Illumination and Visibility of Workers in Nighttime Highway Work Zones

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Abstract

Much of the construction work that occurs on high-speed roadways takes place at night to minimize impacts on drivers. Performing work at night exposes workers to hazards that are not present during the daytime such as driver drowsiness, alcohol use, and reduction in visibility. Illuminating the area where work is taking place can provide sufficient lighting for the workers to see their work and help them to be more visible. Depending on various factors such as the amount of light needed and the nature of work operation, different lighting equipment is used for illumination. Mobile lights attached to the construction equipment, portable lights, and personal lights worn by workers are examples that can be used to provide the necessary lighting. The authors performed a survey of current lighting systems and practices in preservation project work zones across the U.S. The impact of two lighting systems including the light tower and balloon light on visibility of the workers was evaluated. The authors examined the visibility of workers at different distances, various locations in regards to the light and with different high visibility apparel. The results of the survey showed that a portable light tower and balloon lights are the most commonly-used types of lighting system in construction work zones. Moreover, workers feel safer when using additional personal light equipment such as a flashlight. The location of the worker on the roadway relative to the light location is a significant factor in the visibility of the worker. Selected lighting strategies are provided to be considered in designing nighttime work zones to improve the visibility of workers and increase safety in highway work zone construction.

INTRODUCTION

Highway construction and maintenance activities often are executed at nighttime to reduce the potential impact a work zone could have on travelling vehicles. Benefits such as decreased material delivery time (Bryden and Mace, 2002), decreased project duration (El-Rayes and Hyari, 2003) and reduced congestion and delay (Shepard and Cottrell, 1985) have been associated with nighttime construction. Although conducting construction activities at night next to the live traffic has its inherent risks such as higher traffic speed, impaired drivers and reduced visibility (El-Rayes and Hyari, 2003). Exposing workers to such an environment increases the potential of an accident that could lead to a crash resulting in an injury or even fatality. On average, 121 highway construction workers are killed in work zones while working every year (CDC 2016). As a result, several safety technologies such as rumble strips, speed enforcement systems, work zone intrusion systems, radar speed signs, and changeable message signs have been introduced to work zone to improve night time construction safety (Gambatese et al., 2017; Jafarnejad et al., 2017). More specific to illumination, reflective clothing, temporary lighting systems, and portable lighting systems have been implemented in work zones to improve worker visibility (Steele et al., 2013). Implementation of additional lighting is expected to reduce the risk exposure of workers and motorists, lead to fewer worker injuries and fatalities in work zones, and improve mobility through work zones. Although researchers have evaluated the impact of glare from light systems on drivers (Odeh et al., 2009) and flagger illumination (Gambatese and Rajendran, 2012), limited research focused on strategic location of temporary lighting systems to optimize worker's safety have been conducted.

RESEARCH NEED AND OBJECTIVE

As the need for highway construction increases due to aging infrastructure, nighttime construction is expected to increase. This required increase will expose construction workers to more hazards associated with nighttime highway construction. Introducing technologies that improve worker visibility in the work zone is considered an effective method for reducing potential accidents. Nevertheless, limited studies have been conducted to document various types of temporary lighting in work zones. In addition, sparse literature exists regarding effective strategies for deploying temporary illumination in work zone. Therefore, the objective of the present study is to document current work area lighting systems and practices in preservation project work zones and identify potential strategies for additional illumination of work zones using available lighting systems.

It is expected that findings from the present study will complement the previous work zone safety and flagger illumination by providing additional knowledge of the performance of light systems in work zones.

METHODS

To achieve the research objectives, a review of existing literatures was conducted to identify and document current temporary lighting systems. Subsequently, a survey of highway construction stakeholders using an online questionnaire was conducted to determine current work zone lighting practice. Finally, temporary work zone lighting systems were evaluated in a controlled situation to determine effectiveness and potential strategies for the future deployment.

LITERATURE REVIEW

Decreased visibility in the work zone is one of the main concerns of nighttime construction which can negatively impact both workers and drivers. Safety in the work zone, quality of work, and the morale of workers are all directly related to work zone lighting (Bryden and Mace, 2002). Illuminating the work area using several lighting systems could have a positive impact on overall project performance (El-Rayes and Hyari, 2003).

