FINAL REPORT

Nighttime Construction: Evaluation of Lighting for Highway Construction Operations in Illinois

Project VD-H1, FY 00/01

Report No. ITRC FR 00/01-2

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16. Abstract

This report presents the findings of a research project that investigated lighting design for nighttime highway construction operations. The objectives of the project were (1) to survey work zone lighting practices used in Illinois and other states, (2) to evaluate and recommend design criteria for lighting nighttime construction operations, and (3) to evaluate the performance of selected lighting arrangements for typical construction operations. To achieve these objectives, the research tasks were organized in five major phases: (1) literature review; (2) surveys; (3) evaluation and recommendation of lighting design criteria; (4) field studies; and (5) recommendations for lighting arrangements.

In the first phase of the project, a thorough literature review was conducted to establish baseline knowledge of the latest research and developments in lighting nighttime construction operations. Surveys were conducted in the second phase to investigate current nighttime lighting practices and needs in Illinois and other states. In the third phase, lighting design criteria were evaluated and recommended for nighttime construction operations. The design criteria included requirements for illuminance, uniformity, glare, and light trespass during nighttime construction, and are summarized in a sample lighting specification. Field experiments were conducted in the fourth phase to examine the performance of selected lighting arrangements. In these experiments, a number of practical lighting arrangements were found to satisfy the requirements of the recommended lighting design criteria. The fifth and final phase of the project provides practical recommendations to help nighttime construction personnel in complying with the requirements of the recommended lighting design criteria.

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EXECUTIVE SUMMARY

NIGHTTIME CONSTRUCTION: EVALUATION OF LIGHTING FOR HIGHWAY CONSTRUCTION OPERATIONS IN ILLINOIS

This report presents the findings of a research project, funded under ITRC contract VD-H1, FY00-01, that investigated lighting design for nighttime highway construction operations. The objectives of this project are (1) to survey work zone lighting practices used in Illinois and other states, (2) to evaluate and recommend design criteria for acceptable performance of lighting nighttime construction operations considering construction workers, the traveling public, and adjacent property; and (3) to evaluate the performance of selected lighting arrangements for a variety of typical construction operations. In order to achieve these objectives, the research team conducted research work in five major phases: (1) performing a literature review; (2) conducting surveys of contractors, resident engineers and other state DOTs; (3) evaluating lighting design criteria; (4) conducting field studies to evaluate selected lighting arrangements; and (5) providing practical recommendations for lighting arrangements in nighttime construction.

In the first phase of the project, a literature review was conducted to establish baseline knowledge of the latest research and developments in nighttime lighting for construction operations. Sources of information included textbooks, publications from professional societies, journal articles, on-line databases, and contacts from DOT's. The review of literature focused on the latest developments in roadway lighting, work zone lighting, guidelines for lighting design from governmental agencies and professional societies, and light trespass and pollution.

Surveys were conducted in the second phase of the project, targeting resident engineers, contractors, and state departments of transportation. The survey questions were designed to gather information on nighttime work experiences, advantages and challenges of nighttime construction, lighting design criteria/parameters/procedures, and methods for nighttime lighting inspections. Key findings of the survey include: (1) the utilization of nighttime construction has increased in recent years, as it was reported by participating DOTs that an average of 17% of the total volume of their highway construction projects in 2001 involved work during nighttime hours; (2) the lack of detailed standards/guidelines to regulate lighting design for nighttime construction operations, as only 8 out of the 20 participating DOTs indicated that they had some sort of standards, specifications, or guidelines; (3) the major advantages of nighttime construction were reported to include reduced traffic congestion in daytime, and increased freedom in planning lane closures at night; and (4) the main challenges of lighting nighttime construction were reported to be insufficient lighting, non-uniformity of lighting, and glare to road users.

The third phase of the project was designed to evaluate and recommend lighting design criteria for nighttime construction operations. The recommended criteria were developed by analyzing available standards acquired from a number of sources including professional organizations, state DOTs, and surveyed resident engineers

and contractors. These standards provided a good baseline for the research team to establish lighting criteria for various construction operations common for IDOT operations. Design criteria were developed for (1) lighting levels; (2) lighting uniformity; (3) glare; and (4) light trespass during nighttime highway construction operations. First, lighting level requirements for construction activities are divided into three major categories: (a) low with a recommended lighting level of 54 lux (5 f c); (b) medium with a recommended lighting level of 108 lux (10 fc); and (c) high with a recommended lighting level of 216 lux (20 fc). Low category is recommended for eight major construction activities: earthwork (excavation/embankment/backfill); landscaping (seeding/mulch/sodding/ planting); erosion control (riprap/ditch lining); subgrade; sub base/base courses; shoulders (earth and aggregate); work zone access and materials handling; and work zone setup, take down and revision. The medium category is recommended for fifteen activities: paving bituminous surfaces; rolling bituminous surfaces and pavements; milling and removal; pavement resurfacing; shoulders (bituminous and PCC); paving PCC surfaces; finishing PCC pavements; concrete sawing; bridge construction and maintenance; culverts and sewers; drainage structures; guardrail and fences; highway signing; pavement marking (stripping/markers); and work zone flagger station. The high category is recommended for four activities: electrical wiring and cables; electrical poles and posts (lighting and traffic signals); pavement patching; and crack and joint sealing. Second, a maximum lighting uniformity ratio of 6 is recommended for lighting nighttime construction sites (calculated as an average to minimum lighting level in the work zone). Third, glare is recommended to be controlled on and around construction sites using the ratio of maximum veiling luminance to average pavement luminance. Fourth, light trespass can be controlled using a maximum allowed vertical illuminance, measured at the edge of property at an appropriate height that corresponds to the level of an observer's eye at possible viewing locations. The recommended vertical illuminance limits in this report depend on the location of work zone and the time of night, and conform to those recently recommended by IESNA for controlling light trespass.

Field tests were conducted in the fourth phase of this project to evaluate the performance of selected lighting arrangements for a variety of typical nighttime construction operations. The experiments were designed to examine the performance of selected lighting arrangements, which utilize commonly used lighting equipment, in satisfying the recommended lighting design criteria. The field tests were conducted to evaluate the performance of four major types of lighting arrangements, namely: (1) fixed lighting arrangements; (2) mobile lighting arrangements; (3) flagger station arrangements; and (4) transition zone arrangements. In these tests, a number of practical lighting arrangements were examined and found to satisfy the requirements of the recommended lighting design criteria for typical work zone configurations. The field experiments confirmed the adequacy of recommended levels of lighting for typical construction operations. Also, the conducted tests illustrated that the recommended design criteria were attainable using commonly used lighting equipment, which ensure practicality of the developed criteria.

The fifth and last phase of the project provides practical recommendations to help nighttime construction personnel in complying with the requirements of the recommended lighting design criteria. These practical recommendations are provided for: (1) fixed lighting arrangements; (2) mobile lighting arrangements; (3) glare control measures; and (4) selection of lighting equipment. Key findings of this phase include: (1) high pressure sodium and metal halide lamps are the most widely used types of lamps in nighttime construction operations, but metal halide lamps provide better visibility in outdoor environment and improved peripheral vision; (2) temporary lighting arrangements can be provided in the form of fixed lighting arrangements and/or mobile lighting systems. Factors that should be considered in selecting lighting arrangements include: work zone size and layout, required mobility, duration of work, required illuminance level, existing lighting, cost, and power requirements; and (3) three measures can be utilized to control glare during nighttime construction operations including: selection of lighting sources that minimize glare on site, proper design and arrangement of lighting equipment, and utilizing glare control hardware.

The findings of the above five phases were used to develop a sample specification of lighting for nighttime highway construction operations. This sample specification provides technical requirements for lighting levels, uniformity, glare control, and light trespass for nighttime construction operations. The sample specification can be found in Appendix A.

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INTRODUCTION

1.1 Nighttime Construction

Highway construction and repair projects often alter and/or close existing roads during construction operations, resulting in traffic congestions and delays to the traveling public. In order to alleviate these adverse effects of construction operations, an increasing number of highway construction and repair projects throughout the United States are being performed during off-peak nighttime hours (El-Rayes and Hyari 2003; Bryden and Mace 2002; and El-Rayes and Hyari 2002).

The use of nighttime operations in highway construction and repair projects is reported to provide many advantages including: (1) reduced traffic congestion and motorist delay (Shepard and Cottrell 1985); (2) minimized adverse economic impacts of traffic congestion on local commerce particularly for shipping and delivery services (Bryden and Mace 2002); (3) decreased pollution from idling vehicles stopped at construction site (McCall 1999); (4) improved work-zone conditions as the smaller amount of traffic at night creates an opportunity to enlarge work zones allowing the concurrent performance of multiple tasks (Shepard and Cottrell 1985); (5) longer working hours at night (Shepard and Cottrell 1985); (6) enhanced work conditions during hot construction seasons due to lower temperatures experienced at night (Shepard and Cottrell 1985); and (7) faster delivery of material to and from the work zone since traffic conditions are better at night, leading to less idle time for both labor and equipment (Price 1986).

Despite the above advantages, nighttime construction is often confronted with a number of challenges including: (1) decreased levels of safety for both workers and motorists due to inadequate lighting conditions and higher levels of glare during nighttime hours (Shepard and Cottrell 1985; Hancher and Taylor 2001); (2) reduced construction quality and productivity due to insufficient lighting conditions on site (Shepard and Cottrell 1985); (3) increased cost of nighttime operations due to artificial lighting arrangements, labor premiums and overtime, and additional traffic control devices (Hinze and Carlisle 1990); (4) adverse impact on neighboring environments due to light trespass and construction noise problems resulting from nighttime work (Shepard and Cottrell 1985); (5) increased levels of hazards at night due to drivers with insufficient sleep, vision problems, and/or alcohol/drug impairment (Shepard and Cottrell 1985); and (6) difficulties in material delivery, utility services and urgent equipment repairs due to the difference in working hours between the project and these service providers (Shepard and Cottrell 1985).

