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IMPROVING THE EFFECTIVENESS OF NIGHTTIME TEMPORARY TRAFFIC CONTROL WARNING DEVICES, VOLUME 1: EVALUATION OF LIGHTS ON NIGHTTIME WORK ZONE CHANNELIZATION DEVICES

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Improving the Effectiveness of Nighttime Temporary Traffic Control Warning Devices

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16. Abstract

Currently, the Illinois Department of Transportation (IDOT) is one of the few state transportation agencies that require warning lights on nighttime work zone channelization devices, such as drums and barricades. The intent of the steady-burn, amber warning lights is to increase visibility of the channelization devices, providing guidance to motorists and preventing intrusions into the closed lane. However, their additional benefit beyond that provided by the high-reflectivity materials used on the channelization devices themselves has not been evaluated, including taking into consideration their initial, maintenance, and replacement costs; and the environmental and economic issues of routine battery replacement.

Applied Research Associates, Inc. (ARA) studied the effectiveness of warning lights on nighttime channelization devices by reviewing pertinent literature, experimental studies of nighttime work zones with and without lights on drums, driver surveys, and focus groups of driver perceptions and behavior in work zones using traffic drums. We applied a cognitive model of driver mental processes to this information to determine the influence of drum warning lights, if any, on driver perception and response.

The research showed that, when unprompted, most drivers did not perceive a difference or respond any differently in nighttime work zones using lights on drums than in those without lights. However, when asked to make direct comparisons between work zones with and without lights on drums, there was a slight preference for lights on drums due to the perceived increase in nighttime lighting they provide. Nighttime work zones, and work zones in general, are visually cluttered environments; and the presence (or absence) of lights on drums was not significant enough to attract the drivers' attention, given competing visual cues such as work zone traffic control devices, other vehicles, and activities in the work space. In addition, the reflective prismatic sheeting on drums in Illinois provides sufficient visibility without warning lights.

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DISCLAIMER

EXECUTIVE SUMMARY

Applied Research Associates, Inc. (ARA) studied the effectiveness of warning lights on nighttime channelization devices by conducting a review of pertinent literature, field experiments of nighttime work zones with and without lights on drums, driver surveys, and focus groups of driver perceptions and behavior in work zones using traffic drums. We used a cognitive model of driver mental processes to analyze this information and determine the influence of drum warning lights, if any, on driver perception and behavior.

Driver feedback from rest area surveys and focus groups indicated that drivers think the retroreflective prismatic sheeting used on drums in Illinois provides adequate visibility without auxiliary steady-burn lights. When shown images of the same work zone with and without lights on drums, drivers were not able to detect the difference and indicated that their certainty and behavior would be no different in either case. This finding is consistent with the field experiments, which showed no significant difference in driving performance indicators, including speed and lateral lane position. In fact, the rest area surveys showed that drivers actually remembered more details and more precision in details for the work zones without lights on drums, indicating they can better focus on other important work zone factors in the drums without lights condition. Ultimately, several other factors, including work zone layout, traffic conditions, the presence of workers and equipment, and the presence of other traffic control devices had a much greater effect on driver cognitive processes and behavior than the presence of lights on drums.

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CHAPTER 1 INTRODUCTION

1.1 BACKGROUND

Currently, the Illinois Department of Transportation (IDOT) is one of only a few state transportation agencies that require warning lights on channelization devices in nighttime work zones. The intent of the steady-burn, amber warning lights is to increase visibility of drums and barricades; thereby, providing provide guidance to motorists, and preventing intrusions into the closed lane. However, their benefit beyond that provided by the high-reflectivity materials now specified on the channelization devices has not been evaluated, including taking into consideration their initial, maintenance, and replacement costs; and the environmental and economic issues of routine battery replacement.

1.2 PROJECT OBJECTIVE AND SCOPE

This project studied the effectiveness of warning lights on channelization devices to determine their benefit, if any, to drivers approaching and passing through nighttime construction work zones on limited-access, interstate highways in Illinois.

1.3 RESEARCH APPROACH

Applied Research Associates, Inc. (ARA) studied the effectiveness of warning lights on nighttime channelization devices by reviewing pertinent literature, performing observational field studies of nighttime work zones with and without lights on channelization devices, conducting driver surveys, and mediating focus groups to solicit driver input. We applied a cognitive model of driver mental processes to this information to determine the influence of drum warning lights on driver perception and response. The detailed scope of work included the following:

- **Kickoff and Quarterly Panel Meetings**: ARA participated in regular panel meetings to discuss the project scope and objectives, to plan the next project phases, and to present current results and findings.
- **Literature Review**: We reviewed pertinent literature regarding federal and state highway standards, applicable research performed by others, and relevant cognitive processes, such as perception and memory.
- **Field Experimental Studies**: ARA and the Illinois Department of Transportation (IDOT) coordinated experimental studies at three IDOT construction sites to study driver behavior in work zones; to collect visual aids for the focus groups; and in two cases, to conduct driver surveys at nearby rest areas. The three sites were located on I-57 at Buckley, Champaign, and Salem, and included two paving operations and one bridge project.
- **Focus Groups**: ARA conducted focus groups to gain insight into what drivers perceive and comprehend, and how they respond, when driving through work zones. Four focus groups were conducted at two locations to capture input from a diverse range of drivers in both urban and rural areas.
- **Data Analysis and Findings**: Following the completion of all data collection phases, ARA analyzed the data from the observational studies, focus groups, and pertinent literature review to apply to a cognitive model developed as an evaluation framework for this project.
- **Recommendations and Report**: ARA's findings and recommendations regarding the effectiveness of warning lights on nighttime channelization devices are summarized in this report.

Figure 1.1 Do lights on drums improve driver perception
and guidance in nighttime work zones?

CHAPTER 2 PERTINENT LITERATURE REVIEW

ARA performed a literature review of highway standards, specifications, and applicable research to gain insight into what is currently required in terms of lights on work zone drums and the experience of other agencies.

2.1 STANDARDS AND SPECIFICATIONS

2.1.1 IDOT

The IDOT Standard Specifications for Road and Bridge Construction (IDOT 2012) and the IDOT Highway Standards (IDOT 2013) describe a full range of traffic control devices (TCDs) for construction work zone channelization and delineation purposes. These include cones, barricades (types I, II, and III), drums, vertical barricades, and direction indicator barricades. Figure 2.1 shows an example of each device. Of direct interest to this study are the drums, which are commonly used on multilane roads for channelization of traffic through the work zone. The arrow-equipped direction indicator barricades used to form the lane-closure tapers are also important. According to the specification book, the devices must meet Federal Highway Administration (FHWA) crashworthiness standards and IDOT quality standards for work zone TCDs. The traffic control plan, IDOT standards, and the *Manual on Uniform Traffic Control Devices (MUTCD)* (FHWA 2009) determine the number, type, color, size, and placement of the devices. Figure 2.2 shows the typical application of TCDs to form the lane closure and provide channelization for a multilane highway. The standards specify a 50-ft spacing between direction indicator barricades in the taper and a 100-ft spacing between drums or barricades along the tangent section of the work zone.

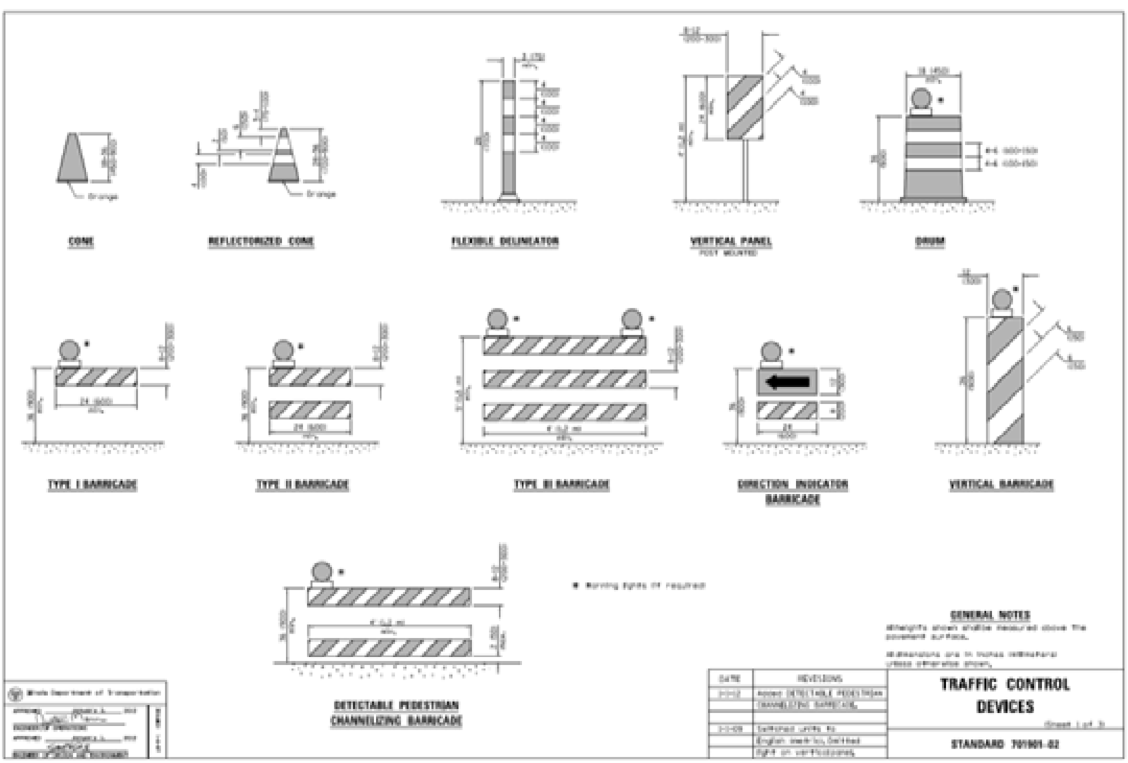

Figure 2.1 TCDs typically used for channelization on IDOT construction projects (IDOT Standard 701901-02).

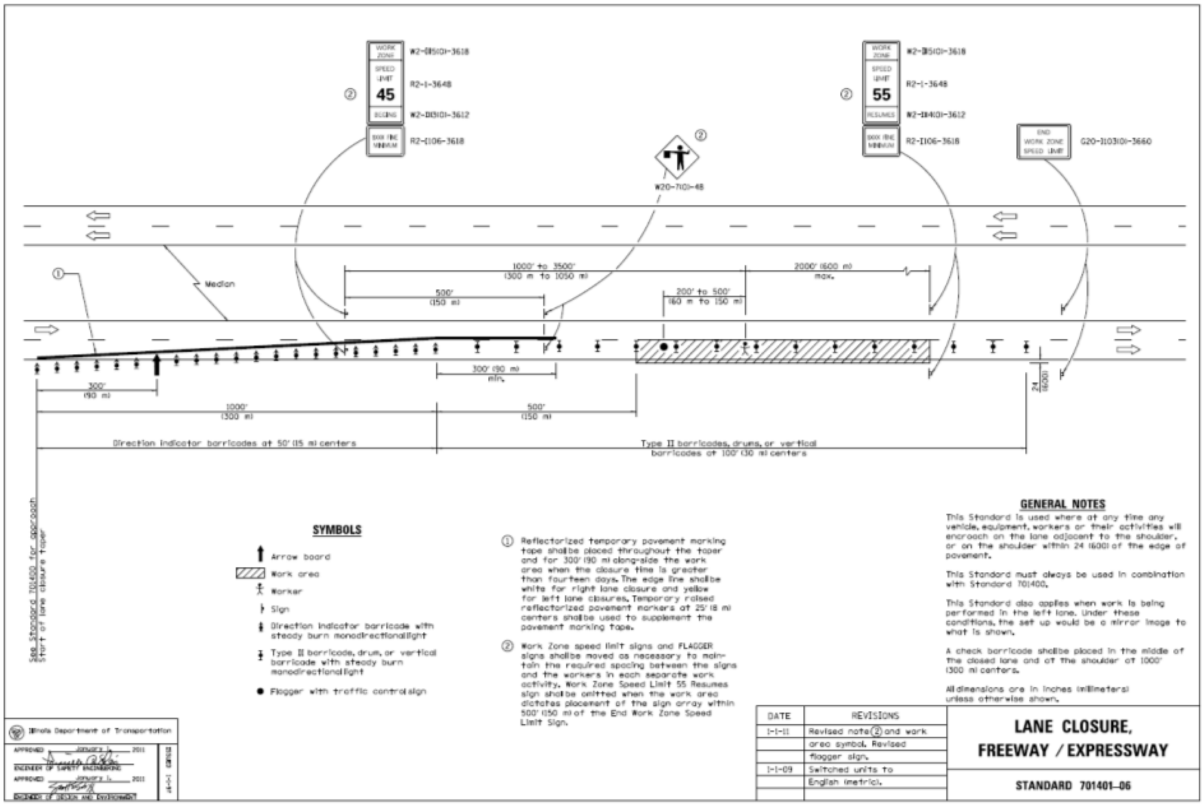

Figure 2.2 Typical application of TCDs for lane closure and channelization on a multilane highway (IDOT Standard 701401-06).

As directed by Section 701.16 of the specification book, steady-burn, mono-directional lights must be used on lane-closure tapers and channelizing devices for nighttime lane closures on multilane roads. Section 1106.02 of the IDOT Standard Specifications for Road and Bridge Construction describes the steady-burn (type C) lights in detail, including their power source, case, photoelectric cell, and testing and certification requirements. This section also provides information on the channelizing devices themselves, including their retroreflective materials. In the case of drums, they must contain at least two white and two fluorescent orange alternating horizontal stripes, each 4 to 6 in. wide. The retroreflective prismatic sheeting must meet initial minimum coefficient of retroreflection values as specified in the IDOT Standard Specifications for Road and Bridge Construction and other properties as determined by ASTM D4956. This section also provides corresponding information for the design of the direction indicator barricades used to form the lane-closure taper. Figure 2.3 shows examples of the drums and direction indicator barricades with steady-burn lights.

Figure 2.3 Examples of a drum and a directional barricade with retroreflective prismatic sheeting and steady-burn lights.

2.1.2 Illinois State Toll Highway Authority

The Illinois State Toll Highway Authority's Roadway Traffic Control and Communications Guidelines are a customization of IDOT specifications and standards to the unique characteristics of the Illinois State Toll Highway Authority, including high-speed, high-volume, fully controlled access expressways (Illinois State Toll Highway Authority 2010). The guide contains much of the same information as the IDOT specification book, including a description of the various types of channelizing devices, characteristics, and lighting requirements, when applicable. Specifically, it states that drums should contain a minimum of three orange and two white reflectorized, alternating, horizontal stripes 4 to 8 in. wide and that warning lights are required for all channelizing devices used overnight. The guide also contains quality standards for drums and lights that must be met during their use. Figure 2.4 shows an example traffic control standard using channelization devices to form the lane-closure taper and the lane closure on a multilane expressway, including 50-ft spacing in the taper and 100-ft spacing along the tangent section of the work zone.

