining the extent to which the different types of sheeting are used and or required in work zones. It was determined in this research that a current practices survey was the most effective method to determine the current state of practice with regard to the sheeting type used on construction drums within work zones on a state by state basis. When considering the method of distributing the survey to each department of transportation, email was deemed the most effective method based on its wide use, and low distribution expense. As such, a current practices survey, along with a letter explaining the purpose and goals of the research, was sent to the individual or office at each state department of transportation which was primarily responsible for work zone design, safety and regulation.

Questions asked in the survey related to the current procedures and devices used for traffic channelization in work zones. These questions included the current types of channelization devices used, the approximate percentage each device constituted, the sheeting type required on construction drums, and why the department did or did not require diamond grade sheeting.

The recipients were given approximately one month to complete and return the survey after which the individuals were contacted by phone in an attempt to increase the number of returned surveys. Those states which were contacted via phone were allowed an additional 3 weeks to complete the survey after which a second email and phone call was sent to each of the departments of transportation which had not responded to the survey. At the completion of this research 40 of the 50, or 80% of the states had responded to the survey. Of those returned many were still not fully completed due to a variety of reasons including but not limited to non-applicability to the individual department or possible confusion as to the question meaning. This was accounted for when analyzing and reporting the results of the survey.

4.2 Lane Placement

Lane placement data for this research was collected during daytime and nighttime driving conditions in work zones utilizing construction drums for a lane closure. Data was collected from sites using high intensity sheeting on the construction drums as well as from sites using the diamond grade sheeting. The data collection was performed by videotaping a lead vehicle as it entered, progressed through, and exited the work zone. This was accomplished through the use of a camcorder and tripod placed in the front passenger seat of a trailing vehicle. Taping began approximately ½ mile prior to the lane closure and was completed as the vehicle exited the work zone. Efforts were made to not alert the leading car to the fact it was being taped. These included spotting lead vehicles from entrance ramps and entering the highway behind the selected vehicle in a normal manner, approaching the vehicle at an average speed, merging in behind "lead" vehicles as if it were normal traffic, and keeping as safe of a distance behind the "lead" vehicle as possible while still collecting usable lane placement data. This was to help ensure natural driving habits of the leading vehicle when collecting data.

4.3 Speed

Speed data was collected using a Laser Tech Inc. UltraLyte LTI 20-20 laser speed gun. Speed data was collected as vehicles entered the work zone, at the middle of the work zone, and as vehicles were exiting the work zone. During the collection of speed data attempts were made to be out of the vehicles line of sight while keeping the required angle between the vehicle and speed gun for accurate readings. When possible bridge overpasses were utilized for the collection of speed data. When overpasses were not available speed data was taken from shoulder or median locations where the reseacher was mostly blocked from the sight of drivers. Attempts to be out of the line of sight of drivers were made in order to assure natural driver behavior of the driver population used for data collection.

4.4 Sample Size Determination

Prior to data collection in Illinois a sample size estimate of approximately 100 vehicles was selected for lane placement. This estimate was based on the analysis performed in a similar study, in *The Evaluation of Steady Burn Warning Lights Comparing a Field Experiment. Simulator Experiment, and Repeated-Use Experiment*, in which lane placement was also considered as a parameter of effectiveness. This initial estimate was then later refined based on the data collected and the statistical power desired in this study. Approximately 100 speeds were collected at each location throughout the work zone. This was determined based on the approximate sample size required to consider a 1.0 mile per hour speed difference between groups to be considered significant. This estimate was also checked and, where when necessary, refined once the initial 100 data points were collected.

Data collection was performed along Interstate 72 near Champaign Illinois at a site utilizing diamond grade sheeting on the work zone traffic control barrels. Lane placement data was collected both during daytime and nighttime driving conditions. The total sample size collected for diamond grade nighttime data lane placement was approximately 120 subjects while the total sample size collected for diamond grade daytime lane placement was approximately 110 subjects. The discrepancy in sample size collected was based solely on chance, and not significant to the study performed.

Lane placement and speed data from work zones utilizing drums with high intensity sheeting were collected from three separate work zones. The locations were all rural 4-lane work zones with 2 travel lanes in each direction as with the sites utilized for data collection for diamond grade sheeting.

A more refined estimate of the sample size was then attained using a random sampling of the data collected. This was performed through extracting the lane placement data for 5 subjects in each of the four conditions, nighttime with diamond grade sheeting, nighttime with high intensity sheeting, daytime with diamond grade sheeting, and daytime with high intensity sheeting. The lane placement data was extracted for each separately. The average lane placement throughout the work zone was then combined for each vehicle based on day and nighttime conditions only. The diamond grade and high intensity data were combined in an attempt to attain a sample size which would allow for the consideration of a small difference in lane placement data to be considered significant when analyzing the high intensity work zone data with the diamond grade work zone data. It was arbitrarily desired at this stage of the research to maintain statistical power while considering a lane placement variation of 0.25’ significant.

The daytime data will not be analyzed against the nighttime data and therefore daytime and nighttime data were not considered together in the sample size estimation. This is due to the likelihood of differing subject populations. The nighttime subject is less likely to include seniors and will likely include more truck traffic. Since these subject populations are different, a difference in lane placement analysis between the two scenarios would only prove a difference in population behavior, and could not be considered a difference caused by the sheeting used.