1.2 Problem Statement

In order to overcome many of the previously noted challenges, proper and adequate lighting arrangements need to be provided on nighttime construction sites. Insufficient lighting contributes to an increase in worker injury rates (California Department of Transportation 1988), and adversely affects work quality (Hinze and Carlisle 1990). Excessive and improper lighting arrangements can cause glare for drivers on the road and/or equipment operators in the work zone. Nighttime drivers passing near a nighttime construction zone may find difficulty adjusting to the extreme changes in lighting level when they travel from a relatively dark roadway environment to a bright lighting condition in the work zone. Similarly, the vision of equipment operators in the work zone may be impaired by bright and direct lighting sources. Furthermore, improper lighting arrangements in urban areas can lead to light trespass to adjoining properties, causing nuisance to the property owners and leading to unnecessary waste of energy.

These vision impairments associated with nighttime construction often lead to injuries and fatalities to drivers and construction workers. In order to fully realize the benefits of nighttime construction and minimize its adverse effects on work safety, research is needed to (1) evaluate and recommend design criteria for an acceptable level of lighting for nighttime construction operations; and (2) evaluate the impact of selected lighting arrangements to ensure that the recommended design criteria is practical and can be implemented on nighttime construction sites.

1.3 Research Objectives

The objectives of this study are:

(1) To survey the types of work zone lighting practices currently being used in Illinois and other states.

(2) To evaluate and recommend design criteria for acceptable performance of lighting nighttime construction operations considering construction workers, the traveling public, and adjacent property.

(3) To evaluate the performance of selected lighting arrangements (both mobile and fixed) for a variety of typical construction operations.

1.4 Research Methodology

A research team led by researchers from the University of Illinois at Urbana-Champaign and Bradley University jointly investigated the effects of lighting conditions and their impact on construction workers and the traveling public. The team conducted a review of the literature to establish baseline knowledge of existing research in lighting nighttime construction operations. In addition, the team visited several nighttime construction sites in Illinois. These visits were followed by conducting surveys in order to identify current practices in Illinois, safety concerns, and lighting problems in nighttime construction operations. The surveys were conducted to gather knowledge from resident engineers, contractors with experience in nighttime operations, and state departments of transportation. The knowledge gathered from the literature, surveys, site visits and field tests were used to develop and refine practical design criteria for lighting nighttime construction operations. The practicality of these criteria was tested using field studies that examined the performance of selected lighting arrangements (both mobile and fixed) for a variety of work zone layouts. Recommendations for lighting arrangement in nighttime operations, including fixed locations and mobile operations, were presented based on the knowledge acquired from the previous phases of the research.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

An extensive literature review was conducted to gather the latest research and practices in lighting nighttime construction operations. This chapter provides a summary of the collected information and organizes the literature review results in four major sections: (1) roadway lighting design; (2) work zone lighting design; (3) government agency practices for work zone lighting; and (4) light trespass and light pollution.

2.2 Roadway Lighting Design

This section provides a general discussion on lighting design for roadways. It should be noted that the requirements for roadway lighting design might differ from those for work zone lighting. For example, roadway lighting focuses on vehicular and pedestrian traffic, while work zone lighting focuses on workers safety and the quality of work. Despite this difference, this section provides a review of current practices in roadway lighting design due to: (1) similarity in design criteria, parameters, and designers concerns in both roadway and work zone lighting design, and (2) the availability of established design practices in roadway lighting and the lack of such practice in work zone lighting. This section focuses on the following main topics in roadway lighting design: (1) design criteria; (2) design parameters; and (3) design procedures.

2.2.1 Design Criteria

The purpose of designing roadway lighting is to satisfy a number of design criteria including: (1) illuminance; (2) luminance; (3) glare; (4) visibility; (5) uniformity; and (6) quality. The following sections provide a brief description of each of these criteria.

2.2.1.1 Illuminance

Illuminance can be defined as the density of luminous flux (time rate of flow of light measured in lumens (lm)) incident on a certain surface measured in foot-candles (fc) or lux (Kaufman 1981). This is an important criterion of the lighting design since it represents the quantity of roadway lighting and significantly affects other lighting criteria (e.g. luminance).

2.2.1.2 Pavement Luminance

Luminance can be defined as a "quantitative measure of brightness" measured in candelas per square meter or foot lamberts (Triaster 1982). Pavement luminance depends on several factors including: (1) quantity of light reaching the pavement; (2) reflection characteristics of the pavement; (3) relative angle of incidence; and (4) location of the observer. According to the Illumination Engineers Society of North America (IESNA 2000), pavements can be classified into four categories (i.e. R1 to R4) according to their reflectance characteristics as shown in Table 2.1. This classification will be used later for the development of specific requirements for the design of lighting systems for each type of pavement.

Table 2.1. Pavement Categories and their Characteristics (IESNA 2000).

Class	Description	Mode of Reflectance
R1	Portland cement concrete road surface. Asphalt road surface with a minimum of 15 percent of the artificial brightner (e.g. Synopal) aggregate (e.g., labradorite, quartzite).	Mostly diffuse
R2	Asphalt road surface with an aggregate composed of a minimum 60 percent gravel (size greater than 10 millimeters).	Mixed (diffuse and specular)
R3	Asphalt road surface (regular and carpet seal) with dark aggregates (e.g., trap rock, blast furnace slag); rough texture after some months of use (typical highways).	Slightly specular
R4	Asphalt road with very smooth texture.	Mostly specular

2.2.1.3 Glare

Glare is a term used to describe the sensation of annoyance, discomfort or loss of visual performance and visibility produced by experiencing luminance in the visual field significantly greater than that to which the eyes of the observer are adapted (Triaster 1982). Glare can be classified into two types, disability glare and discomfort glare. Disability glare (also known as veiling luminance) can be defined as "a luminance superimposed on a retinal image, which reduces its contrast. It is this veiling effect produced by bright sources, or areas in the visual field, that result in decreased visual performance and visibility" (Kaufman 1981).

Discomfort glare is defined as "glare which causes visual discomfort without necessarily impairing the vision" (Pritchard 1995). Unlike disability glare, the mechanism of discomfort glare is not very well understood. However, some laboratory studies were able to obtain a measure of the threshold value of luminance that causes discomfort based on the luminance of the background. Two separate studies produced the following two formulas for this threshold value (Kaufman 1981):

$$BCD = 302\ F^{0.44} \tag{2.1}$$

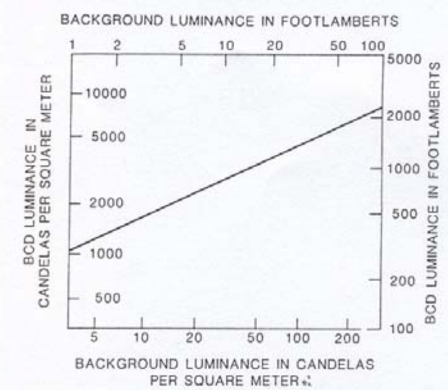
$$BCD = 529\ F^{0.44} \tag{2.2}$$

Where:

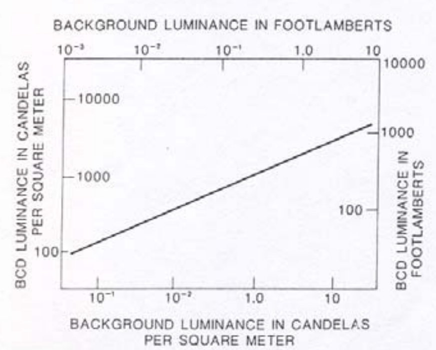
BCD = "border between comfort and discomfort" and is also referred to as L_b;

F = luminance of the background.

The plot of these two formulas is shown in Figure 2.1 (Kaufman 1981).



The luminance of a glare source at discomfort threshold (BCD) as a function of the background luminance (light to which the eyes are adapted) – moderate background luminances. $L_b = 302\ F^{0.44}$.



The luminance of a glare source at discomfort threshold (BCD) as a function of the background luminance (light to which the eyes are adapted)—low luminance backgrounds. $L_b = 529\ F^{0.44}$.

Figure 2.1. Plots of Border between Comfort and Discomfort (BCD).

2.2.1.4 Visibility

Visibility is often considered to be a more valid criterion for roadway lighting design than luminance and Illuminance (Janoff 1989). This is mainly due to the findings of research studies that indicated the existence of a correlation between visibility and both nighttime safety and human visual performance, and the inability to establish such a correlation between luminance or illuminance and these factors (Janoff 1989). Despite its significance, no research has been directed towards overcoming the difficulty of measuring visibility (Ellis et al. 1995). Currently there are a limited number of devices to measure visibility in controlled environments such as laboratories, all of which are based on reducing the illuminance of the scene until a predetermined object called the critical detail, can barely be seen (Kaufman and Christensen 1987).

A quantitative measure of Visibility is the Visibility Index, which is calculated by Equation (2.3) (Janoff 1989):

$$VI = C \times RCS \times DGF \tag{2.3}$$

Where:

C = physical contrast;

RCS = relative contrast sensitivity; and

DGF = disability glare factor.

Visibility is also an important criterion in roadway lighting design because humans use luminance contrast to distinguish between the target object and the background. As such visibility is affected by both glare and contrast sensitivity (Janoff 1989).