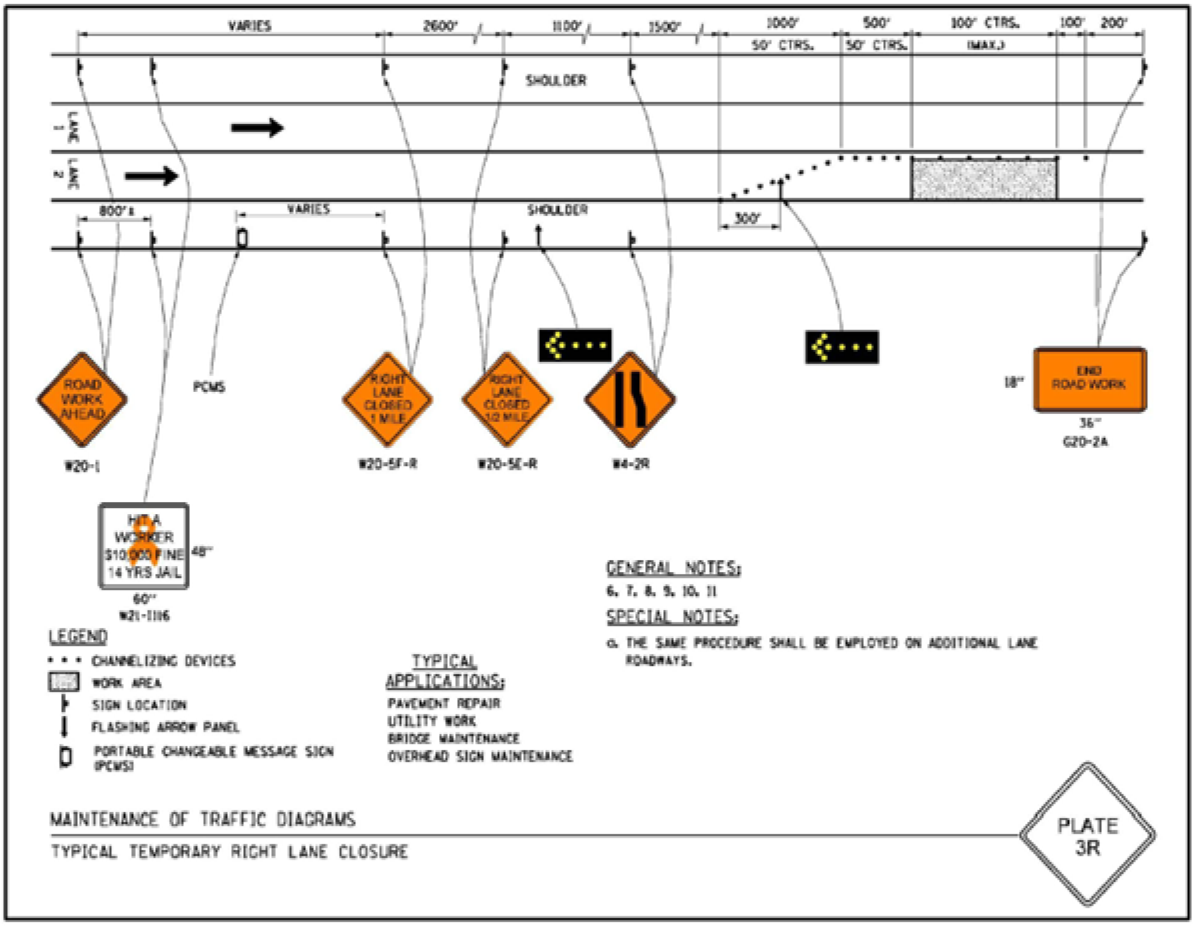

Figure 2.4 Example of Illinois State Toll Highway Authority lane-closure standard using channelization devices.

2.1.3 *MUTCD*

The *MUTCD* (FHWA 2009) provides guidelines that all state highway agencies must follow. Therefore, much of the information provided in the IDOT and Illinois State Toll Highway Authority standards is similar to the *MUTCD,* including the types of channelization devices, characteristics, and warning light characteristics, if used. A major difference between the *MUTCD* and IDOT standards is that the *MUTCD* allows for the use of warning lights on channelization devices but does not require them, even for nighttime work. When warning lights are used for channelization purposes, the MUTCD specifies that they be steady-burn. An allowable exception on the lane-closure taper devices is the use of sequential warning lights to increase driver detection and recognition of the merging taper.

2.2 APPLICABLE RESEARCH PERFORMED BY OTHERS

2.2.1 Michigan DOT Study

In 2010, Wayne State University (WSU) published a comprehensive research report on the topic of warning lights on channelizing drums performed for the Michigan DOT (WSU 2010). At the time of the study, the Michigan DOT had recently discontinued the use of steady-burn warning lights on channelizing devices and funded research to study the potential benefits or disadvantages of using lights on drums in Michigan, as well as in other states. The research contained several important parts, including a survey of state practices, crash-data analysis for work zones with and without lights on drums, luminance measurements, and a study of driver behavior in work zones with and without lights. The important findings of this study included the following:

- At the time of the study, the vast majority of state agencies (39 of 42 respondents) either did not use lights on drums or only used them infrequently (that is, in less than 10% of situations). Only three states other than Michigan used lights on a frequent basis (Florida, Illinois, and Oklahoma).
- Based on 2006–2008 work zone crash data from 26 states, only slight differences in crash rates existed between states, based on their frequency of use of lights on channelizing devices (frequent, infrequent, or no use). There was no trend between light usage and crash rates, with the highest crash rate existing in states that frequently used lights and the lowest crash rate in states that used lights infrequently (0.059 vs. 0.034 work zone crashes per million vehicle miles traveled).
- A detailed analysis of 31 Michigan DOT work zones using lights on drums and 25 work zones without lights on drums showed an indistinguishable difference in crash rate in cases where the drums may have influenced the crashes. There was no significant impact of not having lights on drums for either the general population or people 65 years and older.
- Luminance (brightness) measurements made in a controlled environment and in the field on drums with and without lights and using two different grades of reflective sheeting (high-intensity and prismatic) showed that the presence of the light increases the overall device luminance by only a small amount (0.3 to 7.3%). The type of sheeting had a tremendous effect on luminance, with prismatic sheeting increasing the device luminous from 177.1 to 203.6%, compared to high-intensity sheeting. All of the 85 drums with prismatic sheeting measured in the field had luminance values greater than the minimum threshold recommended for sign legibility.
- Driver behavior observations made at 28 field sites showed no statistical difference in the lateral lane position of vehicles passing through work zones with and without lights on drums. The researchers observed a significant increase in the number of steering reversals made by drivers passing through sites with lights on drums. They did not explain why this occurred. Likewise, mean vehicle speeds were 3.9 mph higher at sites with lights on drums; but because different sites were used for the lights-on-drum measurements versus the drums-without-lights measurements, the authors concluded that factors such as work zone layout, roadway geometry, and the presence of workers may have contributed to this result.
- A cost analysis estimated that drums with lights cost $5,744 to $7,157 per mile more on an annual basis than drums without lights. This estimate does not take into account the disposal costs of the lights themselves or their batteries.
- The authors concluded that “steady burn warning lights demonstrated little, if any, additional value to nighttime visibility, improvements in driver behavior, or crashes when used on work zone channelizing drums with high-intensity or microprismatic sheeting materials.” The authors noted that the use of prismatic sheeting provided a “far greater increase in visibility compared to the addition of a steady burn warning light to the drum.”

At the time of the WSU report, Michigan DOT had already discontinued the use of lights on drums. However, based on a memo on the Michigan DOT's website from their chief operations officer to regional personnel, the DOT again modified their policy, this time allowing lights to be used in certain situations where the construction engineer or project design engineer determines that "an area of the work zone warrants usage of lights on plastic drums" (MDOT 2012).

2.2.1 Florida DOT Study

The Texas A&M Transportation Institute (TTI) recently completed a study on the effectiveness of warning lights in work zones on temporary traffic control devices. for the Florida DOT (Theiss 2013). The researchers performed several luminance evaluations, including measuring the effect of fog, dew, and dirt, and conducted driving studies of older drivers to evaluate visual glance behavior, lane position, and driver opinions. Finally, the researchers performed a cost-effectiveness analysis to determine the necessary improvements in work zone safety that would need to be achieved to offset the cost of providing and maintaining steady-burn warning lights throughout all Florida DOT work zones.

The researchers found that fog adversely affects the apparent luminance, and thus visibility distance, of both retroreflective sheeting and warning lights, but at fog levels expected in the field, retroreflective sheeting is still likely to be visible at distances needed for path guidance and delineation purposes, and that the use of warning lights may not provide substantial additional benefit to drivers. Dew can also significantly reduce luminance, but the amount of luminance achieved under dew conditions is still likely to be sufficient for path guidance purposes. Warning lights did increase the luminance of channelizing drums with dirt and grime accumulation, but the research staff measured a greater increase in luminance by cleaning the drums.

The study of older drivers showed that the use of warning lights on drums did not affect their visual glance behavior or lane positioning when traveling adjacent to drums. While the study participants did indicate a preference for warning lights, none of the participants noticed the absence of lights on drums in the experimental study.

The researchers determined that typical costs for using LED warning lights on drums ranged from 6 to 20 $/mile/day, depending on the application, especially the drum spacing. A crash reduction benefit analysis indicated that the use of warning lights in urban areas would need to result in a 10% reduction in all nighttime crashes relative to what would occur if warning lights were not used on channelizing devices. Although a warning light crash modification factor is not currently available, the researchers believed it would be extremely difficult for the addition of warning lights themselves to consistently generate this amount of nighttime crash reduction.

Based on the results of their evaluations, the researchers recommended that the statewide application of steady-burn warning lights in all work zones be discontinued.

CHAPTER 3 COGNITIVE FRAMEWORK

ARA has significant experience in studying human cognitive processes over a broad range of knowledge domains. We use field experiments and driver focus groups to study the mental processes that motorists experience while driving through highway work zones at night. A detailed description and literature review of the pertinent cognitive functions—including attention, perception, and memory—are presented in Appendix A. Using this cognitive approach, we understand not only what motorists do but also why they do it. By knowing what factors attract drivers' attention and influence their decision making and behavior, we can better predict the effect of changes made to their environment, such as using traffic drums without lights. The following sections summarize the key cognitive functions pertaining to nighttime driving.

3.1 ATTENTION

Attention is the "gatekeeper" of our consciousness that lets relevant information in and keeps irrelevant information out (Wolfe 2000). The human body passively gathers stimuli from the surrounding environment through sensory functions, such as visual images detected by our eyes. Our sensory memory processes this information and collects more information than what we can attend to. This process filters out nonessential information, allowing for sustained mental focus on an object, item, or activity as we attend to important stimuli. Attention plays an important role in driving safety and behavior, such as the detection of an orange "road construction ahead" sign, a flashing light, or workers along the highway. Factors that are known to increase attention-getting include color, contrast, flash rate (for example, flashing or steady-burn), and luminance.

3.2 PERCEPTION

Perception is our ability to receive information from our senses and interpret this information. In the case of this research, we are largely interested in visual perception at night, such as the detection and interpretation of reflective signs, lights, pavement markings, the roadway surface, and other vehicles. At night, the lack of visual cues diminishes several important driving functions, including the ability to judge driving speeds and distance from other objects. Likewise, a visually cluttered environment, such as a work zone with hundreds of temporary traffic control devices, can increase reaction times as drivers struggle to separate nonessential visual information from important cues. This task is especially troublesome for older drivers. Our expectations about events and our environment also have a large effect on perception. Things that are familiar to or expected by us are easier to perceive than those that are unexpected or new. In other words, it is more difficult and takes longer to perceive situations that are unexpected, such as a new highway construction zone or an emergency vehicle that was not there the day before.

3.3 MEMORY

Memory is the process by which we encode, store, and retrieve information, and applies to the sensory, short-term, and long-term memory stores. To reach short-term memory, we must attend to information that reaches the sensory memory. In short-term memory, we store information briefly before we encode it to long-term memory or discard it. Memory is an important component to the performance of higher-order cognitive processes such as reasoning, problem solving, and decision making. Many driving situations rely on experiences stored in long-term memory. Common and repeated experiences form mental representations of events that we store in our memory (called *schemas*), which help us quickly recognize new information. For example, when we perceive a flashing arrow at the start of a work zone, drivers understand that they should change to the other lane, or that the color orange is associated with construction and they should proceed with caution.

We can think of the information available at each step in these cognitive processes as a funnel, wherein each subsequent step in the process contains a subset of the previous process. In other words, we cannot attend to all the information that we sense, we cannot perceive all information we attend to, and we cannot remember all information that we perceive. Figure 3.1 provides an illustration.

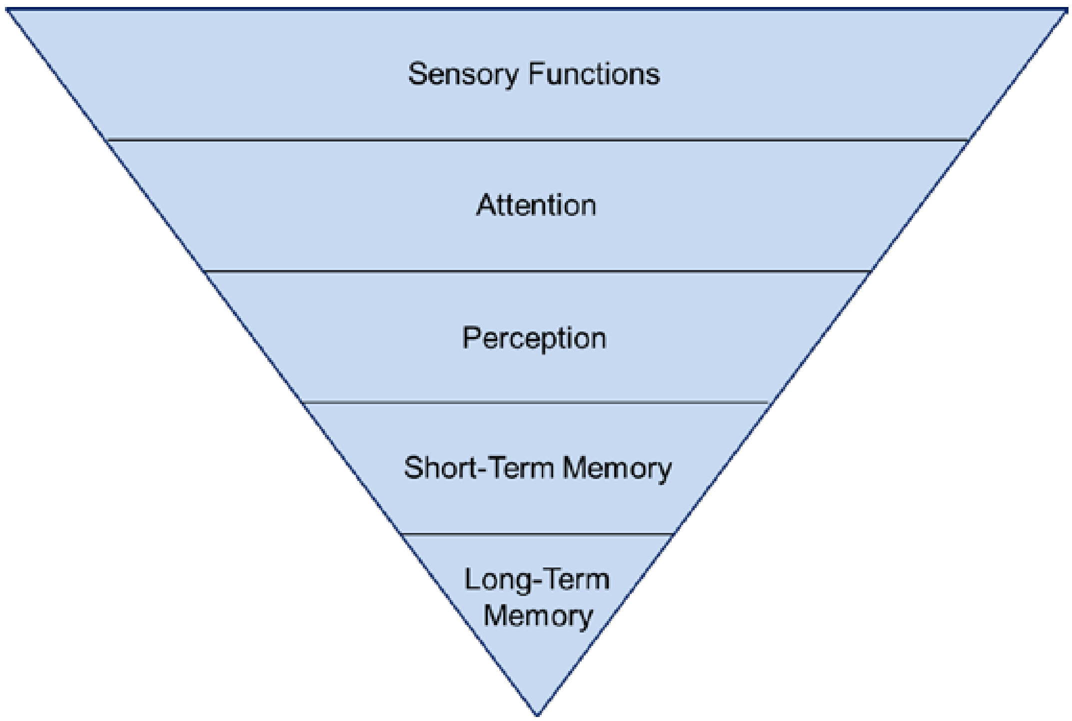

Figure 3.1 Visualization of the reduction of information occurring at each step in the cognitive process.