The two major factors which affect the sample size required are the level of significance and the power of the test. [15] For this analysis a level of significance of $\alpha = 0.05$ was used. Based on this and a 4:1 ratio of β to α, the power of the test was, $\beta = 0.80$. Both the level of significance and the power of the test were taken into consideration when determining the sample size required. The level of significance was considered using the following equation for sample size:

$$n = \frac{Z^2 * \sigma^2}{\varepsilon^2} \qquad [15]$$

Where: $Z = 1.96$

σ = Sample Standard Deviation

ε = Acceptable Error

The following equation was utilized to calculate the needed sample size based on the power of the test:

$$n = \frac{(Z_\beta - Z_{\frac{\alpha}{2}})^2 * \sigma^2}{\varepsilon^2} \quad [15]$$

Where: $Z_{\alpha/2} = 1.96$

$Z_\beta =0 .842$

σ = Sample Standard Deviation

ε = Acceptable Error

In the initial sample size estimation based on the random sampling of the collected data the sample size was known and the error, or significant difference, was calculated. From this a reasonable acceptable significant difference was selected and a sample size estimate was calculated.

The sample sizes calculated from these equations are deemed the minimum sample size needed. Being such, the larger sample size calculated, either daytime or nighttime, was that selected as the minimum required sample size. Data collection efforts were then aimed to exceed this required minimum size to account for possible differences in overall sample behavior as compared to the random sampling used for the minimum sample size calculation.

This method of sample size determination calculates the sample size based on the behavior of the subject population rather than engineering judgment or industry standards.

This process was repeated to determine the sample size needed for speed data collection. Based on the sample data collected, an error or 1.25 mph can be considered significant when considering the differences between the high intensity and diamond grade sheeting work zones.

Upon the completion of the lane placement and speed data collection and extraction the above equations were used with the sample standard deviations and the 0.25' acceptable error. The required sample size was determined to be approximately n = 25. The actual sample size was approximately n = 200. The beta equation was then used to calculate the actual error which could be considered significant while still keeping $\beta = 0.80$, and $\alpha = 0.05$. It was determined that, based on the sample data collected, an error of 0.15' can be considered statistically significant.

5.0 DATA EXTRACTION

Upon the collection of lane placement data with a video camera, extraction of lane placement was required. The interval at which the lane position data needed to be extracted, 1- 5- or 10-seconds, was unknown. A 1-second interval would provide the most accurate lane placement data however it would require much more time for data extraction then a 5- or 10-second interval and may not provide significantly different results. Conversely, though requiring less time for data extraction then a 1-second extraction interval, a 5- or 10-second data extraction interval may not accurately portray the subject behavior and therefore would not provide accurate experimental results. It was necessary to determine if a significant difference in the average, minimum and maximum lane placements for the subject population existed when considering the 1, 5, and10 second data extraction intervals. To determine this, a random sample of the collected data was analyzed using a 1-second data extraction interval. From this data, the 5- and 10-second lane placement data was also extracted. The average, minimum, and maximum lane placements were calculated at each interval for each sample. A one-way ANOVA was conducted on the data using SPSS 16.0 statistical software. This analysis indicated that there was no significant difference between the data extracted at a 1-, 5- or 10-second interval. From this it was determined that a 10-second interval would be used for lane placement data extraction.

As stated previously, lane placement data was collected by videotaping a lead vehicle from behind as it traveled through a work zone. This provided a visual reference of each vehicle but not actual lane placement data. To extract the lane placement data for each car within the work zone at the determined 10 second interval the video tapes were viewed, pausing at the vehicles entrance and every 10 seconds after the vehicle entered the work zone to record the vehicles lateral position. Lane placement was taken as the distance a vehicle was away from the center of the traveled lane. This was recorded as positive when the vehicle favored being further away from the construction drums and negative when the vehicle favored the construction drum side of the lane. Effort was made during the data collection to maintain a relatively similar distance between the lead vehicle and the vehicle collecting the data. However, it was impossible to maintain an exact distance between sample lead vehicles at all times. Due to the changes in distances between the lead vehicle and the data collection vehicle the horizontal scale at which the vehicle was taken was continually changing. In order to account for this varying scale during the data extraction an object of uniform size on all vehicles was needed as a baseline. It was determined that the standard U.S. state license plate measured approximately one foot in width. To account for the differences in scale between measurements, the license plate of each vehicle, at each interval was used as a 1.0 foot scale. The license plate was used as a measure of the vehicle’s horizontal distance from the center line of the lane and was recorded to the nearest 0.5 ft.

6.0 STATISTICAL METHODOLOGY

There were several statistical comparisons to be made in this research. Difference in speed variation with respect to the posted work zone speed limit and vehicle placement within the lane while in the construction zone were the primary parameters considered to determine if there existed a significant impact on the behavior of drivers traveling through work zones with the different sheeting types. Several comparisons were made between the means of the groups of data collected in the attempt to determine if significant differences in speed or lane placement existed between the sheeting types. The comparison of means performed included:

Speed data: (Student's t-test)

DG with HI Daytime

DG with HI Nighttime

Speed data: (ANOVA)

DG entering with HI entering

DG middle with HI middle

DG exiting with HI exiting

DG Entering with Middle with Exiting

HI Entering with Middle with Exiting

Lane Placement (Mann-Whitney U)

DG nighttime with HI nighttime

DG daytime with HI daytime

There are four assumptions which must be checked and adhered to in order to maintain statistical power when using parametric tests on sample data. The data must be normally distributed, the sample variances between groups must be homogeneous, the data must be interval data, and the sample observations should be independent. If any of these assumptions are invalid for the sample data collected the robustness of the test performed and therefore the significance of the test results could be adversely affected. The magnitude of the effect of an invalid assumption on the test result varies by test and therefore should be considered specifically for each parametric test.