Contrast sensitivity is “the ability to detect luminance difference”, while contrast can be defined as “the relationship between luminance of an object and its immediate background” and it is given by the following equation (Kaufman 1981):

$$\text{Contrast} = \left| (L_o - L_i)/L_i \right| \tag{2.4}$$

Where:

L_o = luminance of the object; and

L_i = luminance of the background.

2.2.1.5 Lighting Uniformity

Lighting Uniformity is a design criterion that identifies how evenly light reaches the different parts of the target area. This parameter is measured as a ratio between the average or maximum and the minimum illuminance levels in the lighted area.

2.2.1.6 Lighting Quality

Another criterion of lighting design is the quality of light, which represents the ability of people to identify contrast differences, and enables them to detect objects quickly, accurately and comfortably. Quality of lighting is dependent on all the previously mentioned parameters, while the overall quality is achieved by tradeoffs among these parameters (Kaufman and Christensen 1987).

2.2.2 Design Parameters

The main parameters in designing roadway lighting include: (1) luminaire selection; (2) luminaire mounting height; (3) luminaire spacing; (4) lighting termination; and (5) lighting system depreciation (Kaufman and Christensen 1987). The following sections provide a brief explanation of each of these parameters.

2.2.2.1 Luminaire Selection

In the process of luminaire selection, the designer selects the type of lamp and its distribution characteristics. The main types of lamps commonly used for roadway lighting include the following main groups: (1) mercury vapor lamps; (2) metal halide lamps; (3) high-pressure sodium vapor lamps; (4) low-pressure sodium vapor lamps (Homburger and Kell 1988). Mercury lamps are characterized by a blue-white color, and are available with phosphor-coated outer bulb having higher output and more pleasing color rendition. Metal halide lamps are a special type of mercury lamps in which the arc tube contains mercury and certain metal halides that improve the efficacy and color rendition. Low-pressure sodium vapor lamps are characterized by a monochromatic bright yellow color light output, a high efficacy, and an outstandingly low lamp lumen depreciation, however they provide poor color rendition. High-pressure sodium lamps are characterized by a golden-white color light output and they are presently replacing mercury lamps. Each of these four main groups of lamps is associated with different characteristics including: (1) lamp life (hr); (2) efficacy (lm/Watt); and (3) light output (lm) (Homburger and Kell 1988). Table 2.2 shows some of these lamp types and their characteristics.

Table 2.2. Roadway Lighting Lamp Characteristics (Homburger and Kell 1988)

Type of Lamp	Initial Light Output (lm x 10^3)	Approximate Efficacy (lm/W)	Approximate lamp life (hr x 10^3)
Phosphor-coated Mercury	4.0 – 63	40 – 63	18 – 28
Metal Halide	34 – 100	85 – 100	10 – 15
High Pressure Sodium	9.5 – 140	95 – 140	15 – 28
Low Pressure Sodium	1.8 - 33	100 – 183	10 – 18

The other aspect of luminaire selection is the distribution characteristics. Lighting distribution of luminaires is controlled by the following three factors: (1) vertical distribution; (2) lateral distribution; and (3) control of light distribution above maximum candle power. The vertical distribution of luminaires can be classified into short, medium and long distribution luminaires (Kaufman and Christensen 1987).

Selection of the luminaire should satisfy the required lateral distribution for the roadway being designed. Luminaires can be classified into five types as shown in Figure 2.2.

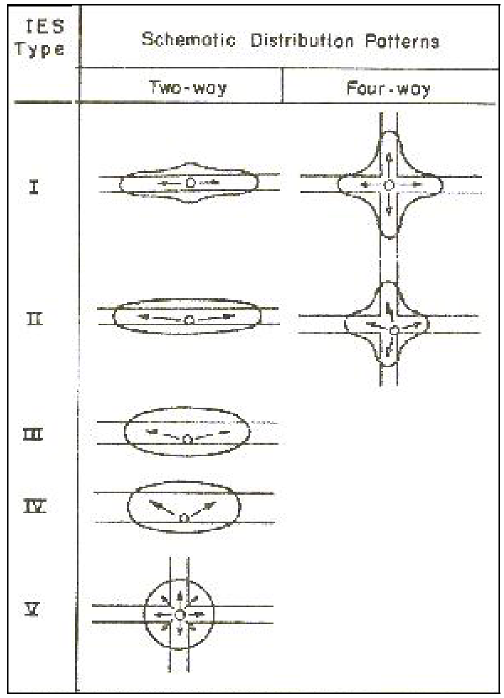


Figure 2.2. Lateral Light Distribution (Homburger and Kell 1988).

The final parameter in lighting distribution that needs to be controlled is distribution above maximum candle power (cutoff). In controlling this factor, the designer must consider the conflicting goals of maximizing pavement luminance and controlling disability glare. These two objectives often conflict since the increase of light emission angles leads to a favorable increase in pavement brightness, and unfavorable increase in both disability and discomfort glare (Homburger and Kell 1988). In order to control glare and light trespass, luminaires can be classified into cutoff, semi-cutoff and non-cutoff as shown in Figure 2.3 and Table 2.3 (Homburger and Kell 1988).

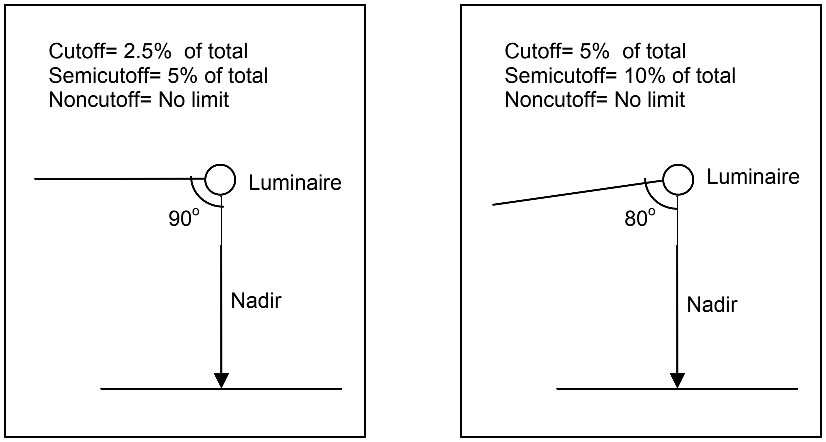


Figure 2.3. Permissible Amount of Light in Upper Portion of Luminaire Beam.

Table 2.3. Light Control in Upper Portion of Luminaire Beams
(Homburger and Kell 1988)

Cutoff Category	Candlepower at 90° above nadir	Candle power at 80° above nadir
Cutoff	2.5% of total	10.0% of total
Semicutoff	5.0% of total	20.0% of total
Noncutoff	No limit	No limit

2.2.2.2 Luminaire Mounting Height

The mounting height (MH) of the luminaire is another important parameter in designing roadway lighting. In general, increasing the mounting height of luminaires may decrease discomfort and disability glare, since it increases the angle between the luminaire and the line of sight. This plays a major role in designing the mounting height, which is also dependent on the luminaire vertical distribution (i.e. long, medium, and short distributions). IESNA specifies the minimum mounting heights for different types of luminaires to control disability glare as shown in Figure 2.4 (Kaufman and Christensen 1987).

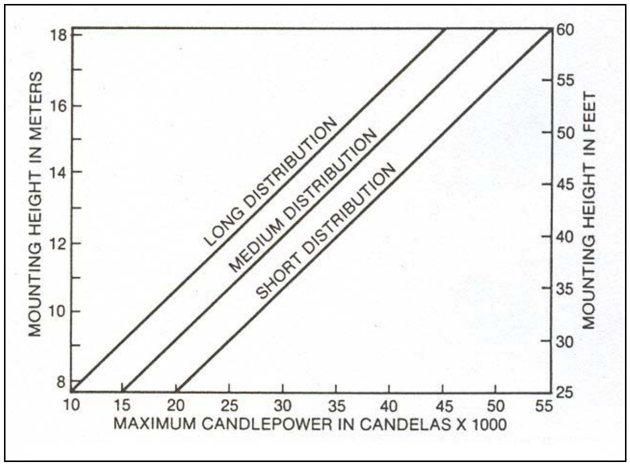


Figure 2.4. Minimum Mounting Heights for Different Types of Luminaires (Kaufman and Christensen 1987).

2.2.2.3 Luminaire Spacing

Spacing between luminaires is dependent on the vertical distribution of the luminaire and its mounting height as shown in Figure 2.5. In general, it is more economical and desirable to use high candle power luminaires to satisfy luminance levels and uniformity requirements at a greater spacing (Kaufman and Christensen 1987).

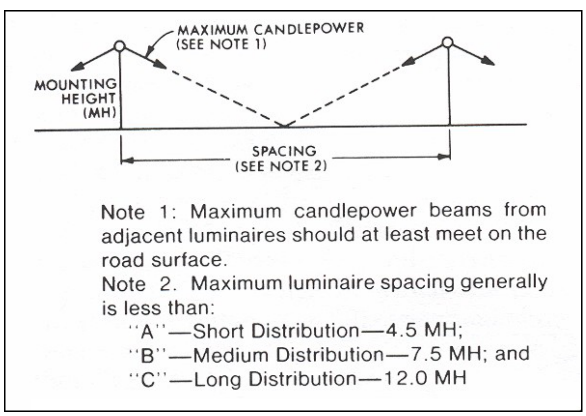


Figure 2.5. Vertical Light Distribution (Kaufman and Christensen 1987).

2.2.2.4 Lighting Termination

Lighting termination/transition is a gradual reduction or increase in levels of lighting before entering/exiting lighted areas to make the change of lighting levels smooth for the road user. This decreases the discomfort of sudden changes in the levels of illuminance. Transition lighting should be considered in the following conditions: (1) sudden and big changes in roadway cross section; (2) severe changes in the roadway alignment; and/or (3) entering or leaving from an area with relatively high lighting levels (Kaufman and Christensen 1987).