CHAPTER 4 FIELD EXPERIMENTAL STUDIES

4.1 METHODOLOGY

ARA performed experimental field studies to compare driver behavior in work zones with and without lights on drums. We conducted experiments at the three I-57 sites, as summarized in Table 4.1.

Table 4.1 Description of the I-57 Test Sites

Site and Location	Dates Observed	Construction Activity	Lane Closure Observed	Construction Work Period
Buckley, mile 269 to 270	July 17–18, 2012	Bridge work	Southbound, left lane closed	Day
Champaign, mile 238 to 241	July 19, 2012	Paving operation	Southbound, left lane closed	Day
Salem, mile 116 to 122	September 13–14, 2012	Paving operation	Southbound, right lane closed	Day and night

At each location, ARA collected data under two conditions: lights on drums and no lights on drums. In addition, we collected data with lights on and off the taper drums only. The research team collected the following data types, and we collected all data at night:

- Vehicle speeds and counts
- Vehicle lateral position within the lane
- Still pictures, mobile video from the driver's perspective, and overhead video from bridges

In addition, we performed an inventory of all work zone traffic control devices (WZTCDs) present, including signs, arrow boards, drums, barricades, speed feedback trailers, portable changeable message signs (PCMSs), and pavement markings. The research team also measured the length of each lane closure and performed a condition survey of the lights on drums, rating each light on a good–fair–poor scale. Good meant that the light was visible, while fair meant the light was dim or misaligned. Poor signified a light that was unlit or missing.

Table 4.2 Inventory of Site Conditions for the Three Test Sites

Site	Closed Length, mi	Work Zone Traffic Control Devices		Condition of Lights on Drums,%		
		Drums	Total	Good	Fair	Poor
Buckley	0.72	92	143	77.2	4.3	18.5
Champaign	3.55	157	345	55.6	23.7	20.7
Salem (lights)	4.0	198	284	91.4	3.0	5.6
Salem (no lights)	1.5	85	171			

4.2 RESULTS

4.2.1 Buckley

The Buckley site was the shortest lane closure of the three test sites and the only bridge construction project. At the time of our data collection, the southbound, left lane was closed for about 0.72 mi; and traffic was first directed to the right lane and then shifted partially to the outer shoulder. ARA collected data with the lights on drums covered with black plastic bags on the first night (which served as the lights-off condition) and with the lights visible on the second night (the lights-on condition). On the first night, we also collected data with the lights on the 20 direction indicator barricades forming the taper in both the non-visible and visible conditions. Figure 4.1 shows overviews of the Buckley site in the lights-off and lights-on conditions, while Figure 4.2 shows the taper with lights-on and lights-off conditions, respectively.

Figure 4.1 Buckley site overview with lights off and lights on drums.

Figure 4.2 Taper with lights off and lights on directional barricades at the Buckley site.

ARA measured vehicle speeds at about 1,000 ft past the beginning of the closed lane (i.e., 1,000 ft after the end of the taper) from a covert position, using a radar gun with trigger activation. We measured vehicle speeds on both nights at about the same time, 10 p.m. to 1 a.m.; and traffic volumes were very similar between nights. Figure 4.3 shows the results for the lights-off and lights-on conditions. In both cases, vehicle speeds were very similar, averaging 47.4 and 47.1 mph, respectively, in an area with a 45-mph posted work zone speed limit. In both cases, speeds were highly variable, ranging from about 38 to 68 mph; and the speed ranges were very similar for the two test conditions.

On the first night, we also measured vehicle speeds with the taper lights in the on condition for about 45 min. Vehicles averaged 45.7 mph, slightly lower than when the taper lights were covered; however, the data set was much smaller than that for the lights-off condition, which may account for the difference in means. Overall, the data suggest that neither the presence of lights on drums nor the addition of lights on the taper barricades influenced vehicle speeds and ranges. Table 4.3 summarizes the Buckley speed data results.

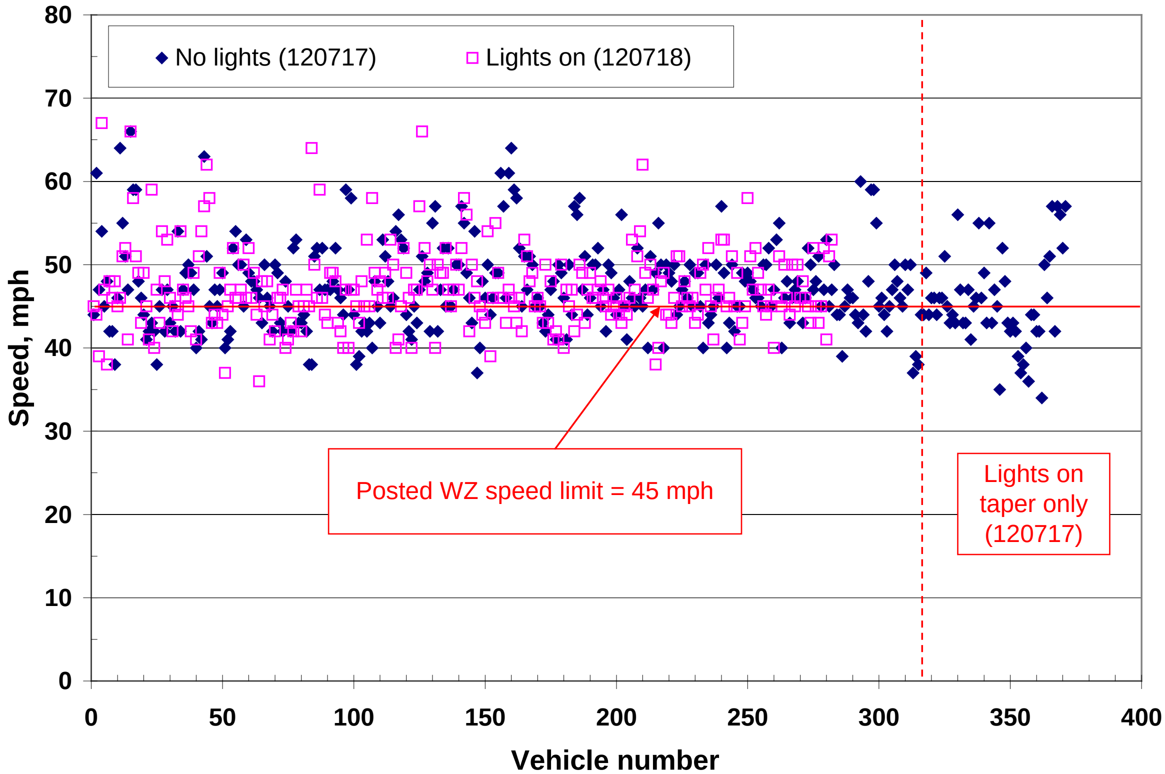

Figure 4.3 Speed data for the Buckley site lights-off and lights-on conditions.

Table 4.3 Summary of Buckley Speed Data

Condition	Mean Speed, mph	Speed Standard Deviation, mph	Number of Observations
All lights off	47.4	5.1	316
All lights on	47.1	4.9	282
Lights on taper only	45.7	5.6	54

The Buckley site did not have a suitable location for overhead videotaping (that is, a bridge overpass in the work zone); therefore, we did not record vehicle lateral position within the open lane or make detailed vehicle counts. We collected mobile videos with a camcorder placed inside a vehicle following a limited number of passenger cars and semi-trucks through the work zone. Although we did not perform a sufficient number of observations to draw any statistically meaningful results from the data, a qualitative review of the videos showed that drivers navigated the work zone without making any significant driving errors, corrections, or urgent maneuvers (such as excessive braking) for both the lights-on and lights-off conditions. In fact, the research team observed that, when undesirable driving behavior occurred, such as swerving over the white line, it typically happened downstream of the work zone, once the closed lane had reopened, indicating that drivers may have been paying closer attention to their performance in the work zone, as compared to when they were outside of the work zone.

4.2.2 Champaign

The Champaign test site consisted of a 3-mi closure of the southbound left lane due to a rubblization and overlay pavement rehabilitation. The research team collected all data in a single night by covering the lights on the first 0.75 mi of drums with black plastic bags, leaving the remaining 2.25 mi of drums with lights on. The transition point from no lights to lights took place beneath the Market Street overpass. From 9 p.m. to 1 a.m., ARA collected data with the taper lights covered with black plastic and then removed the plastic at 1 a.m., restoring the directional barricades to the lights-on condition. We left the bags covering the drums in the first 0.75 mi of the tangent section on all night. Figure 4.4 shows an overview of the Champaign site for the portions of the lane closure with lights off and lights on the drums. Figure 4.5 shows the merging taper with lights off and lights on the direction indicator barricades.

Figure 4.4 Champaign site overview with lights off and lights on drums.

Figure 4.5 Taper with lights off and lights on direction indicator barricades at the Champaign site.

ARA measured vehicles speeds in both the lights-off and lights-on drums sections. In the case of the lights-off section (that is, first 0.75 mi of the lane closure), we measured speeds from a covert position about 1,000 ft past the beginning of the closed lane (i.e., 1,000 ft after the end of the taper) for 1 hr. After this, we relocated about 1,000 ft into the lights-on section for 1 hr. Figure 4.6 displays the data for the lights-off and lights-on section. The data show that vehicle speeds and ranges were very similar for both sections, ranging from about 40 to 70 mph. Table 4.4 summarizes the speed mean and standard deviation for both sections. Although the mean speed for the lights-on section was 2 mph lower than for the section with lights off, this difference does not have any practical significance. This finding may be due to factors other than the presence of the lights on drums. For example, we collected these data later at night and further into the lane closure than the lights-off speed data, which may have caused this small difference. Both sections produced mean values slightly below the posted work zone speed limit of 55 mph.

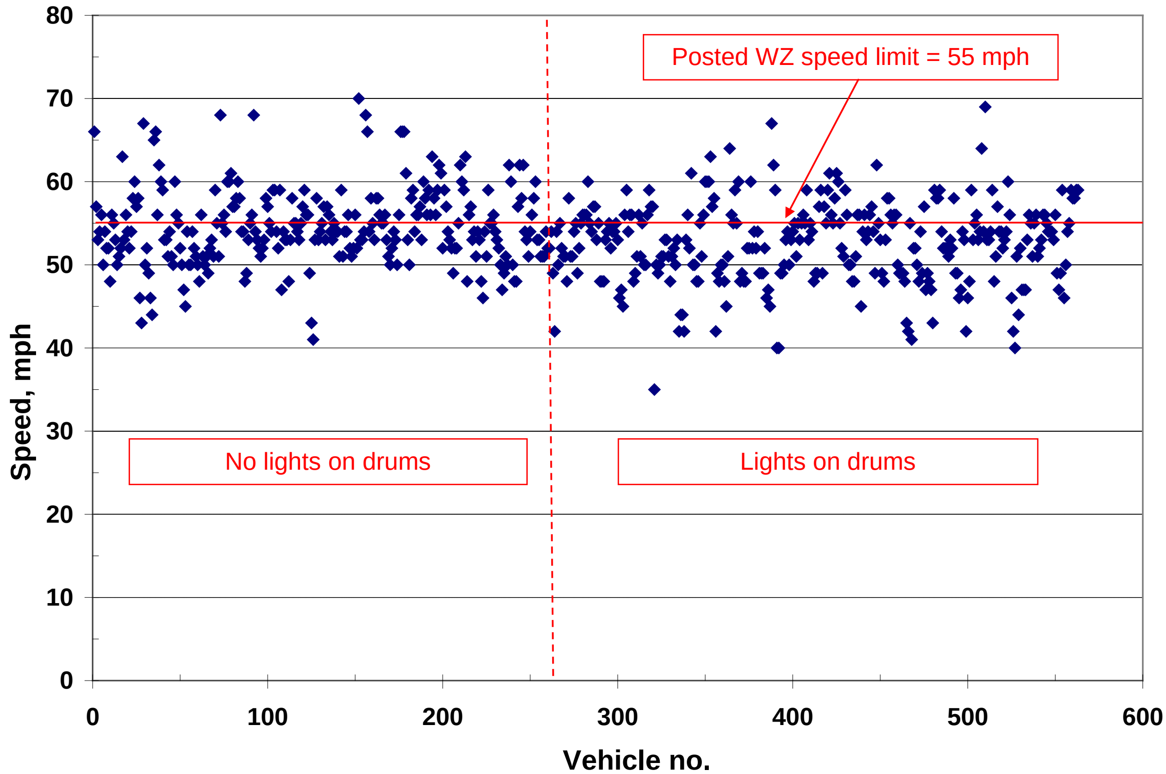

Figure 4.6 Speed data for the Champaign site lights off and lights on conditions.

Table 4.4 Summary of Champaign Speed Data

Condition	Mean Speed, mph	Speed Standard Deviation, mph	Number of Observations
Lights-off section	54.6	4.7	262
Lights-on section	52.6	4.9	301

The research team videotaped driver patterns from the Market Street overpass, which provided views of both the lights-off and lights-on sections. Specifically, we recorded the lateral position of the vehicles with respect to the traffic control drums to see if there was a difference between the lights-on and lights-off conditions. Figure 4.7 shows overhead views of the two sections, and Figure 4.8 presents the results. For both sections, the majority of traffic moved to the right side of the traffic lane (that is, away from the traffic control drums); and those that did not move over stayed in the center of the lane. No vehicles positioned themselves on the left side of the lane, closest to the drums. There was a significant difference between the two sections, with more vehicles in the lights-off section shifting further to the right; but this may have been due to the roadway surface. While collecting our mobile videos, the research team noticed that the road surface in the lights-off section was very rough and became smoother as the driver positioned the vehicle further to the right. The same consideration did not apply to the lights-on section.

Figure 4.7 Overhead view of the light-off and lights-on sections used to monitor lateral lane position at the Champaign site.