Highways sometimes contain existing, permanent lighting to help drivers navigate the roadways. To provide the necessary lighting during nighttime operations, construction crews typically employ light towers, balloon lights, or other types of commercially available lighting systems. Factors such as efficiency, ability to satisfy minimum requirements while controlling glare, availability of power, light trespass, and cost also should be considered when selecting the types of lighting that are best suited for the work zone. Several decision variables such as lighting system selection; light tower positioning; type of luminaire; aiming angle of luminaires; and lamp lumen output influence the development of a work zone lighting plan (El-Rayes and Hyari, 2002). Before designing the lighting plan and creating a layout, the user must choose among different lighting systems-including portable light systems. Portable light systems are extensively used in nighttime operations in different highway projects such as preservation and maintenance projects (Anani, 2015). Portable systems may consist of either ground-mounted or trailer-mounted light towers. There are limited types of portable lighting available for use during nighttime roadway construction, although new technologies and innovations may provide better options in the future. The most commonly used portable lighting systems include those described below.

Portable Light Towers: Portable light towers (also referred to as light plants/light towers) consist of multiple light fixtures (luminaries) installed on a mast arm. In most cases, the mast arm is attached to a trailer with a generator that can be towed by a vehicle. The light fixtures are typically outfitted with four or six of 1,000 or 1,500-watt metal halide bulbs.

Balloon lights: This light consist of luminaires inflated with air or helium that are commonly mounted on portable stands or a vehicle. The illumination emitted by balloon lights could range from 108,000 to 432,000 square feet. Generally, these large balloon luminaires provide uniformly distributed light and are somewhat glare-free.

Nite Lite: This is a dome-shaped luminaire that produces approximately 400-watt. The Nite Lite provides non-glaring, white light from a high-intensity gas-filled lamp ignited by microprocessor-controlled electronics. This system is powered by a 120-volt AC, 60-Hertz and produced an output rated at 42,000 lumens which can illuminate an area of 0.34 acres (1,395 m^2).

Light stands: These are neither balloon lights nor light towers. These types of lighting systems may be used in any work operation, including in the course of flagging operations. Light stands generally have one to two luminaires containing lamps that provide output ranging from 500 to 1,500 watts each.

RESULT AND DISCUSSION

Survey Distribution and Analysis

In order to effectively synthesize information about work zone lighting application, the researchers considered it paramount to aggregate information of work zone lighting use across different state transportation agencies and construction contractors in the US. To achieve this objective, the researchers conducted an online survey in order to improve the chances of a greater geographical spread and response rate. The survey was delineated into three primary categories: personal demographic information, lighting systems used in practice, and additional comments and feedback. The online survey was hosted and administrated through the Qualtrics survey system supported by Oregon State University (http://main.oregonstate.edu/qualtrics). The questionnaire was distributed to highway construction personnel within the Pacific Northwest and to DOT employees across the US.

In total, 305 participants were contacted to participate in the study via email. A total of 67 participants responded to the survey (22% response rate). Although the response rate could be considered relatively low, previous studies on worker safety have recorded lower response rates due to difficulties in reaching construction professionals (Abudayyeh et al., 2006). The 67 participants did not respondent to all questions; however, responses received contained sufficient data to warrant inclusion. Fifty-six percent of the responses received were from general contractors while owner/agencies and subcontractors contributed to 39% and 5% respectively. In total, responses were received from 26 states in the US. Results of the survey indicates that participants had substantial experience in the highway construction industry. Approximately 90% of respondents had over 10 years of experience working on mainly preservation projects.

In order to capture how informed participants are regarding work zone lighting, respondents were asked questions specific to their involvement and knowledge regarding work zone lighting. When asked, “As part of your work responsibilities, are you tasked with determining the type of lighting system(s) to use on projects?”, approximately half (47%) of 58 respondents who answered this question responded “Yes”. Additionally, the respondents were asked about the extent to which they are involved in locating, moving, orienting, adjusting, and/or maintaining work zone lighting systems on projects. Fifty-eight percent of the respondents are either somewhat involved, involved, or very involved with these tasks. Current literature suggest that several lighting systems are used in work zones on different types of projects (Anani, 2015). Participants were asked to indicate which work zone lighting system were used on projects they were/are involved in. Portable light tower/light plant was identified as the most commonly used type of lighting system (96% of respondents) followed by balloon lights attached to a vehicle/equipment (57% of respondents). It is also important to note that contractors generally prefer lighting systems that could be attached to a vehicle or equipment rather than stand-alone lighting systems.