2.2.2.5 Lighting System Depreciation

The lumen output of lamps depreciates as a function of the age of the lamps and the accumulation of dirt on the luminaire. The Light Loss Factor (LLF) is a product of Lamp Lumen Depreciation (LLD) and Lumen Dirt Depreciation (LDD) factors. The average for LLD is 0.85, while LDD can vary between 0.7and 0.85 depending on the atmosphere, the amount of dirt reaching the luminaire, and the degree of maintenance of the luminaire (Homburger and Kell 1988). Replacing the lamps before the end of their rated life and cleaning the luminaires is necessary to maintain the originally intended illumination levels for the roadway (IESNA 1993). Lamp voltage is another factor that affects the operation of the lighting system. A decrease in voltage from the standard reduces the light output, while an increase in voltage improves the light output, but shortens lamp life (IESNA 1993).

Another non-design factor affecting lighting performance with time is the pavement surface condition. Pavement luminance increases with time for asphalt pavements due to the exposure of aggregates, while it decreases for Portland cement concrete due to the increase of Carbon deposits (Kaufman and Christensen 1987).

2.2.3 Design Procedures

In order to satisfy the aforementioned lighting design criteria, three main design procedures have been developed for roadway lighting design: (1) pavement luminance and veiling luminance (glare), (2) illuminance, and (3) small target visibility. Currently, the Illuminating Engineering Society of North America (IESNA) recommends that the designer choose the procedure that meets the needs of the particular situation and design constraints. However, meeting the requirements of two or all of the three design procedures is preferred (IESNA 2000). The first procedure provides a better correlation for the visual impression of the quality of roadway lighting design than the illuminance. It also quantifies the disability glare from the whole lighting system, while illuminance considers only the amount of luminous flux above a certain angle (for an individual liminaire) as the criterion for controlling glare (Kaufman and Christensen 1987). However, illuminance has been modified and is still being used because it is the only available tool to design for high mast lighting, and because of the relative ease of measurement of illuminance compared to luminance. Small target visibility is a new procedure that was developed to improve motorist’s safety, and incorporates recent studies of human visual processes (IESNA 2000).

2.2.3.1 Pavement Luminance and Veiling Luminance (Glare) Requirements

This procedure for roadway lighting design is based on pavement luminance and glare. The luminance levels recommended by IESNA for different road and area classifications that should be maintained in the design to control veiling luminance (glare) are displayed in Table 2.4 (IESNA 2000). It should be mentioned that the recommended luminance levels would not be considered satisfactory unless the uniformity ratios and veiling luminance ratios have been satisfied (Kaufman and Christensen 1987).

The design procedure starts with classifying the roadway type, the area surrounding it, and the pavement type as shown in Figure 2.6. The requirements for the levels of luminance and luminance uniformity are then determined from Table 2.4. After that, tentative luminaire types, light sources, mounting height, and lateral luminaire positions are selected. The lighting calculations are then performed to verify that the selected parameters meet the design criteria. If the initial parameters do not meet the criteria, they are modified and the process is repeated until the parameters that satisfy the criteria are found. After this, the luminaire spacing is determined (Kaufman and Christensen 1987).

Table 2.4. Luminance Levels and Uniformity Ratios for Pavement Luminance Design Procedure (IESNA 2000).

Road and Area Classification		Average Luminance L_{avg} (Cd/m^2)	Uniformity Ratio		Veiling Luminance Ratio (L_{vmax} to L_{avg}) Maximum Allowed
Road	**Pedestrian Conflict Area**		**L_{avg} to L_{min} Maximum Allowed**	**L_{max} to L_{min} Maximum Allowed**	
Freeway Class A		0.6	3.5 to 1	6 to 1	0.3 to 1
Freeway Class B		0.4	3.5 to 1	6 to 1	0.3 to 1
Expressway	High	1.0	3 to 1	5 to 1	0.3 to 1
	Medium	0.8	3 to 1	5 to 1	
	Low	0.6	3.5 to 1	6 to 1	
Major	High	1.2	3 to 1	5 to 1	0.3 to 1
	Medium	0.9	3 to 1	5 to 1	
	Low	0.6	3.5 to 1	6 to 1	
Collector	High	0.8	3 to 1	5 to 1	0.4 to 1
	Medium	0.6	3.5 to 1	6 to 1	
	Low	0.4	4 to 1	8 to 1	
Local	High	0.6	6 to 1	10 to 1	0.4 to 1
	Medium	0.5	6 to 1	10 to 1	
	Low	0.3	6 to 1	10 to 1	

L_{avg}= Average Pavement Luminance
L_{min}= Minimum Luminance
L_{max}= Maximum Luminance
L_{vmax} = Maximum Veiling Luminance

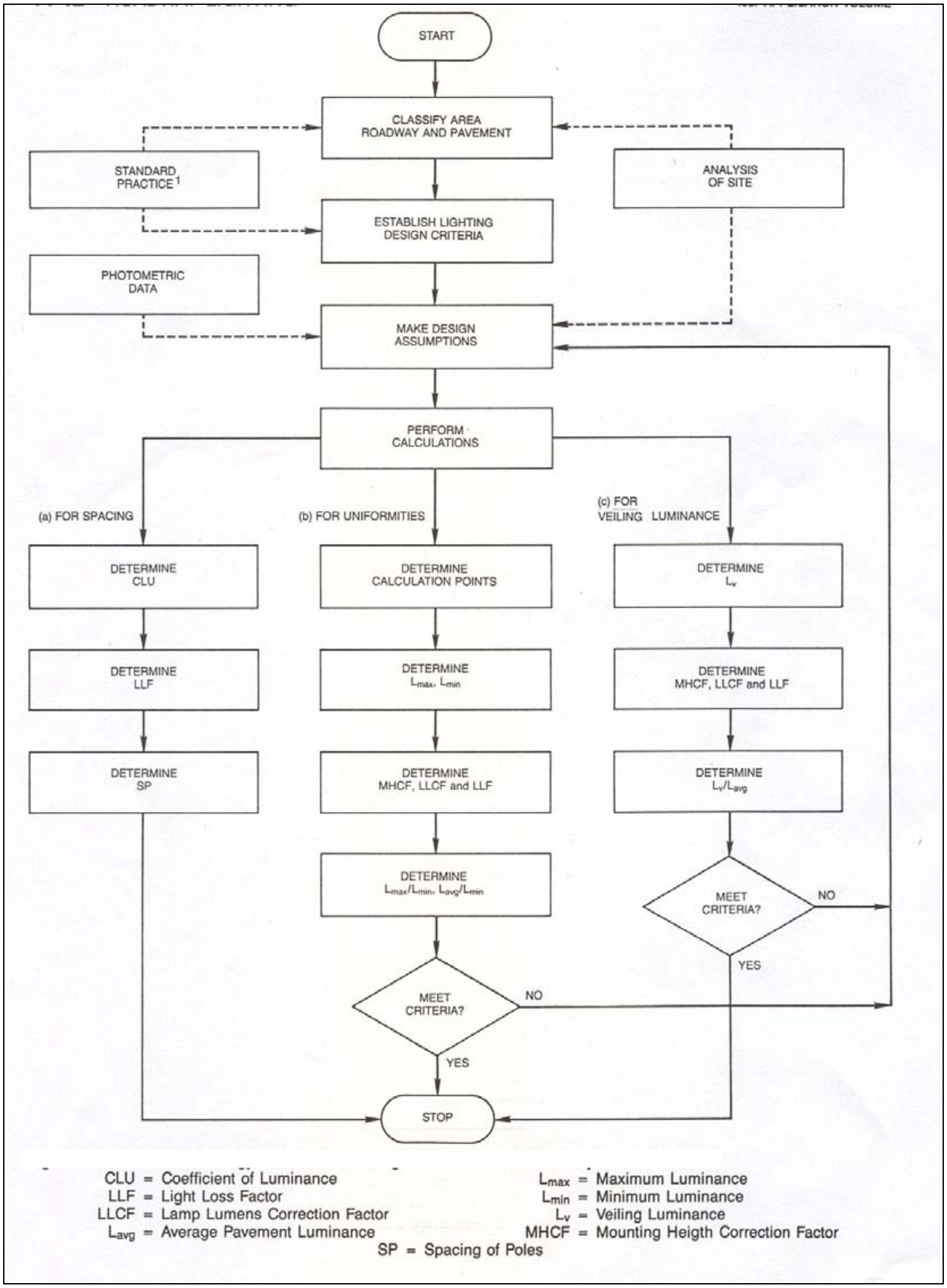


Figure 2.6. Procedure of Roadway Lighting Design with Pavement Luminance Criteria (Kaufman and Christensen 1987).

2.2.3.2 Horizontal Illuminance Criteria

Although horizontal illuminance requirements are the oldest design requirements for roadway lighting, it is still applicable if applied with good engineering judgment. Since the 1980's, luminance criteria have become the main criteria for roadway design, even though illuminance criteria are still the only criteria for the design of high mast lighting (Kaufman and Christensen 1987).

Due to the ease of illuminance measurement, the illuminance requirements for lighting design have been modified to satisfy the pavement luminance requirements. This was done by establishing recommended illuminance levels for each type of pavement, as explained earlier, depending on its reflectance characteristics as shown in Table 2.5 (Kaufman and Christensen 1987). The veiling luminance ratios used in the pavement luminance procedure must also be determined to avoid disability glare from the lighting system (IESNA 2000).

The horizontal illuminance design procedure is similar to the pavement luminance and veiling luminance design procedure. The only difference is that in the horizontal illuminance procedure, the criteria that should be satisfied are illuminance (in terms of average horizontal illuminance), and illuminance uniformity. The steps for roadway lighting using horizontal illuminance requirement are shown in Figure 2.7.