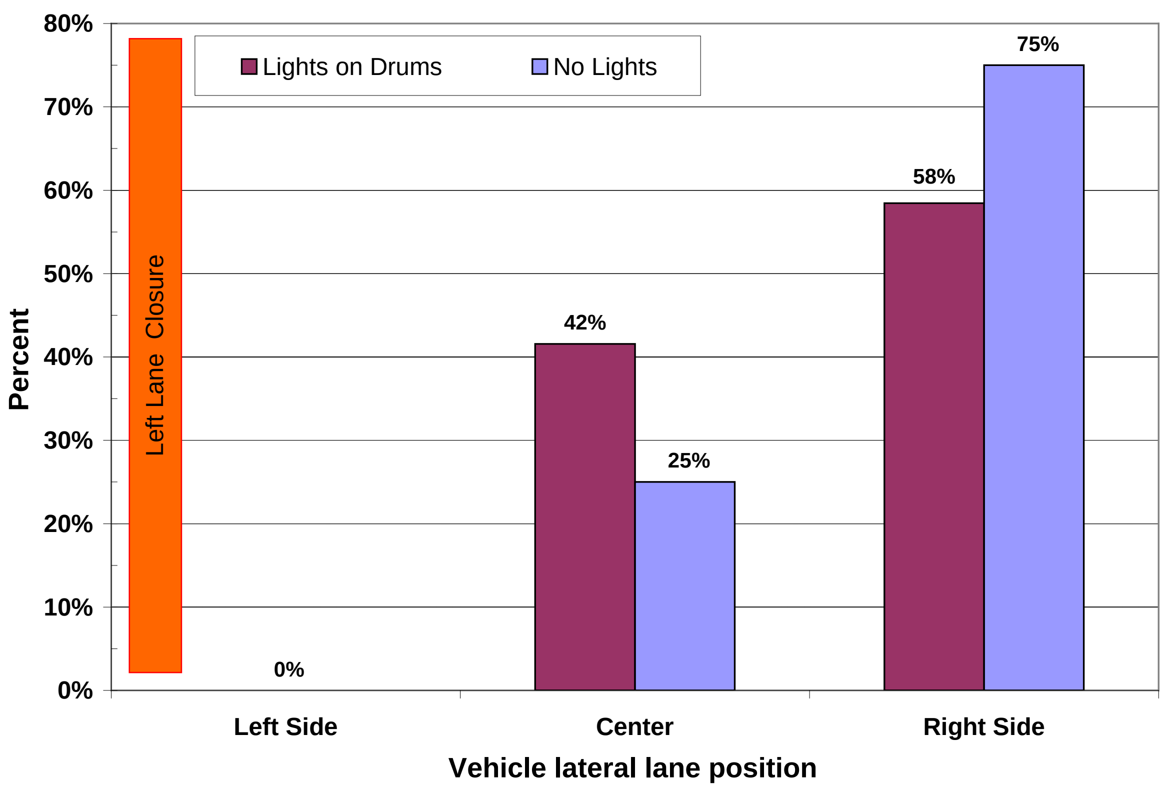

Figure 4.8 Lateral lane positions for the Champaign lights-off and lights-on sections.

4.2.3 Salem

The Salem test site was a right-lane closure of the southbound lanes for pavement milling and overlay. The paving operation advanced about 3 to 4 mi per day; therefore, ARA collected the second night's data in the same lane and traffic direction as the first night's but further south. The nighttime work included paving of the asphaltic concrete surface course, which presented a significant amount of machinery, equipment, vehicles, and workers in the closed lane. In addition, balloon lighting outfitted all of the heavy paving equipment, which illuminated the work area. Typically, the paving operation occupied about a 0.5-mi portion of the overall lane closure, which varied from 4 mi the first night to 1.5 mi the second night. The research team collected data in the lights-on drum condition the first night and the lights-off condition the second. In addition, we monitored driver behavior in the taper area in the lights-off condition on the second night. Figure 4.9 shows an overview of the work area adjacent to the paving operation. This test site was the only one where nighttime work was taking place.

Figure 4.9 Overview of the Salem test site showing the nighttime paving operation.

Figure 4.10 shows the driver's view of the road with the drums in the lights-on and lights-off conditions. ARA took the photos downstream of the paving operation, and they represent what the majority of the lane closure looked like to drivers, as the paving training occupied only the first 0.5 mi of the lane closure.

Figure 4.10 Driver’s perspective of the lane closure for the lights-on and lights-off conditions downstream of the paving operation, Salem site.

Due to the presence of the highly visible paving train, ARA collected speed data at multiple locations along the lane closure, including at the flagger, just upstream of the paver, 2000 ft downstream of the paver, and 0.25 mi beyond the end of the work zone. For the lights-on condition, ARA also collected speeds 1 mi past the work zone end. Figure 4.11 presents the speed profiles for the lights-on and lights-off conditions. The profiles between the two conditions are very similar, showing average vehicle speeds lower than the 45 mph posted work zone speed limit in the paving operation vicinity and increasing with distance downstream of the paver. The differences between the lights-on and lights-off conditions are very small and do not show a consistent trend of drivers in one condition displaying higher or lower speeds. The data show that, although temporarily posted work zone speed limits may affect driver behavior, other factors—such as the presence of the paving operation and workers, and partially shifting onto the shoulder in the paver vicinity—also have a significant effect on driver speeds within nighttime work zones, especially those in which activities are taking place.

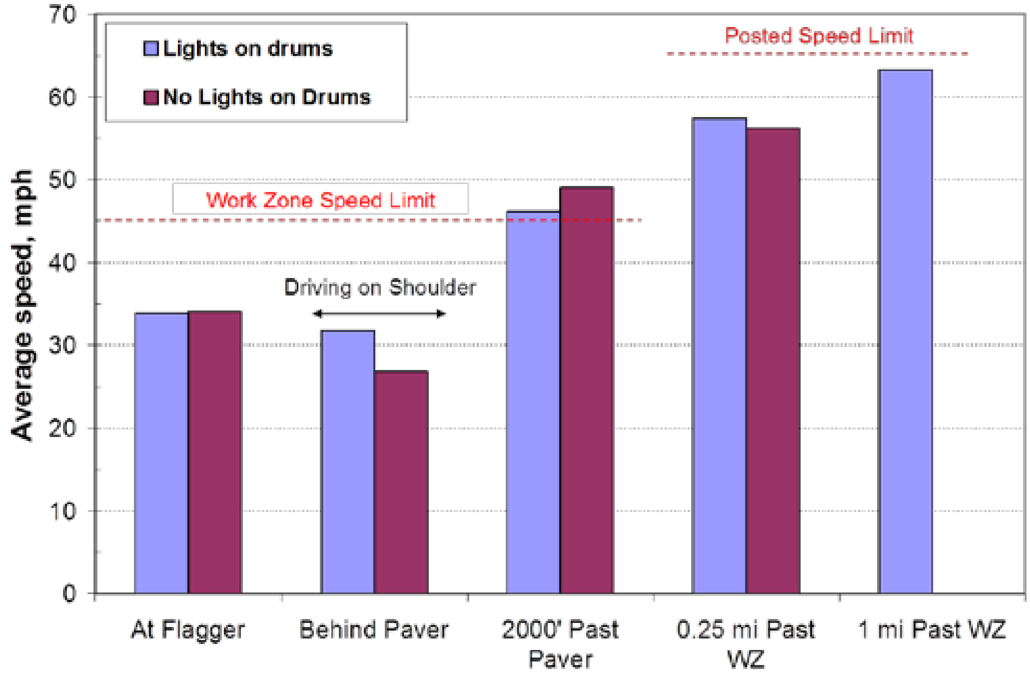

Figure 4.11 Speed profiles for the Salem site in the lights-on and lights-off conditions.

The research team collected overhead video both nights from the Tonti Road overpass to monitor vehicle lateral lane position for the lights-on and lights-off conditions. In addition, we videotaped the merging taper with lights off to see if drivers shifted within the lane while still in the taper. Figure 4.12 shows examples of the lights-on and lights-off cases.

Figure 4.12 Overhead views of vehicle lateral positions the lights-on and lights-off conditions at the Salem test site.

Figure 4.13 displays the lateral lane results for the lights-on and lights-off conditions, plus the merging taper with the lights off. The results show that even in the merging taper with the lights off, about one-third of the vehicles had already shifted away from the side of the closing lane. Further into the work zone (and away from the paving operation), this portion increases to about two-thirds. In the tangent section of the work zone, only about one-third of the vehicles position themselves in the center of the lane; and no vehicles position themselves to the right side of the lane, where the drums are. The slight difference between the lights-off and lights-on cases is not practically significant.

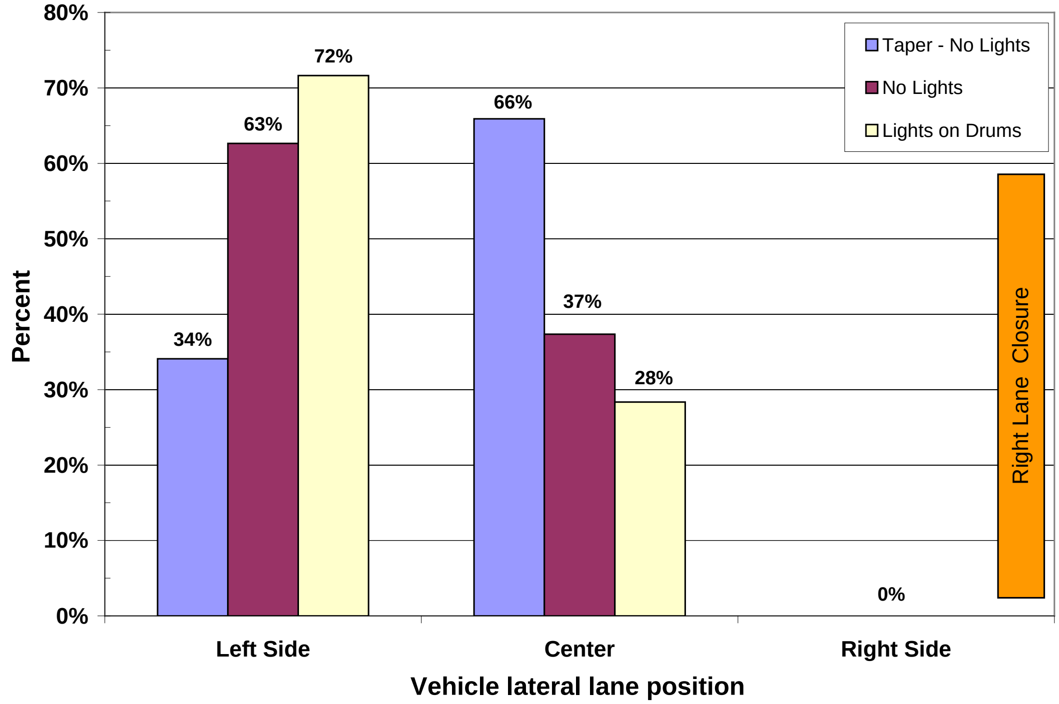

Figure 4.13 Lateral lane positions for the Salem site—three conditions.

CHAPTER 5 DRIVER SURVEYS

5.1 METHODOLOGY

ARA performed driver surveys at the Buckley and Salem rest areas to determine the cues that drivers perceive, attend to, and use to make driving decisions in work zones. Both of the rest areas were located immediately downstream of construction sites, and we conducted surveys on two nights at each location, one night with the drum lights on and one with the drum lights off. We conducted the surveys between 9 p.m. and 1 a.m., and the survey consisted of the following nine questions:

1. Did you notice you drove through a highway work zone (yes or no)?
2. What led you to believe this was a highway work zone?
3. Did you notice any orange and white construction drums/barrels (yes or no)?
4. Please estimate the length of work zone covered by drums.
5. Please estimate the number of drums.
6. What was the level of lighting in the portion of road with drums (1-to-10 scale, 1 = extremely poorly lit, 10 = extremely well lit)?
7. Did you notice anything about the lighting in the portion of the road with drums?
8. Please describe everything you remember about the portion of road with drums.
9. Is there anything else you wish to tell me about the portion of road with drums?

In addition, surveyors recorded basic demographic information, such as the participant's approximate age (> 65 and < 65), gender, and whether the participant was the driver or a passenger in the vehicle. The surveys took about 5 to 10 min to complete, and participants received the equivalent of a free coffee (in the form of coins for the rest area vending machines) as an incentive to participate. Overall, the surveys received positive support from the drivers, with the vast majority of drivers entering the rest areas agreeing to participate.

Figure 5.1 ARA performed driver surveys at rest areas near work zones to identify the cues that drivers perceive and use to make driving decisions.

5.2 RESULTS

5.2.1 Participant Characteristics

Overall, 81 participants took the survey and the breakdown of participants by age, gender, and whether they were the driver or passenger was similar between the two sites and between the two nights at each site. The sample characteristics were as follows:

- Age:
  - 93% under 65 years
  - 5% over 65 years
  - 2% unrecorded
- Gender:
  - 77% male
  - 20% female
  - 3% unrecorded
- Driver or passenger:
  - 81% drivers
  - 17% passengers
  - 2% unrecorded

Passengers who participated in the survey responded “yes” to the first question, which asked whether they had noticed the work zone prior to entering the rest area.

5.2.2 Cues Used to Identify Work Zones

The surveyor asked the free-response question, “What led you to believe this was a highway work zone?” to learn what visual cues motorists used to identify the test site as a construction zone and which cues (such as signs or lights) are the most effective in conveying this message. The question did not contain choices or suggestions. Several common themes emerged from the drivers’ self-reports. Ranked as a percentage of all responses, the most frequent responses were:

- Signs—39.6%
- Lights (all types)—22.8%
- Barriers/barrels/cones—17.4%
- Cognitive operations—8.0%
- Speed information—5.4%
- People—3.4%
- Equipment—3.4%

Signs emerged as the dominant theme in highway work zone identification. Further analysis of the responses revealed drivers believed that signs performed the dual functions of capturing drivers’ attention and providing information about the work zone. The following responses are representative examples:

- “Arrows telling me to merge.”
- “Signs on the highway warning us of a situation to move to the right lane.”

Respondents also mentioned lights as a common cue used to identify the test site as a work zone. Since the question was free-response, some replies were specific (i.e., “flashing arrows”), while others were general, such as just stating “lights”.

5.2.3 Driver Perception of Drums With and Without Lights

ARA asked questions 3 through 7 to assess whether the lights on drums increased their visibility to drivers and increased their attention to the work zone. Because we only tested a single condition per night (lights on or lights off), drivers could not make a direct comparison between the two conditions. Even if we had exposed drivers to both conditions, directly asking them whether lights increased drum visibility would have likely influenced their responses. For example, they may have answered “yes” when in fact they had not noticed a difference because as a general rule lights increase visibility. Therefore, the research team asked questions about the length of the lane closure, the number of drums, and the overall visibility in the area covered by drums. The assumption is that if lights increase visibility then based on the cognitive concepts of attention, perception, and memory, drivers would more accurately estimate the work zone length and the number of drums. Likewise, if the drum lights add to the overall work zone visibility, then this would reveal itself by the participants’ rating of work zone visibility on a 1-to-10 scale (1 = extremely poorly lit and 10 = extremely well lit). In essence, the questions intended to assess drivers’ perception of drums with and without lights, without biasing their responses by stating the research objective.

ARA analyzed the responses regarding work zone length and number of drums by comparing the participants’ answers to the actual length and number of drums for each test configuration. We calculated the mean and standard deviation of the difference score (reported – actual) for each condition (lights on and lights off) and performed a Student’s t-test to determine if the differences between the two data sets were statistically significant at the 95% confidence level. The results showed no statistical difference in either the estimation of work zone length or the estimate of number of drums between the two cases. In other words, the presence or absence of lights on drums did not significantly affect the drivers’ perception. The trends between the Buckley and Salem test sites were similar.