The assumptions of interval data and independence were addressed in the setup of the data collection and extraction processes. Lane placement and speed data was collected from subjects at random. When collecting data, care was taken so as to collect data without influencing the behavior of the subjects. Speed data was taken from overpasses where possible and attempts were made to remain out of the subjects' direct line of sight where overpasses were not present. Lane placement data was collected from a tripod mounted camera in the passenger seat of the vehicle trailing the subject. This data was collected from a distance such that the subjects could not see that they were being recorded. Care was also taken to approach leading vehicles and merge with existing traffic such that no suspicion would arise from subjects due to erratic or unusual driving behavior. Extraction of the lane placement was performed beginning at a defined position with respect to the beginning of each work zone and continued at a 10 second interval for every subject providing interval data.

6.1 Normality/Homogeneous Variance

After the data was collected and extracted normality and variance homogeneity needed to be checked. Many tests exist to check the normality of sample data. The extracted data was plotted in a histogram to check for any outliers and provide a visual representation of the data behavior. The histogram could be used as a check for normality, however, visual analysis of a histogram plot was not deemed accurate enough for this analysis. A box plot was used to determine if where any outliers existed within the data. While the histogram will often show if an outlier exists, it does not show which data point or points are the outliers. Using the box plot the outliers can be pinpointed and further analysis of these data points can be performed to determine the validity of each. In this study there was one outlier in the diamond grade daytime data. Transformation of the data point was attempted. However the data point remained an outlier and was therefore removed from the analysis so as to not adversely affect the mean and standard deviation of the remaining data.

Frequency statistics were used to determine the skewedness, the kurtosis and the corresponding standard error of both the combined speed data and the combined lane placement data. The skewedness and kurtosis scores were converted to their corresponding Z-scores using the following:

$$Z_{skewedness} = \frac{S - 0}{SE_{skewedness}} \qquad [16]$$

$$Z_{kurtosis} = \frac{K - 0}{SE_{kurtosis}} \qquad [16]$$

Where:

S = Value of skewedness as given from frequency statistics

K = Value of kurtosis as given from frequency statistics

$SE_{skewedness}$ = Standard Error of skewedness as given from frequency statistics

$SE_{kurtosis}$ = Standard Error of kurtosis as given from frequency statistics

In this research it was decided to consider the data normal if the Z-score was less than or equal to ± 1.96 at a confidence level of 0.05. When the kurtosis or skewedness Z-scores were greater than ± 1.96 statistical transformations were performed on the data to attempt to normalize the data. The transformations performed included:

$$x_{transformed} = \log x \qquad [16]$$

$$x_{transformed} = \sqrt{x} \qquad [16]$$

$$x_{transformed} = \frac{1}{x} \qquad [16]$$

Where:

$x_{transformed}$ = transformed data point

x = data point value

Frequency statistics were performed after each transformation and the skewedness and kurtosis Z-scores recalculated to determine if the data was more or less normal then before the transformation.

Two final statistical tests which can be performed to determine the normality of the data are the Kolmogorov-Smirnov and Shapiro-Wilk tests. These tests compare the values of the experimental data to values that would be expected based on a normally distributed data set with the same mean and standard deviation. If the test result is not significant the experimental sample data does not significantly differ from that of a normal distribution and therefore the sample data is normal [16]. When large sample sizes are considered using this test a significant test result can be produced from small deviations from normality and therefore a significant result may be produced when the data is not non-normal enough to bias analysis. As with all of the tests for normality discussed previously, these tests alone should not be considered as ultimate when determining the normality of data. When the sample data fails tests for normality, the effect of non-normal data any parametric test performed on the data must be considered. Bias from non-normal data in a parametric test may require the use of non-parametric tests for the analysis of the sample data.

In this research it was determined that the speed data collected was normal data, however, the lane placement, even after log, reciprocal, and square root transformations were performed, did not follow a normal distribution.

Along with normality, homogeneity of variance must also be checked and confirmed in order to guarantee the robustness of a parametric test. Lavene's test can be used to test for the homogeneity of variances. A significant result from Lavene's test indicates that the variances between samples are non-homogeneous. This test was selected to be run when performing the one-way ANOVA analysis. As with the Kolmogorov-Smirnov and Shapiro-Wilk tests for normality, this test can produce significant results from small deviations in variances when the sample sizes are large [16].

A second test which can be utilized to check the homogeneity of variance is the variance ratio. The ratio of the larger sample variance to the smaller sample variance should be less than 2. If the ratio is 2 or less the variances can be considered as homogeneous [16]. If the variances between samples are not homogeneous it is necessary to consider its effect on the robustness of any parametric test performed on the data and may require the use of non-parametric tests.

In this research it was determined based on the ratio test that the variances of the speed data were homogeneous while the variances of the lane placement were not homogeneous. Based on these findings, non-parametric tests were required to analyze the lane placement data since violated both the normality and homogeneous variances assumptions. The speed data however is both normal and by the ratio test the variances are homogeneous. From these findings the speed data can be analyzed using a parametric test. The test chosen to analyze the speed data was the one-way ANOVA. Variance homogeneity is a major factor when considering the robustness of this analysis and therefore the Lavene's test for homogeneous variances will be run on the data to ensure the variances are homogeneous.