Table 2.5. Recommended Average Illuminance Levels for Different Types of Pavements (IESNA 2000).

Road and Pedestrian Conflict Area		**Pavement Classification (Minimum Average Values)**			**Illuminance Uniformity Ratio E_{avg} to E_{min}**	**Veiling Luminance Ratio Lvmax/Lavg**
Road	Pedestrian Conflict Area	R1 Lux/Fc	R2 & R3 Lux/Fc	R4 Lux/Fc		
Freeway Class A		6.0/0.6	9.0/0.9	8.0/0.8	3.0	0.3
Freeway Class B		4.0/0.4	6.0/0.6	5.0/0.5	3.0	0.3
Expressway	High	10.0/1.0	14.0/1.4	13.0/1.3	3.0	0.3
	Medium	8.0/0.8	12.0/1.2	10.0/1.0	3.0	0.3
	Low	6.0/0.6	9.0/0.9	8.0/0.8	3.0	0.3
Major	High	12.0/1.2	17.0/1.7	15.0/1.5	3.0	0.3
	Medium	9.0/0.9	13.0/1.3	11.0/1.1	3.0	0.3
	Low	6.0/0.6	9.0/0.9	8.0/0.8	3.0	0.3
Collector	High	8.0/0.8	12.0/1.2	10.0/1.0	4.0	0.4
	Medium	6.0/0.6	9.0/0.9	8.0/0.8	4.0	0.4
	Low	4.0/0.4	6.0/0.6	5.0/0.5	4.0	0.4
Local	High	6.0/0.6	9.0/0.9	8.0/0.8	6.0	0.4
	Medium	5.0/0.4	7.0/0.7	6.0/0.6	6.0	0.4
	Low	3.0/0.3	4.0/0.4	4.0/0.4	6.0	0.4

2.2.3.3 Small Target Visibility

This procedure introduces visibility criteria in roadway lighting design through determining the visibility of an array of targets on the roadway based on the following factors: (1) luminance of the object, (2) luminance of the immediate background, (3) adaptation level of the adjacent surroundings, and (4) disability glare (IESNA 2000). The small target visibility (STV) is the weighted average of the visibility levels of an array of targets on the roadway, taking into consideration the veiling luminance ratio.

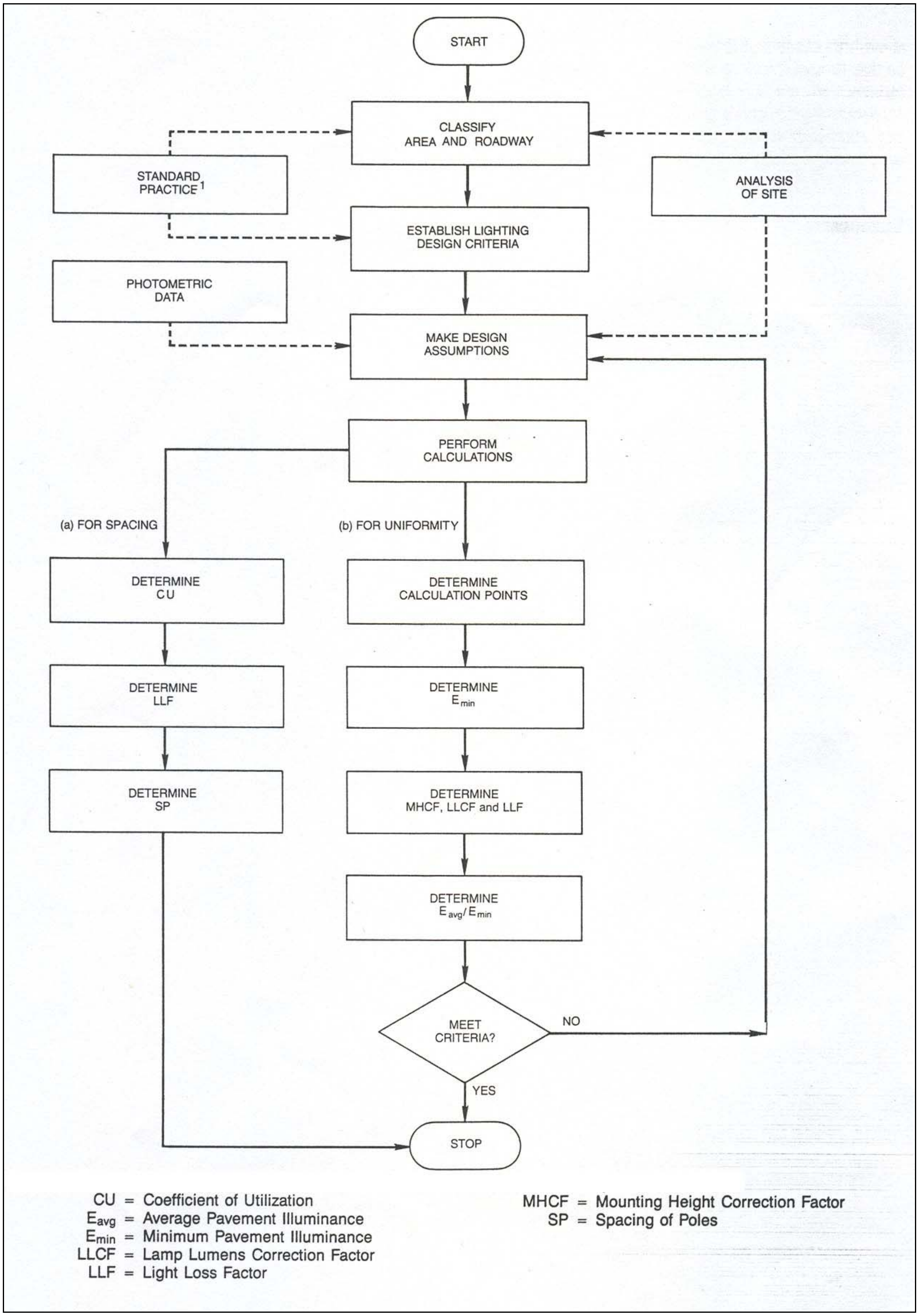


Figure 2.7. Procedure of Roadway Lighting Design with Horizontal Illuminance Requirements (Kaufman and Christensen 1987).

The recommended values for STV, luminance, and uniformity for different road and area classifications that should be maintained in the design are shown in Table 2.6.

Table 2.6. Small Target Visibility – Recommended Values (IESNA 2000)

Road and Pedestrian Conflict Area		**STV Criteria**	**Luminance Criteria**		
Road	Pedestrian Conflict Area	Weighting Average VL	L_{avg} cd/m² (Median <7.3 m)	L_{avg} cd/m² (Median >7.3 m)	Uniformity Ratio L_{max}/L_{min} Maximum Allowed
Freeway "A"		3.2	0.5	0.4	6.0
Freeway "B"		2.6	0.4	0.3	6.0
Expressway		3.8	0.5	0.4	6.0
Major	High	4.9	1.0	0.8	6.0
	Medium	4.0	0.8	0.7	6.0
	Low	3.2	0.6	0.6	6.0
Collector	High	3.8	0.6	0.5	6.0
	Medium	3.2	0.5	0.4	6.0
	Low	2.7	0.4	0.4	6.0
Local	High	2.7	0.5	0.4	10.0
	Medium	2.2	0.4	0.3	10.0
	Low	1.6	0.3	0.3	10.0

*Table based on a 60 years old driver with normal vision, an 18cm x 18cm (7.1 in. x 7.1 in.) 50 percent reflective target, and a 0.2second fixation time.

2.3 Work Zone Lighting Design

Proper work zone lighting design is of great importance since work zone lighting does not just affect the safety and quality of work but also affects the safety of the traveling public. The following section describes some recommendations for the design of lighting arrangements in a work zone.

2.3.1 Recommended Illuminance Levels

Despite the availability of lighting standards for industrial activities, there were no recommendations for lighting levels in highway construction activities until recently. A recent research study has focused on specifying recommended illuminance levels for twenty seven highway construction and maintenance tasks as shown in Table 2.7 (Ellis et al 1995). This study was based on a comparative analysis of typical highway tasks and non-highway tasks in order to correlate and develop the illuminance levels for the highway tasks. This analysis was composed of three main steps: (1) identifying factors affecting visual requirements of highway tasks; (2) selecting a number of outdoor industrial tasks and assigning visual requirement factors to them; and (3) performing a correlation analysis for the different visual requirements and the lighting levels associated with them.

Table 2.7. Suggested Illuminance Levels for Typical Construction and Maintenance Tasks (Ellis and Amos 1996).