Overall, there was also no statistical difference between driver perception of work zone visibility between drums with and without lights. On a 1-to-10 scale (1 = extremely poorly lit and 10 = extremely well lit), drivers rated the visibility of drums with and without lights a mean of 7.1 and 7.3, respectively. Interestingly, contrary to driver perception of work zone length and number of drums, the responses to this question showed different trends between the Buckley and Salem test sites. Participants rated the work zone with lights on drums higher than the lights off condition, with scores of 6.9 and 5.3, respectively. A Student’s t-test of only the Buckley data showed that this was statistically significant. However, the Salem visibility ratings for the lights-on and lights-off conditions were 7.3 and 8.5, respectively, with the unexpected result that drivers rated the lights-on case marginally lower.

The Salem site was very different from Buckley in one important way—a brightly lit nighttime paving operation was taking place at the time of the Salem surveys. Driver attention to the balloon lighting of the paving operation would explain the systematically higher ratings for the Salem visibility. Another factor that may have had an effect was the length of the Salem test sections. ARA studied the lights-on case on the first night when the lane-closure length was more than twice that of the lights-off night (4 mi vs. 1.5 mi). For the lights-on case, the overall effect of the brightly lit but relatively short paving train may have been diluted by the longer test section. Drivers spent more time driving in parts of the work zone where the paving train did not influence their perception, thus lowering their overall score.

5.2.4 Driver Perception of Work Zone Details With and Without Lights

The third method we used to evaluate the influence of lights on drums was to ask participants to describe what they remembered about the section of the work zone covered by drums. We hypothesized that if lights on the drums increase driver attention to and perception of the work zone, drivers should have better memories for cues in the work zone. Specifically, we analyzed the data for the quantity and precision of details provided by drivers in the lights-on and lights-off conditions. For example, if a participant responded that s/he remembered seeing drums and signs, the response received a quantity score of 2. Furthermore, responses that described the devices in greater detail received higher precision scores. For example, a response of “drums” received a numerical score of 1, while a response of “orange and white drums” received a score of 2. We then defined the precision score as the ratio of the number of precise details over the total number of details. Therefore, the greater the number of precise details, the higher the precision score.

Concerning the quantity of details, both the Buckley and Salem sites produced results counter to our hypothesis. The mean of all responses for the lights-on versus lights-off condition were 2.3 and 3.4, respectively, indicating that drivers remembered a greater number of details for the case of lights off. A Student’s t-test verified that this was statistically significant. The precision results showed the same trend, meaning drivers reported more precision of details for the lights-off case. The mean of all responses for the lights-on versus lights-off condition were 0.5 and 0.7, respectively. Again, both the Buckley and Salem sites produced similar trends, and the difference was statistically significant. It appears that participants report not only more details but also more precise details for the lights-off case. Perhaps lights on the barrels reduce drivers’ ability to attend to other cues in the work zone.

CHAPTER 6 FOCUS GROUPS

ARA organized a series of focus groups to understand nighttime drivers' decision-making requirements, traffic control device preferences, and challenges associated with nighttime work zone driving. In general, focus groups provide the opportunity to investigate in more depth specific topics of interest, such as themes presented by the rest area driver surveys. Specifically, we sought to do the following:

- Identify the cues drivers use to perceive and comprehend nighttime work zones
- Identify the traffic control indicators and warnings that drivers best respond to and the behaviors that result from these indicators and warnings
- Identify any uncertainties drivers have in nighttime work zones and suggestions for improvement

We conducted four focus groups at two sites, Champaign and Downers Grove, Illinois. Champaign is in central Illinois, a largely agricultural area; and was selected to represent drivers accustomed to driving on rural highways. Downers Grove is located in the western suburbs of Chicago, and was selected because drivers in this area are experienced with driving on urban freeways and interstates. ARA recruited focus group participants through several means, including word of mouth, posting of flyers, and radio announcements for the Champaign focus group and advertising on Craigslist and posting flyers in Illinois State Toll Highway Authority oases for the Downers Grove group. In both cases, we prescreened potential applicants using a survey posted on SurveyMonkey; and we selected participants who met the following criteria:

- Possessed a valid driver's license
- Indicated that they drove *sometimes*, *often*, or *all the time* on highways at night
- Were available the time and date of one of the sessions

The research team selected participants to represent a range of age and driving experience, and we selected about equal numbers of female and male drivers. We compensated the participants $50 each at the end of their session, which lasted 2 hours.

6.1 PARTICIPANT CHARACTERISTICS

The research team selected 20 participants for the Champaign focus group, of which 19 attended. We selected 20 attendees for the Downers Grove session, of which 14 attended. We also asked participants for information about their age and driving experience. Strong correlation exists between the two variables, as expected. Figures 6.1 and 6.2 show the participants' gender and age distributions in the four sessions. All participants reported that they were typical drivers, or those who drove for work, school, or other personal-related reasons and reported having significant nighttime highway driving experience, as shown in Figure 6.3.

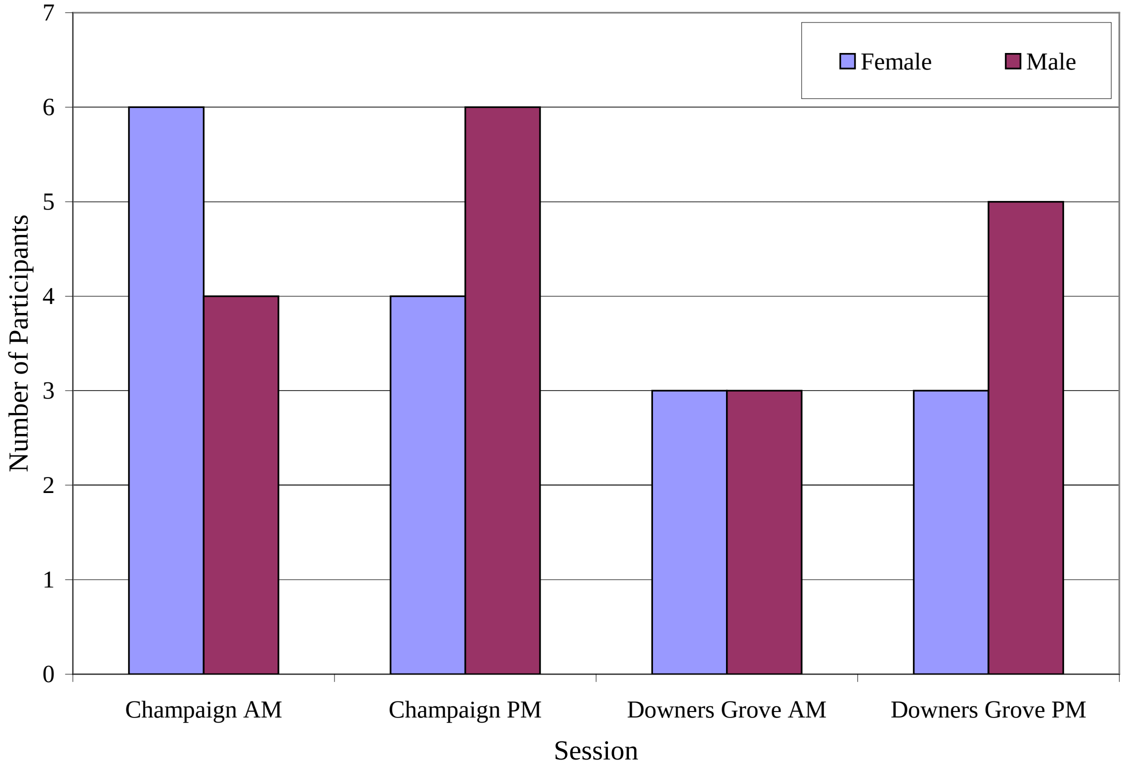

Figure 6.1 Gender distribution of participants.

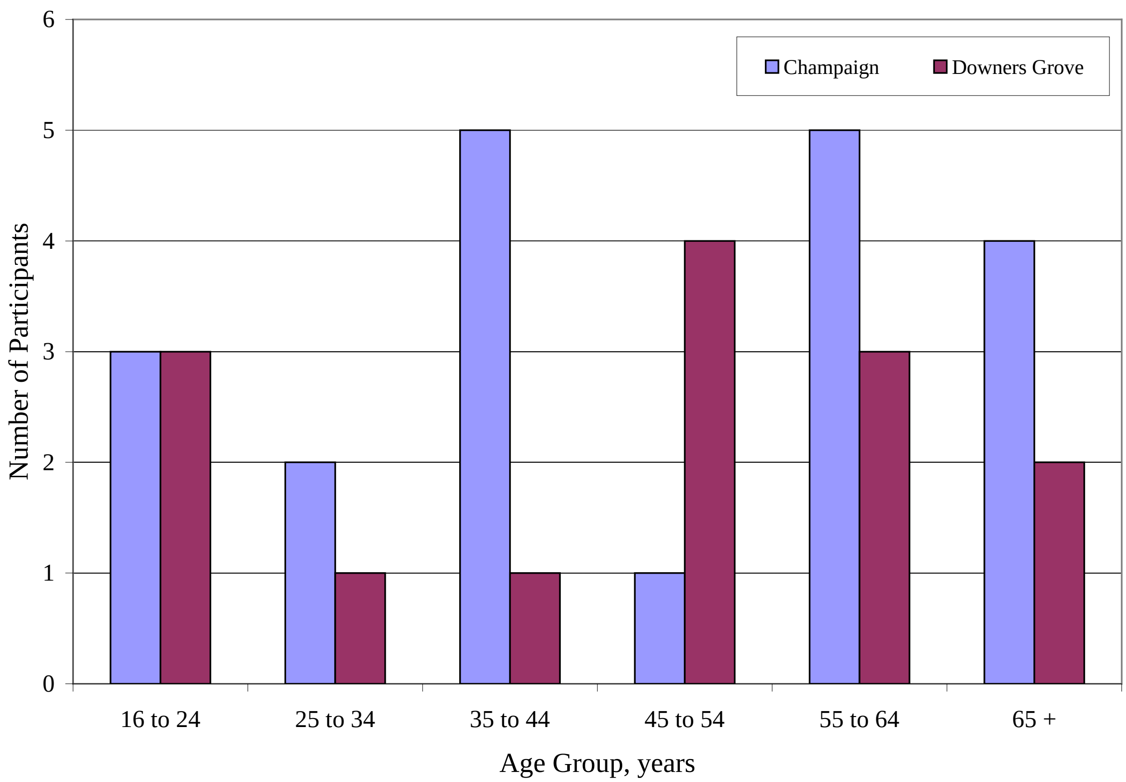

Figure 6.2 Age distribution of participants.

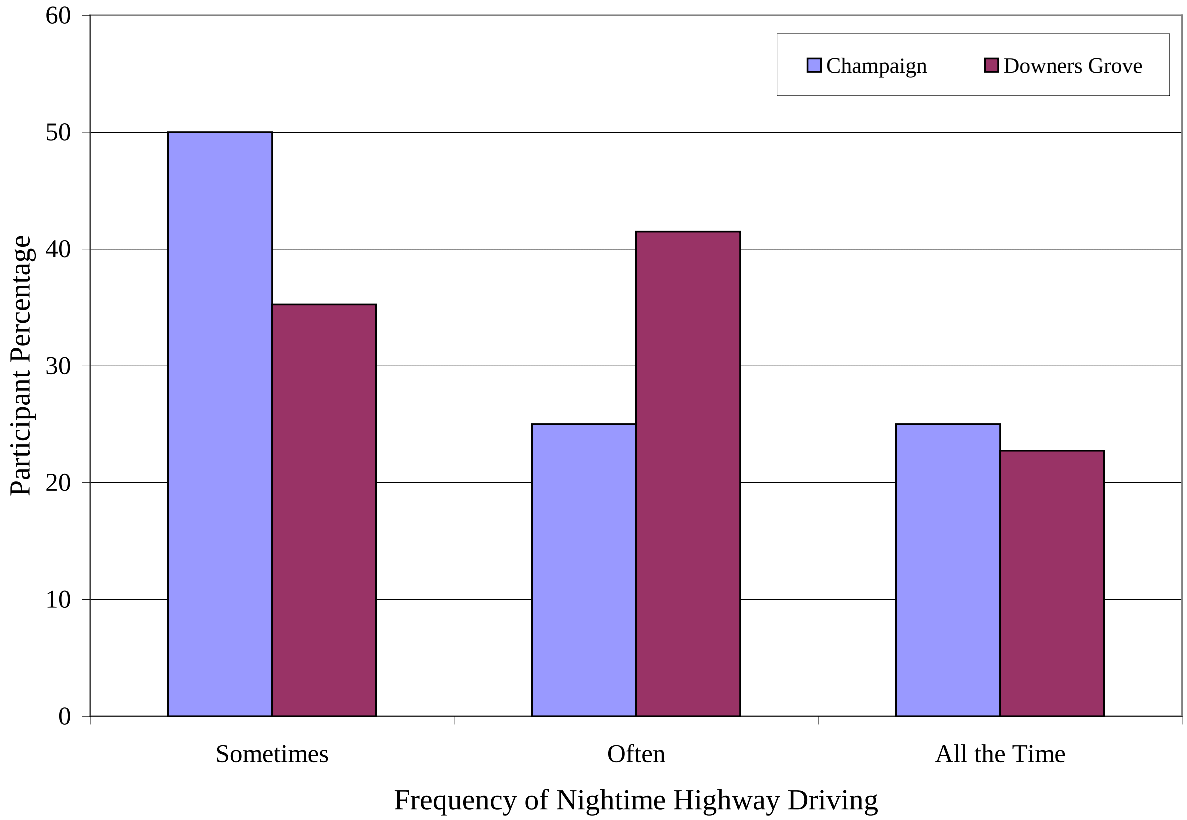

Figure 6.3 Nighttime highway driving experience of participants.

6.2 MEETING AGENDA

The focus groups contained three main parts:

- A group discussion regarding general nighttime work zone driving experiences
- A group discussion regarding specific driver perceptions and behaviors in nighttime work zones
- A detailed questionnaire covering general and specific topics related to nighttime work zones

The session began with a welcome from Doug Steele, followed by an introduction of the project background by Jess Marcon. After this, the focus group leader, Laura Zimmerman, introduced the focus group goals and objectives.

Zimmerman then led the two group discussions, each one lasting about an hour. First, we discussed drivers' general mental models of nighttime work zones, using uncaptioned pictures of actual field setups as visual aids. Second, we used videos of actual nighttime work zones to discuss specific scenarios. Finally, each participant completed a detailed questionnaire to allow quantifying of driver perceptions and behaviors in nighttime work zones. The entire focus group session lasted 3 hours.

6.3 GROUP DISCUSSION: GENERAL WORK ZONE TOPICS

We broadly defined nighttime work zones and showed participants photographs that represented these scenarios. Figure 6.4 shows sample photos of nighttime work zones used to stimulate discussion. We did not present all examples of nighttime work activity; rather, we presented representative examples that might prompt participants to think about the variety of scenarios they may have experienced.