The respondents were asked to provide their perspective on criteria used to select the type of lighting system to use. 15 possible criteria were identified through literature review and informal discussions with industry experts. As seen in Table 1, the amount of light emitted from the lighting system was considered the most important criteria (mean score = 4.60) while the expected life span of the bulb was considered the least important criteria (mean score = 3.02). In addition, the survey explored the potential impact of lighting systems. Table 2 highlights the primary reason respondent implemented lighting systems in work zone. Improving worker safety (mean score = 4.86) was identified as the primary reason while speed of passing vehicle was considered the least (mean score = 3.60).

Table 1. Importance of Selection Criteria

Selection Criteria	(1 = Not important, and 5 = Very important)			
	Mean	**Min.**	**Max.**	**Std. Dev.**
Amount of light emitted (n = 48)	4.60	1	5	0.82
Ability to move/relocate (n = 48)	4.54	2	5	0.77
Ease of operation (n = 48)	4.48	2	5	0.85
Impact of light on passing traffic (n = 47)	4.38	2	5	0.95
Availability (n = 45)	4.33	2	5	0.83
Height to which it can be raised (n = 47)	4.09	2	5	0.93
Size of the system (n = 48)	4.08	1	5	1.01
Amount of maintenance required (n = 48)	3.85	1	5	1.18
Cost (purchase or lease) (n = 47)	3.81	1	5	1.12
Time required to demobilize system (n = 47)	3.68	1	5	1.20
Already own it (n = 39)	3.64	1	5	1.22
Type of light emitted (n = 47)	3.47	1	5	1.14
Ability to change amount of light emitted (n = 47)	3.19	1	5	1.26
Time required for lamps to turn on (n = 47)	3.06	1	5	1.24
Expected lifespan of bulbs (n = 46)	3.02	1	5	1.20

Table 2. Impact of Lighting Systems on Project and Work Performance Criteria

Project and Work Performance Criteria	(1 = No impact, and 5 = Significant impact)			
	Mean	**Min.**	**Max.**	**Std. Dev.**
Worker safety (n = 51)	4.86	4	5	0.35
Work quality (n = 50)	4.56	3	5	0.70
Quality of work zone (n = 50)	4.54	3	5	0.71
Worker productivity (n = 51)	4.43	3	5	0.64
Project costs (n = 51)	3.63	1	5	1.04
Speed of passing vehicles (n = 51)	3.61	1	5	1.25

Controlled Testing Description

Prior to actual field testing, it is essential that equipment is evaluated in a controlled environment to generate useful information that will improve the implementation on actual projects. Therefore, the authors conducted a pilot test in a controlled environment to document the usefulness and limitations of the balloon light and light tower. The selected location provides a stretch of approximately 24 feet wide by 2,000 feet long paved road, containing two lanes, that is predominantly devoid of vehicular and human traffic. The light equipment was placed near the end of the road so that there was enough distance away from the light for observation. Markings were placed on the roadway in the upstream direction at 50, 100, 500, and 1,000 feet away from the light. The markings were used for setting the camera at different distances from the light to capture photos and to compare the visibility of different strategies. Pictures were taken using a Cannon D5200 DSLR camera. The balloon light used for this study was a Sirocco 2000 mounted on a tripod. This is a 110-volt system containing two 1,000-watt halogen lamps surrounded by an envelope (balloon) with a diameter of 3 feet and height of 2 feet. The light tower used for this study was a Genie TML-4000. The tower has four luminaires, each one containing a 1,000-watt metal halide HID lamp. Only two luminaires were turned on to be comparable to the 2000-watt balloon light. Although several tests could be conducted using different variables, the researchers focused on the effect of the selected work zone lights on observation distance and location of light. These two tests were considered sufficient to meet the study objectives.