Task No.	Task Description (Construction)	Factors					Compared Averages	Suggested Illumination	
		Imp.	Refl.	Spd.	Size	Dist.		Category	Level lx (fc)
1	Excavation-regular, lateral ditch, channel	L	L	N	L	L	1.3	I	54 (5)
2	Embankment, Fill and Compaction	L	L	M	L	L	0.6	I	54 (5)
3	Barrier Walls, Traffic Separators	M	M	N	M	L	10	II	108 (10)
4	Milling, Removal of Pavement	M	M	M	M	L	10	II	108 (10)
5	Resurfacing	M	H	M	L	L	10	II	108 (10)
6	Concrete Pavement	M	H	L	M	L	10	II	108 (10)
7	Subgrade Stabilization and Construction	L	L	L	L	M	1.86	I	54 (5)
8	Base Course Construction	M	L	M	M	L	10	II	108 (10)
9	Surface Treatment	M	H	M	L	L	10	II	108 (10)
10	Waterproofing and Sealing	M	H	M	M	M	10	II	108 (10)
11	Sidewalks	M	M	L	M	M	20	II	108 (10)
12	Sweeping and Cleaning	M	M	L	D	M	17.5	II	108 (10)
13	Guardrails, Fencing	M	M	N	L	M	15.7	II	108 (10)
14	Painting stripes/markers/metal buttons	M	H	M	M	L	10	II	108 (10)
15	Landscaping, grassing, sodding	L	L	N	S	L	1.3	I	54 (5)
16	Highway signing	M	M	N	S	M	15.7	II	108 (10)
17	Traffic signals	H	M	N	M	S	43.3	III	216 (20)
18	Highway lighting system	H	M	N	L	M	70	III	216 (20)
19	Bridge decks	M	L	N	M	M	10	II	108 (10)
20	Drainage structures, culverts, storm sewer	M	M	N	L	M	13.3	II	108 (10)
21	Other concrete structures	M	H	L	M	L	10	II	108 (10)
22	Maintenance of earthwork/embankment	L	L	M	L	L	0.6	I	54 (5)
23	Reworking shoulders	L	H	M	L	L	0.4	I	54 (5)
24	Repair of concrete pavement	M	M	M	D	M	10	II	108 (10)
25	Crack filling	H	M	L	F	M	30	III	216 (20)
26	Pot filling	M	M	N	F	M	13.3	II	108 (10)
27	Resetting guardrail/fencing	M	M	N	M	M	15.7	II	108 (10)

The first step focused on developing a list of five main factors affecting visual requirements for highway construction and maintenance tasks, including: (1) importance and accuracy of the task; (2) background reflection; (3) speed; (4) size of the object to be seen; and (5) distance of seeing. Due to the difficulty of measuring and quantifying these factors, subjective levels of measurement (i.e. L: low, M: medium, H: high) were developed for each factor as shown in Table 2.8 (Ellis et al 1995).

The recommended illuminance levels were assigned from one of the following categories (Ellis and Amos 1996): (1) category I, with a minimum illuminance requirement of 54 lux (5 fc), which is recommended as the general illumination level for the safety of crew movements in work zones and for tasks which do not require high accuracy such as visual tasks with large objects; (2) category II, with a minimum illuminance requirement of 108 lux (10 fc), which is recommended for visual tasks associated with equipment and for illuminating construction equipment; (3) category III, with a minimum illuminance requirement of 218 lux (20 fc), which is recommended for certain tasks that require efficient visual performance. The assignment of these categories was based on: (1) compared average illuminance levels obtained from the comparison with non-highway tasks; (2) the current illuminance standards and regulations for construction; (3) current state requirements for illuminance; and (4) researchers' observations of current practices on nighttime highway construction.

Table 2.8. Factors Influencing Task Illuminance Requirements and their Subjective Levels (Ellis and Amos 1996).

Task No.	Factors	Subjective Levels
1	Importance and accuracy of the task	L – Low M- Medium High- High
2	Background Reflection	L- Low M- Medium H- High
3	Speed	N- Not applicable L- Low M- Medium H- High
4	Size of the object to be seen	F- Fine S- Small M- Medium L- Large
5	Distance of Seeing	S- 1 to 5 ft M- 5 to 15 ft L- > 15 ft

In the second step of the analysis, a list of certain outdoor industrial tasks was selected for the comparison, and the levels of the different factors were assigned to the various tasks as shown by Table 2.9 (Ellis et al 1995).

The third and final step involved performing a correlation analysis for the assigned levels of the different factors and the illuminance requirements associated with these levels, giving the highest priority in matching to the first factor (i.e. the importance and accuracy factor). Then the mean illuminance levels of non-highway activities are assigned to highway tasks that match at least four of the five factors, including the importance and accuracy factor.

Table 2.9. Factor Description and Illuminance Levels for Outdoor Industrial Tasks and Spaces.

Task No.	Area	Task Description (Construction)	Factors					Recomm. Level fc (lx)
			Imp.	Refl.	Spd.	Size	Dist.	
1	Automotive Industry	Frame assembly	H	M	L	S	S	50 (540)
2		Welding area	H	H	N	S	S	50 (540)
3		Machining operations	H	H	H	F	S	75 (810)
4		Coal yards and oil storage	L	L	N	L	L	0.5 (5.4)
5		Outdoor substation, parking	L	L	N	L	L	1.5 (16.2)
6		Entrance, truck maneuverability	L	L	L	L	L	5 (54)
7		Furnace area, sheet rolling	H	M	N	M	S	30 (324)
8	Iron & Steel Industry	Mold yard	L	L	N	M	L	5 (54)
9		Scrap stock yard	M	M	N	M	L	10 (108)
10		Hot top storage	M	H	M	M	L	10 (108)
11	Petrochemical Industry	Pump rows, valves, manifolds	L	L	N	M	L	5 (54)
12		Heat exchangers	L	L	N	M	L	3 (32.4)
13		Maintenance platforms	L	L	N	L	L	1 (10.8)
14		Operating Platforms	L	L	N	M	L	5 (54)
15		Cooling towers, equipment	L	L	N	M	L	5 (54)
16		Furnaces	L	L	N	M	L	3 (32.4)
17		Active ladder, stairs	L	L	L	L	L	5 (54)
18		General area	L	L	N	L	L	1 (10.8)
19		Extruders and mixers	M	M	L	M	M	20 (216)
20		Conveyors	L	L	M	L	L	2 (21.6)
21		Outdoor plants, equipment	L	L	N	S	M	5 (54)
22		Outdoor substation	L	L	N	L	M	2 (21.6)
23		Plant road: Frequent use	L	L	M	L	L	0.4 (4.3)
24		Plant road: Infrequent use	L	L	L	L	L	0.2 (2.2)
25		Plant parking lots	L	L	L	L	L	0.1 (1.1)
26	Petrochemical Industry	Outdoor bulk storage	L	L	N	L	L	0.5 (5.4)
27		Large bin storage	L	L	N	L	M	5 (54)
28		Small bin storage	M	M	N	S	M	10 (108)

Table 2.9. (Continued). Factor Description and Illuminance Levels for Outdoor Industrial Tasks and Spaces.

Task No.	Area	Task Description (Construction)	Factors					Recomm. Level ft (lx)
			Imp.	Refl.	Spd.	Size	Dist.	
29		Small parts storage	M	M	N	F	M	20 (216)
30	Pulp and Paper Industry	Groundwood mill grinder	H	M	H	S	M	70 (756)
31		Beater room	H	M	L	M	M	30 (324)
32		Roll dryer	H	M	M	S	M	50 (540)
33		Cutting & sorting	H	M	H	S	S	70 (756)
34		Active warehouse	M	M	L	M	M	20 (216)
35		Shipping truck shed	M	M	L	M	M	20 (216)
36		Roadways	L	L	M	L	L	0.4 (4.3)
37		Log pile	L	L	N	M	L	3 (32.4)
38		Log unloading	L	L	L	M	M	5 (54)
39	Industrial Outdoors	Excavation	L	L	N	L	M	2 (21.6)
40		General construction	M	M	N	M	M	10 (108)
41		Active entrance	L	L	L	L	L	5 (54)
42		Inactive entrance	L	L	N	M	L	1 (10.8)

2.3.2 Construction Equipment Illumination

Construction equipment operating at night needs to have specific distance lighted in its directions of travel for visual detection of hazards. Available lighting specifications for work zones recommend a minimum distance of illumination in front and behind construction equipment (Ellis et al 1995). The minimum area to be illuminated in front and behind construction equipment should be at least equal to the equipment stopping distance at its maximum operating speed. The equipment stopping distance is a function of machine mass and speed, and it is composed of two components: (a) distance traveled at maximum speed during a 1.5 second operator's reaction time interval, and (b) the breaking distance required by the equipment (Ellis et al 1995). In this specification, highway construction equipment were divided into two major categories: (1) slow moving equipment with a suggested illuminance level of 10 fc in distances 4.9 meters in front and behind the equipment; and (2) fast-moving equipment with a suggested illuminance level of 10 fc in distances of 17.7 meters in front and behind the equipment as shown in Table 2.10 (Ellis et al 1995).

Table 2.10. Recommended Illuminated Distance in the Direction of Travel for Various Construction Equipment (Ellis et al 1995).

Type of Equipment	Working Speed mph (km/h)	Reaction Distance ft (m)	Breaking Distance, ft (m)	Distance to be illuminated in front and behind equipment ft (m)
Slow-Moving Equipment				
Paver Milling Machine	4-5 (6.4-8 km/h)	11 (3.4 m)	5 (1.5 m)	16 (4.9 m)
Fast Moving Equipment				
Backhoe Loader Wheel Tractor Scraper Wheel Loader Compactor/Roller Motor Grader	10-15 (16.1-24.2 km/h)	33 (10.1 m)	15-25 (4.6-7.6 m)	58 (17.7 m)

2.3.3 Glare Control

Lighting work zones can often cause glare to the traveling public as well as workers. Glare can be reduced by controlling: (1) vertical beam spread; (2) mounting height;

(3) luminaire positioning; (4) aiming of the light source; and (5) supplemental hardware. Beam spread needs to be controlled to make it as narrow as possible by using cutoff luminaires if needed (Ellis and Amos 1996).

Mounting height can be determined by using a rule of thumb to minimize glare within the work zone as shown in Figure 2.8 (Ellis and Amos 1996). This rule attempts to increase the mounting height by maximizing the angle (a) between the horizontal working surface and a line drawn between the center of the luminaire and a point one-third of the work zone width away from the edge of the work zone nearest to the luminaire as shown in Figure 2.8 (Ellis and Amos 1996). It should be noted that this may be in direct conflict with the need to control light trespass.