To address drivers' mental models and prompt discussion, our focus group leader asked some of the following questions:

- Think back to driving through a highway work zone at night. Tell me about it.
- Describe some of those things you remember (for example, lights, barrels, and so on).
- Do you remember changing your driving behavior?
- To navigate safely through the work zone, what are the critical pieces of information you need to know?

Based on participants' answers, the leader asked follow-up questions to uncover how drivers' understanding and models influence their perception of and behavior around nighttime work zones. This procedure allowed us to elicit information about their expectations and past behavior without prompting them to discuss specific elements. We used this format so that our interests in specific nighttime work activity configurations would not influence participants' memories and participants could respond freely with the elements in work zones that they believed affected their behavior.

Much of the discussion touched on general work zone themes (such as detours, length of delays, and activity type), which were not immediately relevant to the lights-on-drums research. However, several applicable topics surfaced in the discussion. Participants in all focus groups discussed drums (mentioned as either barrels or cones) during the mental models portion. When we asked what participants expected to see in a nighttime work zone, three out of four groups responded that they expected to see drums.

Drum spacing was a theme that consistently emerged across focus groups, specifically as a driving challenge in nighttime work zones. Focus group participants said that drum spacing led to confusion in work zones. They indicated that drums spaced too far apart made the lanes difficult to discern, especially when demarcating exits and on-ramps or when used to indicate that a lane or on-ramp is closed. This situation leads to indecision regarding where to drive, especially if the driver is concerned about where he or she will be able to exit.

Figure 6.4 Examples of nighttime work zones shown during the first part of the focus group.

6.4 SPECIFIC WORK ZONE VIDEOS: DRUMS WITH AND WITHOUT LIGHTS

After a brief break, the leader transitioned into a discussion about specific nighttime work activities. The researchers presented a series of videos and pictures. After presenting each video, the leader asked some of the following questions to prompt discussion:

- How would you interpret and respond to this situation?
- What are your main concerns approaching this work zone?
- To navigate safely through this nighttime work zone, what are the critical tasks that need to be completed?
- What would improve your understanding of the situation?

Each video discussion lasted about 10 to 12 min. One video showed a driver passing through a stationary work zone where drums were present. No lights were present on drums for the first part of the video, but lights were present on the drums for the second part of the video. The images in Figure 6.5 depict each part of the video.

Across all focus group sessions, participants failed to notice the change from no lights on the drums to lights on the drums. Only one participant noticed the change and freely commented about it briefly without prompting from the focus group leader. Once the focus group leader replayed the video with the prompt to notice the barrels, all participants recognized the light change. Most participants indicated that the “lights didn’t mean anything” and that they were not relevant to their driving decisions. Participants in all but one session (Downers Grove morning session) remarked that the reflective striping on the drums was important. Participants in the Champaign and the Downers Grove afternoon sessions noted that the reflective material was more important than the lights on top of the drums, remarking that the “reflection overrides the light” and that the lights “[didn’t] make a difference so long as the reflective material [was] there.”

Figure 6.5 Samples of drums with lights off and on from the video.

6.5 QUESTIONNAIRE

6.5.1 General Topic Responses

After the discussion ended, each participant completed a survey that took about 20 min. The survey covered general questions about work zone characteristics and driver behavior. We created the survey to examine further driver behaviors and nighttime work zone characteristics, as revealed by the rest area interviews. For example, drivers most often recalled signs and lights (of all types) as they passed through the work zone. We incorporated these elements into the survey, along with other relevant challenges to driving through nighttime work zones. The surveys also contained two nighttime work zones containing drums with lights. Participants made judgments about their responses to these scenarios, identified elements about the site that were unclear, their certainty about their actions, and what would improve their work zone comprehension.

Participants ranked how a series of traffic-related items influenced their behavior when driving in traffic work zones at night. These items were ranked on a 1-to-10 scale (1 = least influential, 10 = most influential). Figure 6.6 presents the mode score for each work zone factor.

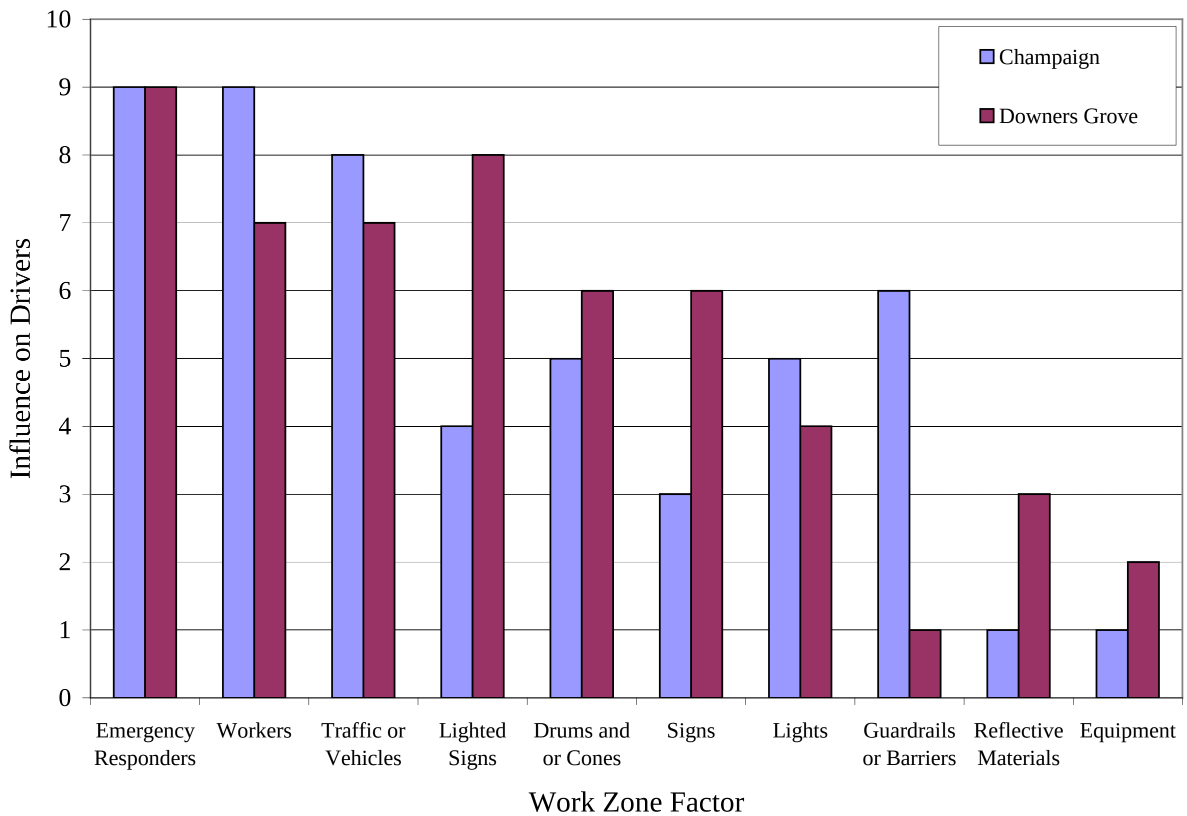

Figure 6.6 Influence of work zone factors on driver behavior (1 = least, 10 = most).

Participants most often ranked *emergency responders, workers,* and *traffic or other vehicles,* as having the most influence on their driving behavior. Similarly, both groups of participants ranked *reflective materials* and *equipment* as having the least effect on their behavior. *Lighted signs, drums and cones, signs*, and *lights (all types)* had a moderate influence on both sets of drivers. The work zone factors were based on responses from the driver surveys and include factors common to stationary lane closures, mobile lane closures, and other nighttime mobile operations, such as incident response. Given the free-response nature of the driver survey questions, some factors, such as lights and reflective materials, are general and can include a wide range of specific devices and applications within each category.

Participants indicated whether they typically experienced too little, just enough, or too much information, reflective material, and light when driving through a work zone at night. Figures 6.7 and 6.8 show that participants (both rural and urban drivers) typically experienced too little information in nighttime work zones. This finding is largely consistent with comments made during focus group discussions, in which participants remarked that they desired more information. For example, they often stated that they wanted to know when workers were present, to see signs with words rather than symbols, and to know the work activity duration. Participants from both groups indicated that there typically exists just enough reflective materials in work zones. Finally, the majority of participants from Champaign indicated that there was too little light in nighttime work zones, while participants from Downers Grove responded that the amount of lighting was just enough. The high-mast lighting typical of urban expressways and interstates may explain the difference between the Downers Grove and Champaign participants' responses.

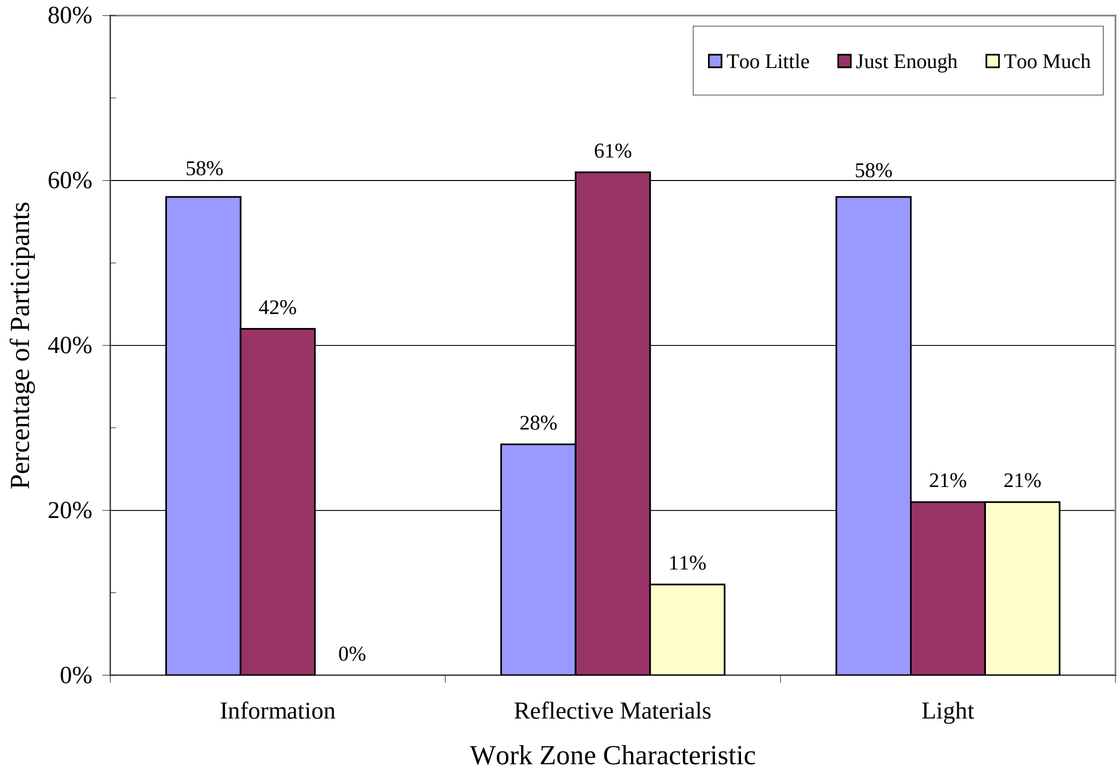

Figure 6.7 Driver opinions of different work zone characteristics—Champaign group.

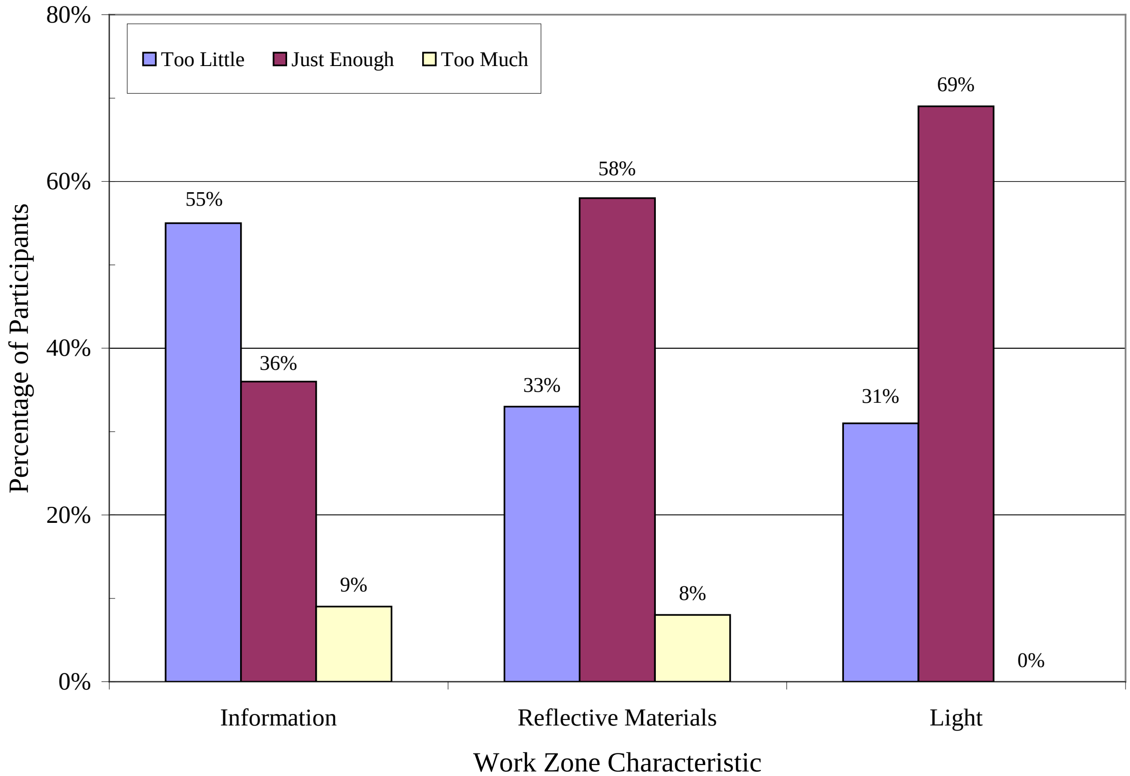

Figure 6.8 Driver opinions of different work zone characteristics—Downers Grove group.

We asked participants to rate how concerned they were about five nighttime work zone characteristics on a scale of 1 to 7 (1 = not concerned at all, 7 = extremely concerned). Figure 6.9 shows that participants rated w*orkers present* as the highest concern, followed by *not enough space*, *unfamiliar area*, and *close guardrails* producing high levels of concern. Participants rated lighting glare as the lowest concern but still gave it a rating in the upper half of the scale range. Ratings between urban and rural groups were statistically similar, with the exception of *not enough space*, in which case, the Downers Grove participants were less concerned about having sufficient space than were the Champaign drivers.