6.2 Student's t-test

The Student's t-test was performed to compare the overall mean speed deviation between sheeting types. The Students t-test is the best known and most popular method for comparing the means of two groups [17]. In this research the sample data was collected from independent populations and therefore the comparison made between sample groups must be made on a per condition basis rather than on a per participant basis [16]. Therefore the differences between the sample group means will be compared as opposed to the differences between pairs of scores [16]. This test uses the standard error of the sampling distributions to assess whether the difference between two sample means is significantly different. There was no assumption made as to how the sheeting type would affect the work zone travel speed of the participants. Since no assumption was made as to the affect the sheeting types would have on the traveled speed, a two-tailed t-test was performed to compare the speed deviation means and determine if a difference between speed deviations within the work zones was present. In the Student's t-test a t-critical statistic was obtained from statistical tables based on the degrees of freedom and the type one error allowed for this analysis. The t-observed was then calculated using the equations presented below. If the t-observed statistic was greater than the t-critical value a significant difference existed in the speed deviation between sheeting types [18].

$$s_p^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2} \qquad [17]$$

Where: n_1 = number of samples in group 1

s_1^2 = variance of group 1

n_2 = number of samples in group 2

s_2^2 = variance of group 2

$$t - observed - \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{s_p^2\left(\frac{1}{n_1} - \frac{1}{n_2}\right)}} \quad [17]$$

Where: $\bar{\bar{X}}_1$ = average value of sample 1

$\bar{X}_2$ = average value of sample 2

The Student's t-test is based on the assumptions of normal data, homogeneous variances, and continuous data [16]. To keep the robustness of the test in the case of non-homogeneous variances the Welch's modification was performed with the Student's t-test. With Welch's test the assumption of normality is retained, however, the assumption of homogeneous variances is no longer made [17]. The Welch's method calculates a W-observed statistic and W-critical statistic which account for the lack of homogeneous variances. The W-critical statistic is based on a Student's t distribution but utilizes adjusted degrees of freedom. The W-observed and degrees of freedom are calculated using the formulas presented below.

$$W - observed = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)}} \quad [17]$$

With adjusted degrees of freedom:

$$df = \frac{(q_1 + q_2)^2}{\frac{q_1^2}{n_1 - 1} + \frac{q_2^2}{n_2 - 1}} \quad [17]$$

Where: $q_1 = \frac{s_1^2}{n_1}$

$q_2 = \frac{s_2^2}{n_2}$

6.3 One Way ANOVA

A one-way ANOVA was used in this research to compare the speed deviations at different locations within the work zones between the sheeting types. The one-way Analysis of Variance, one-way ANOVA, compares the variances of several groups of data together while controlling the type one error [16]. Using the one-way ANOVA several groups can be compared to each other in all possible comparison scenarios and still retain a type one error of $\alpha = 0.05$. The one-way ANOVA performs the comparison between groups through the calculation of the Mean Squares Between the groups, MS_B, and the Mean Squares Within the groups, MS_W. The F-statistic for the comparison is then calculated as the ratio of the Mean Squares Between to the Mean Squares Within. This F-statistic is then compared to the F-critical statistic based on the confidence level desired in the test, the number of groups being compared, df_B, and the size of each group df_W [12]. F-critical can be determined from statistical tables using the degrees of freedom and the desired type one error [19].

$$SS_T = \sum_{i=1}^{n}\sum_{j=1}^{p}(X_{i,j} - \overline{X})^2 \quad [20]$$

Where: SS_T = total sum of squares

n = number of scores

p = number of sample groups

$\overline{X}$ = average value of samples observations

$$SS_B = n_j \sum_{j=1}^{p} (\bar{X}_j - \bar{X})^2$$ [20]

Where: SS_B = sum of squares between groups

$\bar{X}_j$ = average value of observations in j^{th} group

$$SS_W = \sum_{i=1}^{n} \sum_{j=1}^{p} (X_{i,j} - \bar{X}_j)^2$$ [20]

Where: SS_W = sum of squares within groups

$$MS_B = \frac{SS_B}{p-1}$$ [20]

Where: MS_B = mean of squares between groups

$$MS_W = \frac{SS_W}{n-p}$$ [20]

Where: MS_W = mean of squares within groups

$$F_{Obs} = \frac{MS_B}{MS_W}$$ [20]

Where: F_{Obs} = F-statistic calculated from sample observations

With degrees of freedom:

$$df_B = p - 1$$ [12]

$$df_W = n - p$$ [12]

Where: df_B = degrees of freedom between groups

df_W = degrees of freedom within groups

If the one-way ANOVA produces an F-observed which is greater than the F-critical value obtained from the tables the test indicates only that there is a significant difference. The ANOVA does not however provide any indication as to where the significant difference exists. To determine where significant differences exist a planned comparison or a post hoc analysis of the data must be performed. A planned comparison breaks down the variance accounted for by the model into component parts. The post hoc test is performed by comparing the means of every group as in using multiple t-tests, but using stricter acceptance criteria to assure the family wise error rate does not exceed 0.05 [16]. The difference between the two options for determining where the difference exists is likened to the difference between one- and two-tailed tests [16]. The planned comparison, like a one-tailed test, is performed when a specific hypothesis is being tested. The post hoc test, like a two-tailed test, is utilized when the hypothesis is that there is a difference between the groups but no specific guess as to what kind of difference is made [16]. The decision as to which type of test will be run must be made prior to data collection. For this research the post hoc test procedure was selected since the hypothesis was there would be a difference between the sheeting types.

When deciding which post hoc procedure to perform three things were considered: control of the Type I error, control of the Type II error, and the reliability of the test when the test assumptions of the ANOVA are violated. In this research the sample sizes varied and the total number of comparisons is low. Based on these criteria, the Gabriel and Games-Howell post hoc procedures were selected [16]. The Games-Howell post hoc procedure was selected incase the variances of the speed data proved to be non-homogeneous in the Lavene's test [16]. Gabriel's pairwise test procedure was selected to be performed because of its power when sample sizes vary [16].