Visibility of the worker was evaluated with the balloon light, the light tower at 0 degrees offset angle, the light tower at 45 degrees offset angle, and no light equipment present. In all cases, a vehicle was located at the same distance as the observation with its headlights turned on and pointed towards the light. One of the researchers (R1) posed as a worker on the roadway, wearing either the Class 2 vest only, Class 2 vest plus Class E pants, or Class 3 vest only (see Table 3). For each condition, another researcher (R2) took photos of the worker from four different distances away from the light (50, 100, 500 and 1,000 feet). While taking the photos, the car headlights were turned on next to the R2 to simulate the actual working situation on the road when there is a passing vehicle next to the activity area.

Table 3. Light Testing Variables

	Variables considered for pilot testing			
	Light equipment	**Distance away from light (ft)**	**High visibility apparel worn**	**Position of worker on roadway**
Options for each variable	Balloon light	50	Class 2 vest	1
	Light tower, 0° offset angle	100	Class 2 vest + Pants	2
	45° offset angle	500	Class 3 vest	3
	No light	1000		4

In addition to taking photos and observing the worker under different situations, a test grid was marked on the roadway at the light location to measure illuminance in the lighting area. A light meter was used to measure the amount of light for all of the light equipment configurations and outcome measures. The light meter used in the study was an Extech Data logging Light Meter, Model 401036.

Controlled Testing Results

Impact of Distance to the Light

The researchers observed the worker from 50, 100, 500 and 1,000 feet away from the balloon light and light tower to see how well the worker was recognizable at different distances. Photos from every distances were taken while location to the light was varied. Figure 1 shows when the worker (R1) was standing about 20 feet downstream (in the lane adjacent to the light) from the balloon light and light tower while the distance between the motorist (R2) and source of light was 100 feet and 1,000 feet. It can be seen (for both light systems) that while the worker is visible when pictures are taken 100 feet away, it is difficult to ascertain if a person is present 1,000 feet away.

Figure 1. Worker at Different Distances from Light Source
(a) top left, 100 feet Balloon Light; (b) top right, 100 feet Light Tower; (c) bottom left, 1000 feet Balloon Light; (d) bottom right, 1,000 feet Light Tower

Location of Worker Relative to the Light Equipment

Another important variable for visibility of the worker is the location of worker relative to the light. Sometimes just a few feet away from the light could have a big impact on visibility. Based on picture comparison, when the worker is located 20 feet downstream of the balloon light, the worker appears brighter than when located immediately adjacent to the light. This finding was consistent for both light systems.

Following the visibility-based evaluation, the illumination produced by the balloon light and light tower was measured using a light meter. Using a grid system, the illumination was measured when the balloon light and light tower were turned on. Figure 2 shows the levels of illumination recorded throughout the grid. For balloon light, the amount of illumination ranges from 0 fc far from the light to the 28 fc under the light while the light emitted by the light tower ranged from 0 fc to 75 fc. The illumination was recorded three feet above the ground while the researchers faced in the direction of the light (no shading affects). It can be seen that after 30 feet distance from the balloon light, the illumination is less than 1-foot candle which is not enough for any construction work. The illumination emitted by the light tower drops below 1-foot candle beyond 50 feet.

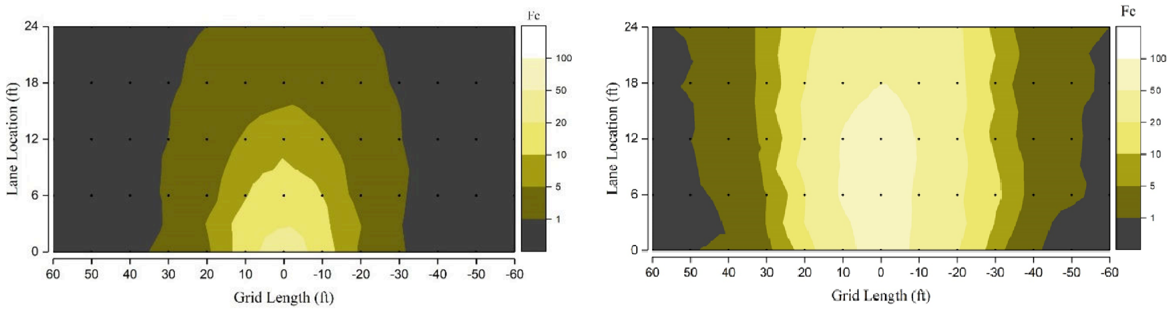

Figure 2. Illumination Intensity, Facing in the Direction of the Balloon Light (fc) (left), Facing Direction of Light Tower 0° offset angle (right)