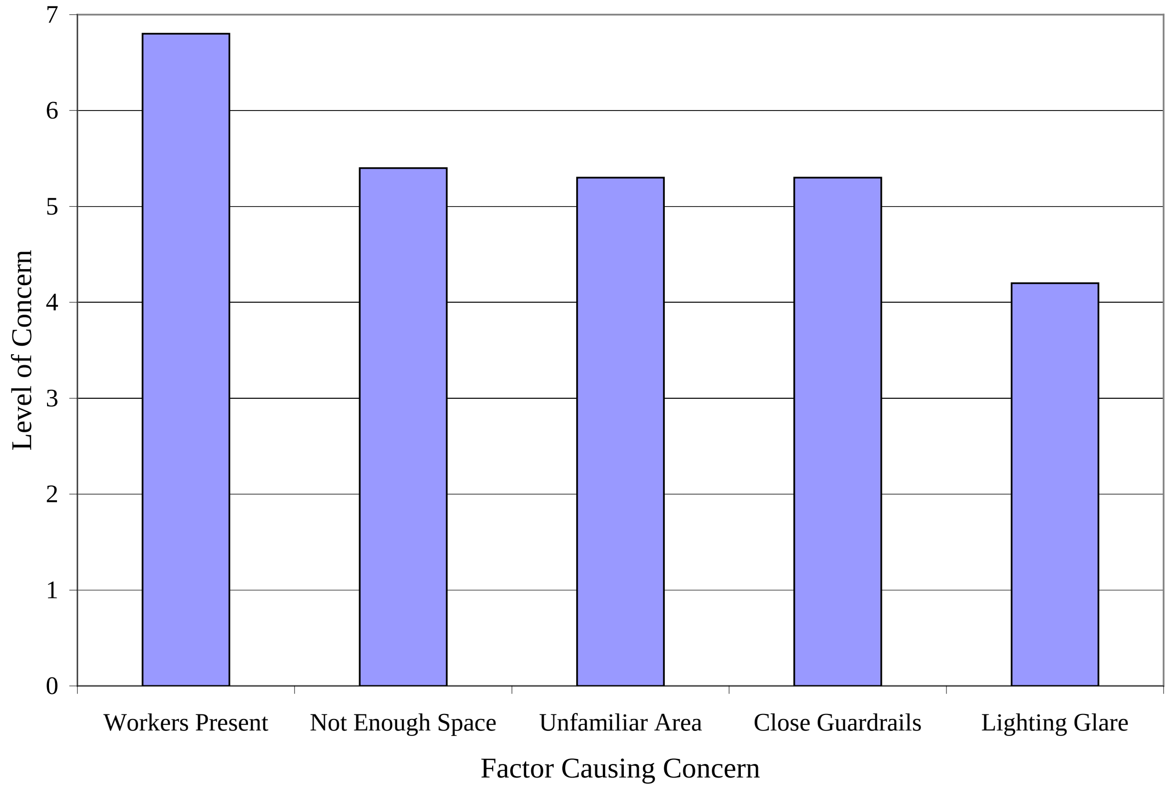

Figure 6.9 Level of driver concern caused by various factors (1 = low, 7 = high).

6.5.2 Responses to Specific Work Zones

Following the general questions, the survey presented images of two nighttime work zones using drums with lights for channelization. A caption with each image provided additional information about the work zone. The questionnaire asked participants to study the work zone image and respond to a series of questions regarding what actions they would take in each situation, how clear their comprehension of the situations was (noting any specific uncertainties), and what could improve the certainty of each situation. Finally, we asked participants to provide any additional comments they may have had regarding the specific work zones. Figures 6.10 and 6.11 show the two work zone images and captions provided to participants in the questionnaire.

Figure 6.10 A left-lane closure on I-57 near Buckley because of bridge construction. Traffic has merged to the right lane and partially shifted on to the shoulder. No workers are present.

Figure 6.11 A left-lane closure on I-57 near Champaign. Traffic has been merged to the right lane, and no workers are present.

6.5.2.1 Which Action Would You Take Most Often?

Participants identified the action that they take most often when approaching the work zones shown in Figures 6.10 and 6.11, making their choices from a list provided in the questionnaire. Table 6.1 summarizes the percentages of responses for both the Buckley and Champaign work zones. Responses varied slightly by work zone and focus group; but overall, participants selected slowing down or slowing down in combination with either staying in the same lane or changing lanes as the action they would take most often in each situation.

Table 6.1 Which Action Would You Take Most Often?

Action	**Buckley Site—Double Column of Drums**		**Champaign Site—Single Column of Drums**	
	Champaign, %	**Downers Grove, %**	**Champaign, %**	**Downers Grove, %**
Do not change my driving behavior	5	0	15	
Slow down	20	28.6	35	42.9
Slow down and stay in lane	15	42.9	15	14.3
Slow down and change lanes	50	28.6	30	42.9
Increase speed	0	0	0	0
Increase speed and stay in lane	0	0	0	0
Increase speed and change lanes	0	0	0	0
Stay in the lane	0	0	5	0
Drive on the shoulder		0	0	0
Prepare to stop		0	0	0
Other	10	0	0	0

6.5.2.2 Which Actions Would You Take First, Second, and Third?

Participants indicated the sequence of actions they would take in each work zone by recording the first, second, and third actions they would perform. Table 6.2 summarizes their reported rankings and shows very consistent results between focus groups and situations. In all cases, participants indicated that their first action in the work zones would be to *slow down*. The Champaign group responded that their second action would be to *slow down and stay in the lane* or *stay in the lane*, while the Downers Grove group answered that their second action would be to either *slow down and stay in the lane* or *slow down and change lanes*. All four focus groups responded that their third action would be to *prepare to stop*.

Table 6.2 Which Actions Would You Take First, Second, and Third?

Action	**Buckley Site—Double Column of Drums**		**Champaign Site—Single Column of Drums**	
	Champaign	**Downers Grove**	**Champaign**	**Downers Grove**
Do not change my driving behavior				
Slow down	1	1	1	1
Slow down and stay in lane		2		2
Slow down and change lanes	2	2	2	2
Increase speed				
Increase speed and stay in lane				
Increase speed and change lanes				
Stay in the lane	2		2	
Drive on the shoulder				
Prepare to stop	3	3	3	3
Other				

6.5.2.3 Situational Certainty

Participants rated how certain they would be about their behavior when approaching the work zone sites on a 1-to-7 scale (1 = completely uncertain, 7 = completely certain). Across groups, the mean rating for the Buckley site was 5.2. The Champaign site produced a slightly higher level of certainty, with a mean score of 5.7. In both cases, no significant differences between the Champaign and Downers Grove participants emerged. These scores indicate a moderate level of driver certainty for these two cases.

When asked if there was anything specifically unclear about the two work zones, 19 participants said that there was nothing unclear, while 13 indicated that something was unclear (2 participants did not respond). No significant differences in the responses between the Champaign and Downers Grove groups emerged. We asked participants to describe what they perceived to be unclear about the situation. They reported general items (such as the length of the work zone and the nature of the activity), visual cues (interpreting signs, lights, and paint marks), and questions about what action to take or decision to make. The following are examples:

- General information:
  - "Why is it there?"
  - "Length of construction"
  - "How long does it last?"
  - "How many lanes are now open?"
  - "What's exactly going on besides (if any) lane closure?"
  - "Where are they working"
  - "How much advance warning is there to change lanes"
  - "How exit and entrance are going to affect traffic"

- Physical cues:
    - “Sign indicating where detours go”
    - “Merging lane from right”
    - “Barrels”
    - “Speed limit”
    - “Rather dark”
    - “Lane perimeters”
    - “Any signs”
    - “The lines on the road further ahead”
    - “The two barrels in the middle of construction zone” (Champaign site)
- Actions:
    - “Am I supposed to totally stay in my lane or shift to the right and drive partially on the shoulder?” (Buckley site)
    - “Not really clear how far over you need to go” (Buckley site)
    - “I’m not sure where I’m being directed” (Buckley site)
    - “From this viewpoint, can I stay in the right lane? It looks as if I have to exit” (Champaign site)
    - “From this picture it looks like you are exiting, but it may be the picture unclear until you get there” (Champaign site)

A desire for *signs* appears prevalent across both groups. During the focus groups, participants expressed a general desire for more information in work zones, especially signs that communicate information with text.

6.5.2.4 What Would Improve Your Comprehension?

Participants provided multiple suggestions for each example about changes that might improve their comprehension. Sign-related suggestions received the most prominent attention—specifically, the desire to have more information conveyed via signs and message boards with text or wording. Overall, 48.7% and 36.7% of the suggestions correspond to signs for the Buckley and Champaign sites, respectively. It should be noted that the survey only included the still photos shown in Figures 6.10 and 6.11, and did not show the entire work zone, including the advance warning area. Participants provided the following example suggestions:

- “More signs”
- “Signs with written instructions”
- “More signage. A sign to let me know how many miles of construction left”
- “Text describing action to take”
- “Maybe a sign saying ‘move off road’”
- “Lit up sign saying ‘Bridge Lane Closure’”
- “A flashing sign about the lane closing and the need to merge”

Lighting was the second most prevalent theme, with 12.8% and 30% of the suggestions being related to lighting for the Buckley and Champaign sites, respectively. Some of the suggestions included:

- “More lighting”
- “Better lighting”
- “Much more lighting”

Finally, participants indicated that arrows would improve their comprehension in 7.6% and 10% of their comments for the Buckley and Champaign sites, respectively. Sample response included:

- “Arrows”
- “A couple of…arrows”
- “Lit arrows”
- Maybe some arrows to go along with the barrels”

The results show the importance of several key work zone components, such as signs and arrows in the advance warning area (not depicted in the photos), on driver comprehension. While devices such as drums, reflective markers, and reflective pavement markings serve as navigational aids at night, other devices, such as signs, arrows, and changeable message signs, provide information that increases driver comprehension of what is happening in the work zone, what to expect, and what actions to take.

6.5.2.5 Additional Comments

The survey provided participants the opportunity to offer additional comments regarding the work zones, and several participants responded. In general, the nature of their comments was similar to the above suggestions regarding uncertainty, comprehension, and suggestions for improvement. Specifically, their responses showed a strong desire for additional signing and information, such as that typically provided in the advance warning area, which was not depicted in the photos presented in the survey. Sample responses included:

- “More signs”
- “Sign with lights; message board warning upcoming work zones”
- “Have people merge earlier; put a sign up early on”
- “More signs; more arrows”
- “Without sign it is confusing”
- “Brighten street lights”
- “Needs more lighting”
- “Further reduce speed limit”
- “I assume that nothing is happening here at the time. If something is happening where I should really slow down then I have no idea from the image.” (Champaign site)

CHAPTER 7 FINDINGS AND CONCLUSIONS

7.1 FINDINGS

This research revealed several important findings regarding driver cognition, comprehension, and behavior while driving in and around highway work zones.

7.1.1 Driver Behavior Field Studies

- Experimental studies at three work zones showed no significant difference in vehicle speeds for the cases of drums with and without lights. On the other hand, mean vehicle speeds between the three sites ranged from about 0 to 10 mph higher than the posted work zone speed limit when no construction activity was taking place. When construction was taking place and drivers were required to drive partially on the pavement shoulder, mean vehicle speeds ranged from 10 to 18 mph below the posted work zone speed limit. While the presence (or absence) of lights on the drums did not affect vehicle speeds, other factors such as work zone layout, roadway geometry, and construction activities had a major effect.
- Vehicle lateral lane positions adjacent to lanes closed with channelization devices showed that about two-thirds of the vehicles shift to the lane edge farthest away from the channelization devices, while the remaining one-third position themselves in the lane center. No traffic operated near the lane edge closest to the drums, and there was no trend of vehicles responding differently to drums with or without lights.

7.1.2 Rest Area Driver Surveys

- Based on rest area surveys of motorists who had recently passed through work zones with and without lights on drums, there was no significant difference in driver-perceived work zone visibility. Nighttime construction activities using balloon lighting on construction equipment significantly increased drivers' perception of visibility, as expected.
- Unexpectedly, in the drums-without-lights condition, drivers reported more details overall and more precise details. In the drums without lights condition, drivers observed and remembered more work zone details, including traffic control devices.

7.1.3 Focus Groups

- Drum spacing was a theme that consistently emerged as a driving challenge in nighttime work zones. For example, focus group participants indicated that drums spaced too far apart made the lanes difficult to discern, especially when they were demarcating ramp exits.
- Drivers did not notice the difference between videos of the same work zone with and without lights on drums. Once the moderator called their attention to the lights, participants indicated that the lights did not convey a specific meaning. A few participants indicated a slight preference toward using them to increase visibility; but many more participants responded that (a) the drums were already highly visible because of the reflective sheeting; (b) that the reflective sheeting overwhelmed the lights; and (c) that as long as the drums used highly reflective materials, the lights were not necessary.
- According to a questionnaire completed by participants regarding the importance of traffic-related items on their nighttime driving behavior in work zones,

drums/cones ranked fifth out of ten items, trailing emergency responders, workers, traffic or vehicles, and lighted signs in importance. This finding could explain the participants' lack of noticing the lights on drums, as they report focusing attention on other, more critical visual cues.

- When asked specifically about three items—information, reflective materials, and lighting—participants in both rural and urban groups indicated that the level of information provided at work zones was too little and that the amount of reflective materials was just enough. Rural drivers felt that the amount of lighting was too little, while urban drivers, who typically drive on roads with overhead lighting, felt that the amount of lighting was just enough. In general, participants expressed a desire for more lighting of nighttime work zones, but this usually referred to high-mast lighting or balloon lighting located in the closed lane.
- When shown pictures of work zones with drums used for channelization devices, participants from all groups indicated that their first action would be to slow down, followed by slowing down and changing lanes, and thirdly, preparing to stop. The work zone traffic control devices gave drivers the message to use caution.
- With respect to the pictures depicting typical work zones, participants expressed a moderate degree of certainty about their behavior when approaching the site. The reasons for uncertainty generally related to comprehension of the visual cues and what actions to take. Participants felt that the use of more signs, including specific information about what was taking place and what they needed to do, could reduce drivers' uncertainty.

7.2 CONCLUSIONS

Work zone driving is cognitively demanding and involves several mental processes, including attention, perception, and memory. Upstream of the work zone, drivers are alerted to the coming event and what actions they need to take, such as slowing down and preparing to change lanes. Approaching the lane-closure taper, drivers need to take action to change lanes, if they have not done so already; and within the work zone, drivers are continuously processing visual cues (for example, traffic control devices, roadway features, other vehicles, and workers and equipment) to make decisions about speed control, spacing between vehicles, and lateral lane position. With literally hundreds of visual cues presented in a matter of minutes in a typical work zone, drivers do not attend to every cue. Instead, their cognitive processes reduce a large amount of information to the few most critical items that determine behavior.

Traffic control devices including signs, changeable message systems, and arrow boards contain critical information (for example, "Road Construction Ahead," "Right Lane Ends," and "Prepare to Stop") for drivers to operate safely in and around work zones. Such devices may contain high attention-getting characteristics, such as flashing lights and lighted text, to gain the driver's attention and actively influence decision making and actions. By contrast, channelization devices, such as drums and barricades, primarily serve as navigational aids and convey very little other information, resulting in a low demand on driver cognitive load. Visibility is their primary characteristic of importance.