To account for the possibility of non-homogeneous variances in the speed data which failed to be indicated by the ratio test of variances the Welch's modification procedure was performed with the ANOVA. This procedure applies a modification to the data and produces a new F-critical and new degrees of freedom from the data to allow a one-way ANOVA to produce robust results for data which violates the homogeneous variances assumption. [17]

$$w_j = \frac{n_j}{s_j^2}$$ [17]

Where: n_j = number of samples in a particular group

s_j^2 = variance of a particular group

$$U = \sum_{j=1}^{k} w_j$$ [17]

Where: K = number of groups

$$\bar{X} = \frac{1}{U}\sum_{j=1}^{k} w_j \bar{X}_j$$ [17]

Where: $\bar{X}_j$ = average sample value within a particular group

$$A = \frac{1}{K-1}\sum_{j=1}^{k} w_j (\bar{X}_j - \bar{X})^2$$ [17]

$$B = \frac{2(K-2)}{K^2-1}\sum_{j=1}^{k} \frac{\left(1 - \frac{w_j}{U}\right)^2}{n_j - 1}$$ [17]

$$F_W = \frac{A}{1+B}$$ [17]

With Degrees of freedom:

$$df_1 = K - 1 \qquad [17]$$

$$df_2 = \frac{2(K-2)}{3B} \qquad [17]$$

6.4 Non-Parametric Tests

The robustness of the results of parametric tests relies heavily on whether the data meets the criterion of normal data, homogeneity of variance within the data, interval data and independent samples. While the last 2 criteria listed can be controlled by the experiment setup and data extraction practices, the first two criteria cannot be strictly controlled. The degree to which violating one of the criteria will affect the statistical results varies depending on the test being performed. When the affect of violating these criteria is larger than deemed acceptable for the use of a parametric test for analysis a non-parametric, or assumption free test can be used to analyze the data. Non-parametric tests work by ranking the data with the lowest rank being assigned to the lowest data score and the highest to the greatest data score. The ranks are then analyzed rather than the data itself [16].

Since the analysis is performed on the ranks of the data rather than the data itself many believe that the non-parametric tests have less power than parametric tests. Statistical power is lost when the data is ranked since the ranking provides no information as to the magnitude of the difference between scores. However, for parametric tests to maintain statistical power the assumptions of homogeneous variance and normality must be met. For data that is normal and has homogeneous variances, the parametric tests have greater statistical power, while when the normality and variance assumptions are violated the power the non-parametric test is greater than that of the parametric test [16].

The lane placement data collected in this research violated both the normality and homogeneous variance assumptions and therefore parametric tests would not provide an accurate analysis of the data. Analysis of the lane placement data included a comparison of the diamond grade data with the high intensity data for the nighttime and daytime driving conditions. This analysis can be performed with one comparison of means for each separate group.

In this research the difference in means between the sheeting types were compared using the Mann-Whitney U comparison of means. The goal of the research was determine if there was a difference in lane placement of the vehicles in the travel lane. Data was collected both during daytime driving conditions and nighttime driving conditions. Since the Student's t-test performed on the speed variation data indicated a significant difference between nighttime and daytime speed deviations it was assumed that the driving behaviors and driver populations varied between the different conditions. Because of this, the lane placement of vehicles was only compared within the daytime and nighttime groupings and not between daytime and nighttime conditions. A direct comparison with the Mann-Whitney U test was chosen rather than the Kruskal-Wallis comparison of means due there being only two groups within each driving condition.

The Mann-Whitney U test, like other nonparametric tests, works by combining the sample data to be analyzed and ranking them from smallest to largest giving no preference to group. The ranks are then separated into their respective groups and summed. The U-statistic is than calculated using the sample sizes and the sum of the ranks of the smaller sample. To determine if the test statistic is significant the mean and standard error are calculated and, since the sample sizes in this research are sufficiently large, then used to calculate the corresponding z-score [20]. Using an α = 0.05 and a two tailed analysis, if the calculated z-score is greater than 1.96 when considering its absolute value, the U-statistic is significant at $p < 0.05$ [20].

$$U = n_1 n_2 + \frac{n_1(n_1 + 1)}{2} - W \qquad [20]$$

Where: n_1 = sample size of group 1, the smaller sample

n_2 = sample size of group 2

W = Sum of the ranks in group 1

$$Z = \frac{U - \left(\frac{n_1 n_2}{2}\right)}{\sqrt{\frac{n_1 n_2 (n_1 + n_2 + 1)}{12}}} \qquad [20]$$

6.5 Practical Significance

The statistical tests performed in this research indicated whether the differences in comparisons made were statistically significant. However, a comparison being significantly statistically different indicates only that the probability of the difference between the experimental data and the expected values computed from a given statistical distribution occurring due to chance is less than the significance level, in this research α = 0.05 [16]. Statistical significance is based on the standard error of the sample which can be controlled by sample sized. Large sample sizes lower the standard error and will correspondingly lower the threshold for considering differences to be significant. Conversely, a small sample size can cause a large difference between groups to be statistically insignificant when in reality the difference may be practically significant [17].

One method provided to consider the practical significance of a result is through the calculation of the effect size. By definition the effect size is the degree to which a phenomenon exists [17]. In this research, the phenomenon would be the diamond grade sheeting caused statistically significant differences in lane placement and traveled speed within work zones when compared to the high intensity sheeting. The effect size calculated is a measure of the number of standard deviations the difference between the groups is from the null hypothesis [15]. The effect size was calculated for each of the tests performed based on the parameters provided in each test.