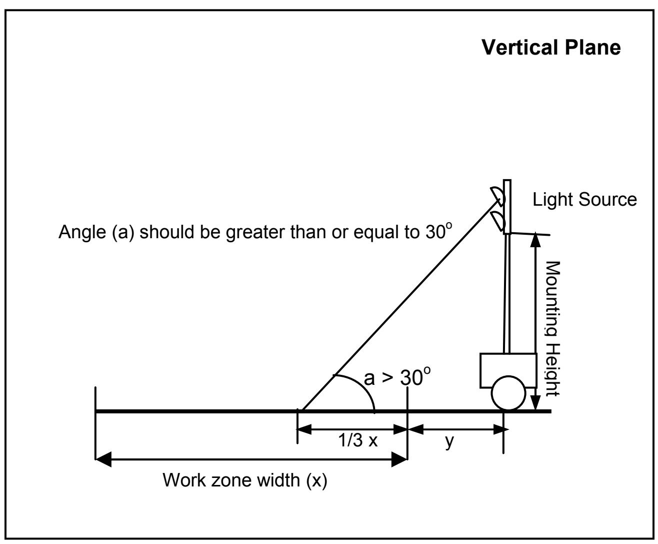


Figure 2.8. Mounting Height of Luminaires in Work Zones (Ellis and Amos 1996)

Luminaire positioning in the horizontal plane needs to be controlled to minimize the effect of glare on drivers. Glare decreases as the horizontal angle (b) between the line of sight and the beam axis (center line of the beam) decreases as shown in

Figure 2.9. Therefore, a minimum horizontal distance (x) should be maintained between the luminaire and the drivers' line of sight so that angle (b) should be greater than 45° as shown in Figure 2.9 (Ellis and Amos 1996). It should be noted that the soundness of this rule depends on the type of the selected luminaire.

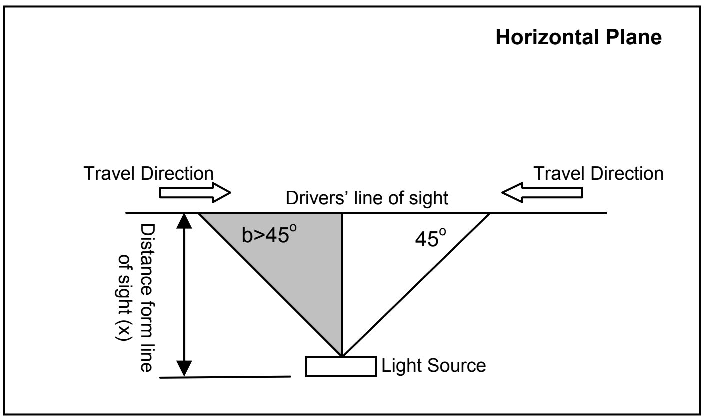


Figure 2.9. Work Zones Horizontal Positioning of Luminaires

Aiming of the light source should be controlled to ensure that the angle (c) between the center of the luminaire beam spread and the nadir should not exceed 60° as shown in Figure 2.10. Another rule for reducing discomfort glare is that the intensity of light at angles greater than 72° from the nadir should be less than 20,000 Candela as shown in Figure 2.10 (Ellis and Amos 1996).

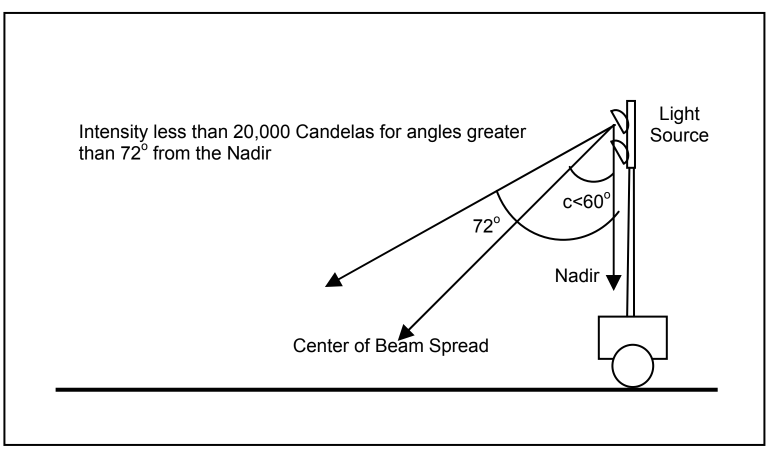


Figure 2.10. Rules for Aiming Luminaires in Work Zones

Supplemental hardware is often used where the control of the above mentioned factors is restricted by the physical constraints of the work zone. In these cases additional hardware such as visors, louvers, shields, screens and barriers can be used to reduce glare. This approach, however, reduces the amount of usable light from the light sources and also creates wind load on the mounting devices that need to be considered. Table 2.11 provides a summary of the aforementioned five factors used to control glare (Ellis and Amos 1996).

Table 2.11. Glare Control Factors (Ellis and Amos 1996).

Glare Control Factors	Control Recommendations
1- Beam Spread	Select vertical and horizontal beam spreads to minimize light spillage. Consider using cutoff luminaries.
2- Mounting Height	Coordinate minimum mounting height with source lumens.
3- Location	Luminaire beam axis crosses normal lines of sight between 45 and 90 degrees.
4- Aiming	Angle between main beam axis and nadir less than 60 degrees. Intensity at angles greater than 72 degrees from the vertical less than 20,000 candelas.
5- Supplemental Hardware	Visors, Louvers, Shields, Screens, Barriers

2.4 Government Agency Practices for Work Zone Lighting

This section provides a summary of the currently available practices developed by government agencies for work zone lighting design including: (1) State Departments of Transportation (DOTs); and (2) Federal Aviation Administration (FAA). It should be noted that additional guidelines and standards were obtained during the surveys which were conducted in this research project and which are presented in more details in the following chapter (Chapter 3). The following sections in this chapter, however, provide a summary of the DOT standards collected during the literature review stage.

2.4.1 State Departments of Transportation

The review of available literature revealed that there is a limited number of existing standards and guidelines for lighting nighttime construction operations in few state DOTs, including: (1) Illinois DOT; (2) New York DOT; (3) Michigan DOT; (4) North Carolina DOT; (5) New Jersey DOT; and (6) Maryland DOT.

2.4.1.1 Illinois Department of Transportation (IDOT)

IDOT developed a draft specification for lighting work zones during nighttime construction operations. These specifications include requirements for: (1) lighting levels; (2) glare control; and (3) lighting design.

Lighting Levels

The minimum average illuminance levels for different construction activities have been grouped into three categories as shown in Table 2.12 (IDOT 2001). These levels of illuminance should be maintained throughout the work area, but will extend a minimum of 20 ft in the direction of travel for slow moving equipment, and a minimum of 70 ft for fast moving equipment (IDOT 2001).

Glare Control

IDOT also specified that the lighting arrangements developed to meet the minimum illuminance requirements should not cause objectionable glare to either the traveling public or to residences adjacent to the work zone. If such objectionable glare exists, the contractor shall change the lighting arrangements and/or provide the necessary hardware to prevent this glare while maintaining the minimum illuminance levels and uniformity (IDOT 2001).

Table 2.12. IDOT Specifications for Work Zone Illuminance Levels

Construction Activities	Category	Minimum average illuminance levels (fc)
Excavation, Embankment compaction, Subgrade construction, Sweeping and cleaning, Landscaping, and Reworking shoulders.	I	5
Barrier walls, Milling, Resurfacing, Concrete Pavement, Base coarse construction, Surface treatment, Sealing and Waterproofing, Sidewalks, Guardrail and fencing, Painting and markers, Highway signs, Bridge decks, Drainage structures, Culverts and Storm sewers, and Repair of concrete pavement.	II	10
Crack filling, Pot hole filling, Structural steel repair, Traffic signals, and Highway lighting systems.	III	20
* Illuminance uniformity ratio over the work area shall not exceed 10:1		

2.4.1.2 New York State Department of Transportation (NYSDOT)

The State of New York Department of Transportation developed a specification to provide lighting requirements for nighttime construction operations in 1995. The specification provides recommendations for: (1) lighting plan; (2) inspection procedures; (3) illuminance levels; (4) lighting equipment; and (5) glare control (NYSDOT 1995). The minimum average illuminance levels required for various construction activities within the work zone area have been grouped into three categories according to the level of accuracy required to perform the task (NYSDOT 1995). These three categories of illuminance levels include (1) 54 lux (5 fc); (2) 108 lux (10 fc); and (3) 216 lux (20 fc).

2.4.1.3 Michigan Department of Transportation (MDOT)

The Michigan Department of Transportation (MDOT) has developed specifications for lighting requirements for nighttime paving These specifications recommend that a minimum illuminance level of 10 fc (108 lx) should be maintained on and around the pavers (Ellis et al 1995).

2.4.1.4 North Carolina Department of Transportation (NCDOT)

The NCDOT has specified requirements for portable lighting during nighttime operations in work zones (Ellis et al 1995). These include the main requirements for tower lighting and equipment mounted lighting. For tower lighting, a minimum illuminance level of 216 lux (20 fc) should be maintained throughout the work area. For equipment mounted lighting, a minimum illuminance level of 108 lux (10 fc) maintained on and around the equipment (Ellis et al 1995).

2.4.1.5 New Jersey Department of Transportation (NJDOT)

NJDOT proposed minimum illuminance requirements according to the type of construction operation. A minimum illuminance level of 54 lux (5 fc) is required for operations such as earthwork and asphalt paving, while a minimum illuminance level of 108 lux (10 fc) is required for structural work and concrete paving (Schexnayder and Ernzen 1999).