Driver feedback from rest area surveys and focus groups indicates that drivers feel the retroreflective prismatic sheeting used on drums in Illinois provides adequate visibility without the need for auxiliary steady-burn lights. Drivers were not able to detect the difference between images of the same work zone with and without lights on drums, and indicated that their certainty and behavior would be no different in either case. This finding is consistent with the field experiments, which showed no significant difference in driving performance indicators, including speed and lateral lane position. In fact, the rest area surveys showed that drivers in the lights-off drums condition actually remembered more details and more precise details about the work zone. This finding indicates that drivers were better able to focus on other important work zone factors in the drums without lights condition. Ultimately, several other factors, including work zone layout, traffic conditions, the presence of workers and equipment, and the presence of other traffic control devices had a much greater effect on driver cognitive processes and behavior than the presence of lights on drums.

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APPENDIX A   COGNITIVE PROCESSES LITERATURE REVIEW

General theories of memory and cognition can help explain why drivers have difficulty seeing and interpreting warning signals at night. In this section of the literature review, we focus on three areas of cognition: attention, perception, and memory. Areas of cognition such as attention and perception occur automatically and without awareness. These processes contribute to higher-order cognition, which requires deliberate focus, such as decision making, problem solving, reasoning, and some elements of memory.

Attention is the lowest level of cognition. Before we pass information into our memory, and even before we perceive objects and process information about these objects in our environment, we need to attend to the objects. Some research suggests that perception can occur without attention (Kimchi and Peterson 2008); however, processing natural scenes requires attention (Cohen, Alvarez, and Nakayama 2011; Silva, Groeger, and Bradshaw 2006; Treisman and Gelade 1980), as does detecting changes in the environment (Rensink, O'Regan, and Clark 1997).

Perceiving a scene and detecting changes are both critical to understanding how drivers interpret items in a roadway. Perception occurs after attention and is the process by which we make sense of the objects in our environment. We must attend to information, process and interpret it, before we can make decisions and take actions. By understanding basic theories of visual perception, attention, and memory, we can better identify the factors that influence drivers and the decisions they may make.

We address the following questions during this literature review:

- What is attention?
  - How does attention help us understand what drivers see when driving?
  - What environmental features (for example, lights, color) capture attention and influence driver behavior?
  - How do drivers' goals or intentions influence where they guide attention (as opposed to instances where drivers attend to objects and then form goals), and why do drivers' goals, memories, and intentions influence attention?
- What is perception?
  - What role does central and peripheral vision play in driving at night?
  - How does perception impact the risk work crews face from drivers at night?
- What is memory?
  - How does memory influence and interact with attention and perception?
  - How does the interaction between memory and these lower-order processes affect driving behavior?
  - How does cognitive load influence driver performance?

A.1 ATTENTION

Attention is sustained mental focus on an object, item, or activity. Attentional mechanisms protect us from too much incoming information from the environment. Information from multiple sensory inputs (e.g., sight and smell) helps to focus attention (Ho and Spence 2009), but only if the sensory inputs are coordinated and meaningful. Because not all inputs are coordinated or meaningful to a given task, we cannot consciously attend to all information (sensory) that is ongoing in our environment. We passively take in information, but we devote attention to the information that is most relevant to our current behavior. Wolfe (2000) described attention as the gatekeeper that allows relevant information in and keeps irrelevant information out. Given these constraints, drivers will not be able to “see” (attend and subsequently perceive) all information available in their visual field.

A.1.1 What Visual Features of Objects Capture Drivers’ Attention?

Visual attention allows us to perceive and recognize objects in our environment. As such, it is generally a precursor to perceptual processes (Wolfe 2000). Basic features of stimuli help select whether we attend to them. For example, color is one feature of objects that directs and prioritizes attention (see, for example, Cave and Pashler 1995). Toet et al. (1998) found that objects must be sufficiently different from their surroundings to capture attention. Objects may be conspicuous because of color, luminosity, distance, or location of information in our visual field.

When an object is a different color from its surroundings, it stand outs and causes people to devote attention to it. Although color might be a feature conspicuous enough to capture attention in some instances, research suggests that a color different from the objects currently grabbing a driver’s attention (for example, a white truck among a set of orange cones) may not necessarily capture attention. It may, in fact, harm a driver’s ability to detect the unexpected object and delay a driver’s reaction to the intrusion.

Some evidence suggests that the ability to quickly detect a stimulus that is a different color from its surroundings may impede a driver’s ability to act accordingly. Most and Astur (2007) studied how well drivers could detect and avoid an unexpected object—in that case a motorcyclist, in a driving simulation. They studied whether drivers’ reaction time and collision rates were different if the motorcycle was the same or a different color as an arrow they were told to attend to and follow. When the arrow and motorcycle were the same color, participants had a collision 7% of the time, whereas when the arrow and motorcycle were mismatched, participants had a 36% collision rate. Participants also took longer to brake in the mismatched condition. This finding is a practical concern for drivers because we all have immediate intentions (for example, looking for a landmark or sign) that can influence our ability to attend to otherwise behaviorally relevant stimuli.

Changes in luminance, or the appearance of brightness, automatically attract attention, regardless of the observer’s goals and intentions (Franconeri, Hollingsworth, and Simons 2005). This information should capture attention immediately because the visual system is so sensitive to changes in luminance.

Distance matters to the extent that the object is inconspicuous. If an object is prominent, it can easily capture attention from far away. However, if the object is relatively inconspicuous, it does not capture attention until one is approaching it closely. Objects capture attention differentially, depending on whether they are in our central or peripheral vision. Information in our peripheral vision grabs our attention more readily than information in our central vision (Posner 1980; Vercera and Rizzo 2003). This phenomenon declines in older drivers because they suffer from reduced peripheral skills (Mestre 2002). As a result, older drivers may be less able to rapidly attend to objects in their peripheral field, reducing their ability to quickly respond to changing elements in a night work zone.

Objects in our central visual field require deliberate attention and, as a result, often require the driver to attend to the objects based on goals, expectations and intentions (Vercera and Rizzo 2003). Our ability to capture attention is meaningless if the visual inputs (or other sensory inputs) are arbitrary. If the objects that capture attention while driving (such as signs or signals) are arbitrary, then drivers have difficulty perceiving and interpreting their meaning (Holmes 1971; Ho and Spence 2009). For example, the sound of a car horn carries meaning (such as watch out, get over, get out of my way!), whereas white noise or pure tones carry little meaning because we generally do not interact with these kinds of sounds regularly (Graham 1999). The same goes for signs: we regularly understand a stop sign, even without the words, because we have attributed meaning to it on a daily basis. However, if the sign is unclear or has little meaning, such as blinking amber lights (without an arrow or some indication the driver needs to take action and move over), drivers may get the sense they should respond to the sign but be unable to interpret a clear meaning from it. This confusion will influence the ability to select the appropriate action to take in response to the object.

A.2 PERCEPTION

Perception is our ability to receive information from our senses and interpret it. In this review, we are largely concerned with visual perception, although the other information we take in from our senses can influence and help to guide visual perception (Ho, Santangelo, and Spence 2009). To receive information and interpret it, we rely on different parts of the eyes to relay information to our brains. Because the focus of this research is on nighttime roadwork, we are primarily interested in understanding vision and visual perception at night.

Our retinas have two general types of photoreceptors: cones and rods. These photoreceptors are able to convert light into signals used by the brain to convey information about the images we see and ultimately help form a visual representation of our world. While someone is driving, peripheral vision is largely responsible for monitoring other vehicles, looking for road signs, and maintaining one's own position in a lane (Mourant and Rockwell 1970). The cones, which are most dense in the center of the retina, are largely active during the day because they are sensitive to high levels of light. At night, the rods are more active because they are sensitive to low levels of light. This means that peripheral vision is more acute at night because rods largely contribute to vision at night. As we switch from day vision to night vision, our visual acuity drops for a number of reasons as this adaptation happens. First, during the adaptation process, our eyes take about 20 to 30 min to adapt properly to night. Although cones adapt quickly, in about 10 min, rods take upwards of 30 min to adapt fully (Lamb and Pugh 2006). Second, because rods are not as good as cones at detecting small details, our visual acuity at night is about two-thirds that of normal daylight acuity (Mestre 2002).

A.2.1 Why Are Work Crews at Risk from Drivers During Night Work?

We rely on external visual cues to help us judge speed. Common items like signs, trees, lights, road edges, and overpasses help us judge how fast other drivers are going and how quickly we may come upon an object on the roadway (Kemeny and Paneri 2003). Such visual cues also help us with simple driving behaviors, such as maneuvering the steering wheel (Karimi and Mann 2008; Wallis et al. 2007). Nighttime or poor driving conditions reduce the visibility of cues, making it more difficult to judge speed and distance. Additionally, drivers have difficulty estimating speed under reduced luminance conditions. Snowden, Stimpton, and Ruddle (1998) found that we tend to overestimate distance to objects when driving at night or in poor conditions. However, they also found that we tend to underestimate our speed, despite the fact that we tend to drive faster as a way to compensate for this misperception (see also, Gegenfurtner, Mayser, and Sharpe 1999).

The lack of cues at night (or in other poor conditions, such as fog and reduced visibility) impedes our ability to judge others' speed (for example, road crews driving along the roadside/in or out of lanes); thus, we tend to increase our own speed. Driving faster than the recommended speed limit narrows our useable visual field, reducing the likelihood that we will detect work crews or construction vehicles moving in and out of roadways (Mestre 2002). One moderator of this effect is driving in urban areas. Speed estimation is generally preserved in urban areas where other cues are present in peripheral vision (Kemeny and Paneri 2003).

Likewise, too much information or clutter on a roadway can also impede our ability to rapidly search for relevant information when driving. In a test of driving performance in a simulator, Ho et al. (2001) investigated how visual clutter, or the nonrelevant information in a visual scene, affected the reaction times and number of errors made by participants. Ho et al. presented participants with photographs of visual scenes they would likely encounter while driving and asked them to search for a specific traffic sign shown briefly before presentation of the scene. Half of the scenes included the target sign and half did not. Participants could identify that the target sign was either present or absent. The researchers found that participants made more errors in high-clutter scenes, especially older adults and at night on target-present trials. Older adults had slower reaction times in high-clutter conditions in night scenes and were especially slow when the target sign was absent. This suggests that a high-clutter environment could be particularly troublesome for older drivers.

Much like attention, top-down processes can influence perception. What we expect to see on a roadway influences our perception of objects as we drive. For example, we may expect to see signs, lights, and objects related to construction. These items are consistent with our schema, or our typical mental representation, of what a roadway looks like. Viewing and perceiving information that is consistent with our schema is easy—because we need little effort to identify this information, we process it faster. Our expectations focus our attention and perception. For example, on a familiar highway, we expect to see the exit sign to our house on the right side of the road. Such signs are easier to perceive and subsequently to act upon because we expect them to be there.

However, unexpected objects, or schema-inconsistent objects, can be present on roadways. For instance, while driving in New Mexico, one of the authors came across a sticklike ball floating across the highway. As an East Coast native, she was unsure how to respond to the object moving toward her. She slowed until she realized this object was a tumbleweed and drove through it gingerly. She had no schema of what to do in this situation because tumbleweeds were inconsistent with her schema of driving.

New construction sites and configurations of emergency response vehicles can be schema-inconsistent for some drivers. By understanding what drivers expect, we can create situations that drivers perceive easily and, thus, are safer for both drivers and night workers.

A.3 MEMORY

Memory is the process by which we encode, store, and retrieve information. The multi-store model of memory (Atkinson and Shiffrin 1968) proposes that memory is made up of multiple stores, each of varying degrees of capacity, permanence, and automaticity. For example, our sensory memory is incredibly brief, automatic, and somewhat larger in capacity (9 to 12 items) but requires attention to pass information to working, or short-term, memory. This store is also brief, somewhat smaller (7 plus or minus 2 items) and requires conscious processing to pass information to our long-term memory store.

Similar to the relationship between attention and perception—that we cannot attend to all information that we sense—we also cannot perceive all information that we attend to, and we cannot remember all information that we perceive. Think of our cognitive systems as a funnel, where only the most relevant information passes through the attention and perception filters. Once information gets to memory, our working, or short-term, memory serves as another filter before information is permanently stored in long-term memory.

Working memory, the short-term memory store, largely does not interfere with attention (Jonides 1981). However, it can interfere with perception. Kang et al. (2011*)* tested undergraduate students to determine whether the information held in visual working memory actually changed their perception of later images. The researchers showed students a set of dots moving in a certain direction and told them to remember the direction the dots were moving. This instruction would ensure that participants held those images in working memory. They then viewed a second display of moving dots and after 2 sec made a judgment about the direction of the second set (a perceptual judgment). Results demonstrated that holding the first motion display in working memory biased their judgments of the second display.

These results demonstrate how working memory can actually bias perception of reality. Images we call to mind while driving are strong enough to affect how we perceive objects in the driving environment, leading to the likelihood that we may miss critical visual cues while driving, if those critical cues were missing from our memory. Despite our best attempts to capture attention and enhance perception, drivers who are thinking about past events or trying to remember information could misperceive the current reality.

A.3.1 Memory Can Actually Interact in Ways That Inhibit Perception

Stokes et al. (2012) found that previous experiences stored in long-term memory influence perception and attention and that it takes little effort to retrieve previous experiences. Previous experiences guide where we devote our attention and perception. For example, we know from information stored in long-term memory that red, blue, and white lights flashing on a vehicle in our rearview mirror means that an emergency vehicle (police or fire) is approaching. When those lights capture our attention and we perceive them, we automatically know what to do (that is, “sirens and lights, move to the right!”). Knowledge stored in our memories, which comprise our schemas and expectations of what those cues mean, prompts this response. Thus, long-term memory guides our attention to capture the lights, helps our perceptual processes to interpret and identify the lights as an emergency vehicle, and allows us take an action based upon that.

A.3.2 How Does Cognitive Load Influence Driver Performance?

Our level of cognitive load affects our memory and attentional processes. Although our long-term memory stores are unlimited, the processes through which information enters our long-term stores are not. The filtering mechanisms of attention and working memory mean that we have a limited number of tasks we can do at one time. For example, if we are trying to maintain our driving and speed, send text messages, and remember that a sign a mile back indicated construction ahead, one of these tasks would likely suffer.

Studies of divided attention show that attending to multiple tasks at once (for example, texting and driving) results in a dramatic increase in accidents (Strayer and Johnston 2001). Lee, Lee, and Boyle (2007) found that the effects of cognitive load and short glances away from the road are additive, such that they have a tendency to increase the likelihood that drivers miss critical events while driving.

Task difficulty itself can induce cognitive load. For example, driving in poor weather conditions could induce cognitive load. It changes a well-practiced, automated task to one that requires conscious and deliberate focus.

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