For the Student's T-test:

$$r = \sqrt{\frac{t^2}{t^2 + df}} \qquad [16]$$

Where: r = effect size

t = t-observed value

df = degrees of freedom of the t-test

For the ANOVA:

$$r = \sqrt{\frac{SS_B}{SS_T}} \qquad [16]$$

Where: r = effect size

SS_B = sun of squares between groups

SS_T = total sum of squares

For the Mann-Whitney U:

$$r = \frac{Z}{\sqrt{N}} \quad [16]$$

Where: r = effect size

Z = z-score calculated from analysis

N = total sample size used in the analysis

Based on standards presented by Cohen, the practical significance, or actual difference of the comparisons made, is as follows:

r = 0.20	Small Effect
r = 0.50	Medium Effect
r = 0.80	Large Effect

7.0 RESULTS

The purpose of this research was to compare work zones utilizing diamond grade sheeting with those using high intensity sheeting on construction drums to determine if there existed a significant difference in driver behavior and therefore difference in safety. A comparative parallel was used for this study to compare driver behavior between work zones using diamond grade sheeting with those using high intensity sheeting on the construction drums utilized for a lane closure. Several 4-lane work zones were utilized to collect lane placement and speed data. The work zones utilized all exhibited one a one lane closure, lacked ambient lighting from street lights or businesses, and were of the freeway/interstate functional class. Lane placement and speed data were collected from each site, combined, and analyzed based on the type of sheeting used within the work zone. Data was also collected from a current practices survey to determine the types of channelization devices being used by departments of transportation currently as well as the types of sheeting being used on any construction drums the departments use.

7.1 Current Practices

The compiled data provided from the current practices survey regarding the type of sheeting used is provided in Table 1 below. The total number of states providing a response to this part of the survey was 39, the percentages reported are the percentages based on those which responded. Those states which replied that they use both diamond grade and high intensity sheeting indicated they utilize the diamond grade sheeting for the orange band and high intensity for the white band on their construction drums.

Table 1: Reflective sheeting type

Sheeting	Frequency	Percentage
High Intensity	26	66.7%
Diamond	8	20.5%
High Intensity and Diamond Grade	5	12.8%

As seen in Table 1, two thirds of the responding agencies or departments require high intensity sheeting for use in work zones, one third require at least the orange band be diamond grade sheeting, and only one fifth of the responding agencies or departments require diamond grade sheeting for both the white and orange bands. Of those states and agencies which responded to the current practices survey and do not as of yet require diamond grade sheeting, 5 of the 26, or 19.2%, stated that their departments or agencies do plan to require diamond grade sheeting in the near future.

As part of the survey, each agency or department was requested to indicate the reasons as to why they require diamond grade sheeting or why they do not require the diamond grade sheeting be used on construction drums in work zones. Table 2 below shows the selected reasoning for requiring diamond grade sheeting while Table 3 shows the results reasoning given by those states which do not require diamond grade sheeting be used.

Table 2: Reasoning of those requiring diamond grade sheeting

Reasoning	Frequency	Percentage
Visibility	1	7.7%
Improved Work Zone Delineation	1	7.7%
Safety, Visibility, and Delineation	9	69.2%
Visibility and Delineation	2	15.4%

In Table 2 it is seen that the majority of those departments or agencies which require the use of diamond grade sheeting feel that the sheeting provides a better delineated, more visible, and therefore safer, work zone as opposed to the diamond grade sheeting.

TABLE 3: Reasoning of those not requiring diamond grade sheeting

Reasoning	Frequency	Percentage
Cost	11	57.9%
Glare	1	5.3%

Other	5	26.3%
All the Above	2	10.5%

In Table 3 it can be seen that the majority of those departments or agencies that do not require diamond grade sheeting do so do to the cost of the diamond grade sheeting material.

7.2 Speed

Speed data was collected at three locations throughout the work zones, as vehicles entered the work zone, at the middle of the work zone, and as vehicles exited the work zone, during both daytime and nighttime driving conditions in work zones with each sheeting type. The work zones utilized for this research had differing posted work zone speed limits. To account for this the deviation from the posted speed limit was compared rather than the actual traveled speed. Approximately 100 sample speeds were collected at each location based on the sample size required to detect a one mile per hour difference in speed at a 95% level of confidence, $\alpha = 0.05$.

The objective of this research was to determine if differences in driver behavior existed between work zones utilizing diamond grade sheeting and those utilizing high intensity sheeting on construction drums. Since the objective was to determine if differences existed between the sheeting types the data in this research was compared only within the time of day conditions and not between the condition groupings when comparing speeds by location within the work zone. This was done based on reasoning that the population of drivers would differ between time of day conditions and therefore any comparison of speeds between time of day conditions would provide information as to differences between populations driving behaviors and not differences due to the sheeting types.

Comparisons of speed data were performed between the overall high intensity and diamond grade sheeting, as well as high intensity with diamond grade at each separate location within the work zone by time of day condition. The comparison of the overall speed data was performed using a two-tailed Student's t-test with a level of confidence of 95 percent. The null hypothesis for these comparisons stated that there was no difference in speed between the different sheeting types. The alternate hypothesis stated there was a difference between the speeds traveled through the work zones with the different sheeting types. The Two Tailed Students t-test determined the calculated t-statistic was greater than the critical t-statistic for both the daytime and nighttime driving conditions.

This result indicates a statistically significant difference between the speed deviations from the posted speed limit between sheeting types exists. Statistical significance can be manipulated based on the sample size used for analysis, large sample sizes can cause very small actual differences to be considered statistically significant and small sample sizes can conversely cause large actual differences to be deemed non-statistically significant. To determine the actual significance of the statistical comparison the effect size was calculated for the differences in speed. The effect size for the comparison of the overall high intensity speed data with the overall diamond grade sheeting was 0.55. Based on the guidelines presented by Cohen, the sheeting type difference caused a medium effect on deviation from the posted speed limit within the work zones. The statistical results from the comparison of the overall speeds are presented in Table 4.