The amount of the light when the researcher facing in the direction of the oncoming traffic (shading impacts present) is shown in Figure 3. The values in Figure 3 left show the illumination level 10 feet upstream of the light (+10), next to the light (0), and 10 feet downstream of the light (-10). The amount of illumination upstream of the light when facing in the direction of the oncoming traffic was significantly less than the illumination level next to and downstream of the light, and mostly less than 1 fc. The illumination values in this figure are shown at locations downstream of the light. For light tower (Figure 3, right), the amount of illumination at locations upstream of the light when facing in the direction of the oncoming traffic were all less than 1 fc. This value does not represent the amount of reflection the driver can see on the worker with the reflective apparel. Measuring the light reflection requires a luminance meter which was not available for this study.

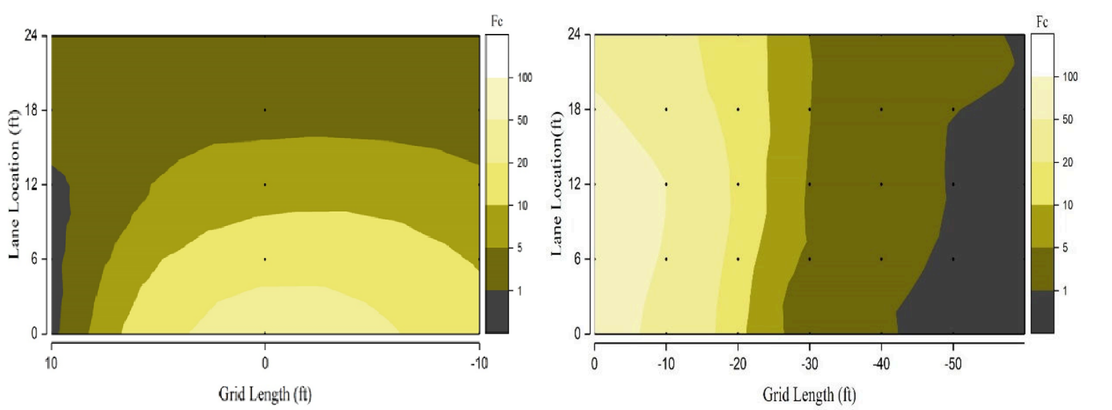

Figure 3. Illumination Intensity, Facing towards the Oncoming Traffic (fc) (Balloon left, Light Tower 0° offset angle right)

In addition, the impact of the light tower on worker visibility was evaluated using two different angles: 0 degree and 45 degree offsets. Although both offset angles provided similar results, when pictures were taken further away from the work zone, 45° offset angle seems to provide better lighting.

Findings from Controlled Testing

The pilot testing results reveal that a worker can be recognized easily from a distance of 50 and 100 feet away from the worker both with and without any additional lighting. From a distance of 500 feet away under the 2,000-watt light tower and the balloon light (other light outputs were not investigated in this paper) with the worker wearing a Class 2 vest and pants, the worker can be recognized. However, from 1,000 feet away or more under similar conditions, it is not very clear that there is a worker present. At the farther distances (1,000 feet and farther) just the light is visible without recognition of anything else present. Considering vehicle stopping distance, having any additional light in the highway work zone can help drivers better recognize workers and react at a safe distance. In addition, the controlled test revealed that balloon lights and light towers illuminate a limited area, approximately 30 feet and 50 feet respectively.

CONCLUSION

The present study set forth to identify and evaluate the impact of work zone lighting systems currently in use on the visibility of construction workers. To achieve this objective, the researchers conducted a review of extant literature, surveyed key project stakeholders, and conducted a pilot test of select lighting systems. Findings from the survey suggests that balloon lights and light towers are predominantly used by contractors. Results from the pilot testing suggests that balloon lights and light towers have the potential to improve worker visibility in actual projects. One main reason for using work zone lighting systems is to help visibility and mobility of vehicles passing through the work zone. To verify the usefulness of the light systems evaluated in the present study, it is essential that these light systems are tested in several actual projects with different configurations. Such a study will inform future guidelines for the implementation of work zone lights as part of speed control mechanism in work zones.

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