Table 4: Overall Speed deviation high intensity and diamond grade

Variable	Diamond Grade	High Intensity
Sample Size	618	583

Mean	2.322	-3.68
Std Deviation	4.48	4.72
Std Error	0.18	0.20

Mean Difference	6.00
Std Error of Difference	0.27
Degrees of Freedom	1184.21
t-calculated	22.55
t-critical	±1.96
95% confidence interval	Upper: 6.52 Lower: 5.48
Effect Size	0.55
Result:	Reject Null: $\mu_{DG} \neq \mu_{HI}$

The speeds at each location within the work zone were then analyzed separately. Analysis was performed on the pairs as separated out by location and time of day conditions. To keep statistical power this test was performed using a one-way ANOVA. The Lavene's test was performed coincidently with the one way ANOVA. The results of the Lavene's test indicated the variances were not homogeneous. To maintain statistical power in the ANOVA with non-homogeneous variances the Welch's modification to the ANOVA was used. The F-statistic and degrees of freedom reported therefore, are those associated with the Welch's modification. The null hypothesis the one way ANOVA comparison was that as there is no difference in speed variation between the diamond grade and high intensity groups. The ANOVA analysis indicated there was a significant difference between the diamond grade and high intensity sheeting speed data. The effect size of the ANOVA comparison was 0.59 indicating the diamond grade sheeting had a medium practical effect on the deviation between the traveled speed and posted work zone speed limits when compared to high intensity sheeting. The results of the one-way ANOVA are presented in Table 5.

Table 5: One Way ANOVA analysis of speed deviation from posted speed limits

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F-calculated	F-critical ($p < 0.05$)	Result
Between Groups	12725.85	11	1156.90	62.63	1.79	Reject Null: $\mu_{DG} \neq \mu_{HI}$ E.S. = 0.59
Within Groups	23424.78	1189	19.70			

To determine where the significant difference or differences were present, Post Hoc analyses were performed. The Gabriel and Games-Howell post hoc analyses were selected for this analysis with a stated null hypothesis that the mean speed deviations from the diamond grade sheeting and the high intensity sheeting were equal. Based on the results of the Lavene's test, the results reported are those from the Games-Howell post hoc since it retains statistical power when the assumption of variance homogeneity is violated. The Games-Howell post hoc indicated a statistically significant difference at all locations within the work zones for both time of day conditions. The results of the Games-Howell are presented in Table 6.

Table 6: Games-Howell post hoc analysis of speed deviation

Comparison	Mean Difference	Standard Error	95% LOC Lower Bound	95% LOC Upper Bound	Result
Daytime Entering	5.07	0.69	2.80	7.36	Reject Null: $\mu_{DG} \neq \mu_{HI}$

Nighttime Entering	5.58	0.61	3.45	7.61	Reject Null: $\mu_{DG} \neq \mu_{HI}$
Daytime Middle	8.29	0.57	6.41	10.18	Reject Null: $\mu_{DG} \neq \mu_{HI}$
Nighttime Middle	3.47	0.61	1.46	5.47	Reject Null: $\mu_{DG} \neq \mu_{HI}$
Daytime Exiting	7.28	0.68	5.03	9.53	Reject Null: $\mu_{DG} \neq \mu_{HI}$
Nighttime Exiting	6.42	0.61	4.40	8.45	Reject Null: $\mu_{DG} \neq \mu_{HI}$

7.3 Lane Placement

Lane placement data was collected for each sheeting type, both during daytime and nighttime driving conditions. Approximately 100 samples were collected for each driving condition to ensure ample sample size for statistical tests performed with a type I error equal to 0.05. It was determined, through the use of a one way ANOVA that a data extraction interval of 10 seconds would provide for a reasonable data extraction time frame without significantly affecting accuracy of the lane placement data. Lane placement data was extracted based on the vehicles position with respect to the lane centerline while traveling through the work zone.

The comparison was made between the sheeting types based on the time of day. Daytime conditions were compared together as well as the nighttime conditions. However, the time of day conditions were not combined or compared between groups. This was based on the reasoning that the driver population differs between the nighttime and daytime driving conditions. Therefore a comparison between time-of-day groups would not compare the difference due to sheeting types but rather the differences between driver populations.

A comparison of the lane placement between vehicles traveling through work zones utilizing diamond grade sheeting and that of vehicles traveling through work zones utilizing high intensity sheeting on the construction drums was performed through a two-tailed Mann-Whitney

U test at a 95 percent confidence level, or α = 0.05. The null hypothesis for each of these comparisons states there is no difference in lane placement between sheeting types. The alternative hypothesis stated that there was a difference in lane placement between the sheeting types.

The Mann Whitney U test determined the calculated z–statistic was greater than the critical z-score for both time of day groups. From these results it can be determined that, at a 95 percent confidence level, there was a statistically significant difference between lane placement between work zones utilizing diamond grade and high intensity sheeting. In order to standardize the results and determine the practical significance of the comparison the effect size was calculated. For the lane placement data, the effect size was calculated to be 0.52 for the daytime driving conditions and 0.67 for the nighttime driving conditions. The results from the Mann Whitney U test are presented below in Table 7, and Table 8.

Table 7: Daytime lane placement statistical analysis summary

Variable	**Diamond Grade**	**High Intensity**
Sample Size	109	104
Mean of Ranks	138.19	74.31
Sum of Ranks	15062.50	7728.50
Mann Whiney U	2268.350	

Z-score	-7.56
Effect Size	0.52
Result:	Reject Null: $\mu_{DG} \neq \mu_{HI}$

Table 8: Nighttime lane placement statistical analysis summary

Variable	Diamond Grade	High Intensity
Sample Size	119	97
Mean of Ranks	146.14	62.32
Sum of Ranks	17390.50	6045.50
Mann Whiney U	1292.50	
Z-score	-9.80	
Effect Size	0.67	
Result:	Reject Null: $\mu_{DG} \neq \mu_{HI}$	

Based on the effect sizes presented by Cohen, the diamond grade sheeting caused a medium effect in vehicle lane placement when compared to the high intensity sheeting.

8.0 CONCLUSIONS

The objective of this research was to determine if there existed a significant difference in driver behavior between diamond grade sheeting and high intensity sheeting when used on construction drums. A comparative parallel study was performed using work zones along SR-32, US-50 and SR-33 in Ohio, and I-72 in Illinois. All study locations were 4-lane corridors with a one lane closure and limited overhead lighting. The data collected included lateral placement within the lane and traveled speed within the work zone at three locations throughout the work zone. The lane placement data was extracted in terms distance away from the lane centerline either toward the closed lane, negative, or away from the closed lane, positive. The posted speed limit varied between data collection sites and therefore the speed data was analyzed in terms of the variation from the posted speed limit with positive deviations indicating traveled speed less than the posted speed limit and negative deviations indicating traveled speed greater than the posted speed limit.

The Student's t-test of means was utilized to compare the overall speed deviations observed from work zones using diamond grade sheeting with those observed from work zones using high intensity sheeting on channelizing drums. The results of the Student's t-test indicated there was a significant difference between the speed deviations both during daytime and nighttime driving conditions. Results from the Student's t-test were then tested for practical significance through the calculation of the effect size. Both the daytime and nighttime speed deviations showed a medium practical result. It was found in this research that the traveled speed of vehicles in work zones using diamond grade sheeting deviated much less from the posted speed limit implying a greater adherence to the posted work zone speed limit in these work zones.

A one-way ANOVA comparison of means was performed to compare the speed deviations at each location throughout the work zones. The results of the one-way ANOVA and corresponding Games-Howell post hoc analysis indicated a statistically significant difference in speed deviations occurred at every data collection location. When testing for the practical significance of these results the effect size calculated indicated a medium effect. From these results it is evident that vehicles traveling in work zones utilizing diamond grade sheeting adhere more closely to the posted speed limit at all locations throughout the work zone.

Vehicle placement within the lane throughout the work zone was analyzed using the Mann-Whitney U non-parametric test. Differences between the means of the sheeting groups were found to be statistically significant during both daytime and nighttime driving conditions. When tested for practical significance both conditions showed a medium effect made by the diamond grade sheeting indicating vehicles traveling through work zones utilizing diamond grade sheeting on construction drums tended to stay farther away from the closed lane then those traveling through a work zone utilizing high intensity sheeting.

In this research, when considering through vehicle behavior, diamond grade sheeting provided safer work zone conditions. Vehicles traveling through the work zones tended to stay further away from the closed lane laterally. These vehicles also adhered closer to the posted work zone speed limit.

The results and conclusions drawn from this research are somewhat limited however, and as such should not be construed as ultimate. Limits to the power of the conclusions drawn in this research exist due to the data collection abilities. The largest limits to the power of the results and conclusions stated in this research are due to the likely limited variation of population demographic used for data collection. Data collected from work zones utilizing high intensity sheeting were collected from three separate sites. However, each of these three sites was located in rural southern Ohio. This was due largely to a limited travel budget for the project and the proximity of the sites to Ohio University in Athens, Ohio. Data collection from work zones utilizing diamond grade sheeting was performed at only one location in Illinois. This was due to the low number of departments and agencies using diamond grade sheeting and a limited travel budget for the research.

While the rural nature of the sites selected for data collection could be considered the worst case scenario for roadway work zones, especially during nighttime driving conditions due to the lack of ambient lighting along the roadway to illuminate the work zone, the data and conclusions may not accurately represent the impacts for an urban or suburban work zone where overhead street lamps and other ambient lighting is present. All sites used for data collection were also 4-lane corridors, two lanes in either travel direction. Since the corridors were only two lanes in each direction with a grassy median, drivers may have felt more comfortable staying further away from the closed lane since there was only a shoulder opposite the work zone, not another travel lane. Based on these limitations to the research these results should only be applied directly to work zones located in rural areas on 4-lane roadways where one of two travel lanes in a direction is closed.

The single largest reason given by the departments or agencies which responded to the current practices for not requiring diamond grade sheeting was cost. Results of the study performed here within indicates a significant difference in driver behavior, both in adherence to the speed limit and lateral clearance given to the work zone, with the use of diamond grade sheeting. The results in this study would imply that the diamond grade sheeting provides for a safer work zone. It might also be assumed from these results that diamond grade sheeting may reduce the number of work zone accidents. If diamond grade sheeting does in fact lower the frequency of work zone crashes the cost of the diamond grade sheeting construction drums may be offset by reduced costs associated with those crashes. Future research should be performed to determine if there exists a significant difference in work zone crash frequencies between the sheeting types.

Future research should also be performed to consider the impacts of diamond grade sheeting during non-ideal weather conditions. The data collected in this research was collected during dry and clear weather conditions. Concerns exist over the possible excess glare cause from the increased retroreflectivity. While this did not appear be a concern during clear, dry conditions, future research should consider daytime and nighttime rain conditions for excessive glare due to the wet conditions. Further research could also include data collection during fog conditions. Both of these conditions may cause field data collection to be unsafe due to the proximity to the leading vehicle the data collection vehicle must travel. However, a driving simulator could provide a safe environment in which fog and rain conditions could be analyzed.

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