2.4.1.6 Maryland State Highway Administration

The Maryland State highway administration has requirements for lighting in nighttime pavement repair work. The required minimum illuminance level is 20 fc, and the minimum mounting height should be 30 ft for directly influenced traveled roadways and 20 ft for indirectly influenced traveled roadways (Ellis et al 1995).

2.4.2 Federal Aviation Administration

The Federal Aviation Administration (FAA) specified requirements for lighting arrangements while asphalt overlay operations are taking place. The average illuminance level that should be maintained throughout the working area is 5 fc. To achieve this level FAA specifies the use of trailer mounted lighting units, each having four 1000 watt metal halide or high pressure sodium luminaires. However FAA recommends the use of metal halide luminaires due to their better color rendition and the nearly daylight effect of their light (Wills 1982). FAA suggested a design to satisfy the required level of illuminance using the specified lighting equipment in which four luminaires are used per mast at a mounting height of 30 ft, and a spacing of 200 ft center to center along each edge of the runway (Wills 1982).

2.5 Light Trespass and Light Pollution

Artificial light, like all man made elements, can alter the behavior of living creatures. The negative effect of artificial lighting is usually caused by light trespass and light pollution. This section describes the rules and regulations governing light trespass and the changes that light pollution can cause to the surrounding environment.

2.5.1 Rules and Regulations Governing Light Trespass

Light trespass can be defined as “light from an artificial light source that is intruding into an area where it is not wanted or does not belong” (Connecticut Municipal Regulation 2001). This light may enter the boundaries of a privately owned property causing nuisance to its owners and leading to a waste of energy (ILE 2000). Some municipal authorities have defined a quantifiable measure of light trespass. The San Diego County in California limits stray light entering a property to 0.21 Lux (0.021 fc), which is equivalent to the amount of illuminance from moonlight, in both the horizontal and vertical planes at a point 1.5 m (5 ft) inside the owner’s property line. Another ordinance was developed in the village of Skokie, Illinois, which defines the light trespass as light from a roadway lighting system falling on adjacent properties with intensity more than 3 lux (0.3 fc) (Schaflik 1997). Milford County in Connecticut also developed an ordinance for lighting in residentially and commercially zoned properties. For residential and business zoned properties, the illuminance on the edge of the property line should not exceed 1 lux (0.1 fc) and 5 lux (0.5 fc) respectively. Watertown county Connecticut on the other hand prevents the location of any lighting within five feet of any property lines (Connecticut Municipal Regulation 2001).

The main cause for light trespass is errors in selecting lighting design parameters, which include the selection of inappropriate vertical distribution, lateral distribution, and/or control of distribution above the maximum candle power (Schaflik 1997). Light trespass can be prevented by adopting a number of measures including: (1) the selection of luminaires should be made carefully and taking into consideration the type of roadway lighted; (2) lighting calculations need to be performed to ensure efficient placement; (3) IES recommended levels of illuminance should be followed in design; and (4) use of cutoff luminaires to increase control of stray light (Schaflik 1997). Another proposed solution for reducing light trespass is to limit the maximum horizontal illuminance at a distance 7 m (25 ft) beyond the property lines to 5 lux (0.5 fc) (Kosiorek 1996).

2.5.2 Influence of Light on Adjacent Environment

Light pollution has a negative impact on humans and wildlife since it alters or extends the natural length of daytime (Falzon 2001). The effect of light pollution on human health is mainly through causing sleep disturbance (Falzon 2001). Several medical researches also indicated that light pollution can cause the disruption of natural hormone production needed by the human body, leading to an increase in the risk of certain types of cancer (Light Pollution Awareness Website 2001). Another effect light pollution has on the quality of human life is the decrease in human visual acuity at night, due to exposure to light from improperly shielded luminaires (Light Pollution Awareness Website 2001).

The adverse environmental effect of light pollution can be considered to be direct and indirect. The direct environmental effect of light pollution can be identified as those negatively influencing wildlife in general. An example of these adverse effects was the early movement of sea turtle hatchlings on a beach in Florida where the roadway Illumination reached the beach (Effects of lighting on wildlife flora and fauna 2001). Similar adverse effects were noticed on other wild animals, insects, fish, frogs, birds, and plants (Light Pollution Awareness Website 2001). The indirect adverse effects on the other hand are mainly due to wasted energy consumed to generate the excess illumination that spills into the sky and adjacent property line needlessly. These direct and indirect effects of light pollution can be avoided by improving the design of lighting systems; however, they may be somewhat less controllable in a work zone.

CHAPTER 3
SURVEY OF LIGHTING PRACTICES

3.1 Introduction

This chapter presents the results of a survey of the current lighting practices for nighttime construction in Illinois and the available guidelines used by other state DOTs. Three surveys were conducted to gather information from: (1) resident engineers working for the Illinois Department of Transportation (IDOT), (2) contractors working on IDOT projects and (3) state DOTs in the United States. The first survey was sent to 38 resident engineers in IDOT. The second was sent to 18 contractors who were identified by IDOT officials as having prior work experience in nighttime construction in Illinois and 52 other contractors provided by the Illinois Road Builders Association (IRBA). The third survey was forwarded to all DOTs in the United States. These three questionnaires can be found in appendices B, C, and D, respectively. Responses have been received from 21 resident engineers, 23 contractors, and 20 DOTs, with response rates of 55%, 33%, and 41%, respectively.

3.2 Current Practice of Nighttime Construction

To gauge the acceptance of nighttime operations in highway construction, participants from state DOTs were asked to estimate the volume of nighttime construction projects during the last fiscal year (2001), and the volume of all construction projects during the same period. Nighttime construction projects included those with both daytime and nighttime shifts. Table 3.1 and Figures 3.1, 3.2, and 3.3 show the volume of nighttime construction projects in fiscal year 2001 for responding DOTs.

Table 3.1. Nighttime Construction Projects Volume in Fiscal Year 2001.

Number	DOTs	All Construction Projects		Nighttime Construction Projects		% Nighttime Construction (based on the value of projects)
		No. of Projects	Value of Projects (millions)	No. of Projects	Value of Projects (millions)	
1	Delaware	93	141	21	32	22.70
2	Florida	*	*	*	*	-
3	Indiana	*	737	30	200	27.14
4	Kansas	500	505	5 **	7	1.39 **
5	Maine	196	125	2	9	7.20
6	Michigan	*	*	300	1500	-
7	Missouri	9	30	1	13.8	46.00
8	Montana	138	240	*	*	-
9	Nebraska	213	259.304	8	32.494	12.53
10	Oregon	*	*	*	*	*
11	Tennessee	500	650	30	75	11.54
12	Texas	122	292.975	7	4.5	1.54
13	Pennsylvania	65	350	20	100	28.57
14	Iowa	500	400	21	3.75	0.94
15	Nevada	44	234.91	15	95.5	40.65
16	Maryland	146	576	12	157	27.26
17	Mississippi	203	415	5	65	15.66
Average Percentage of Nighttime Construction Projects						16.86

* Questions not answered by respondents
** Excluding projects that were partly nighttime construction

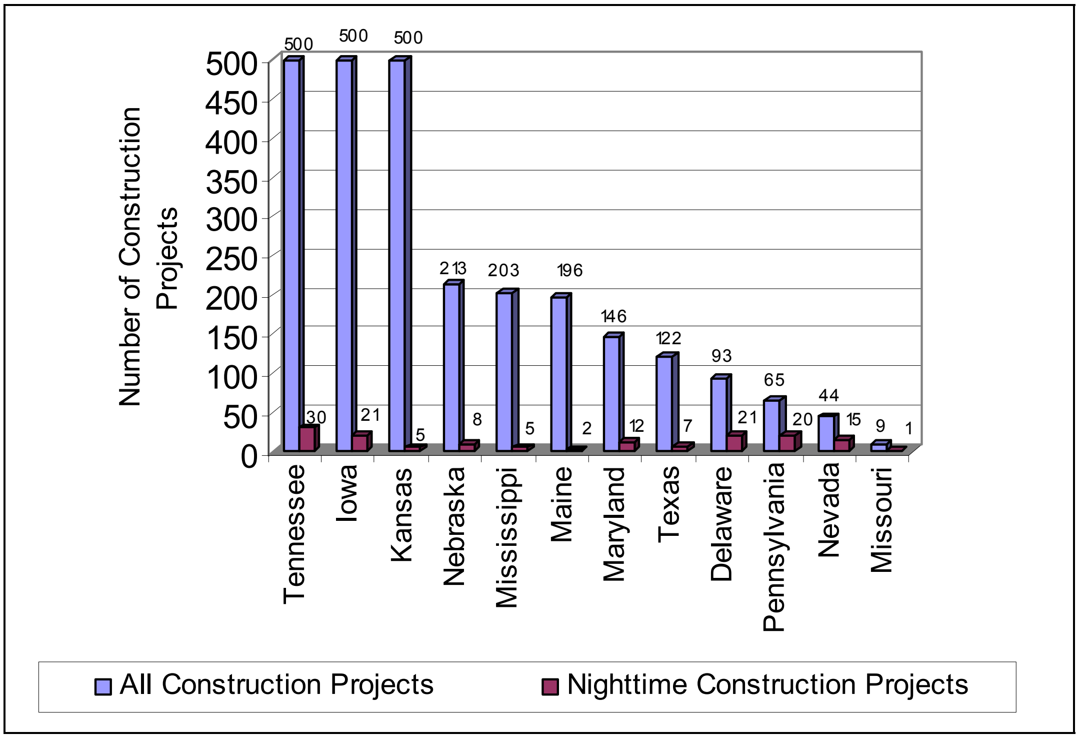


Figure 3.1. Number of Nighttime Projects

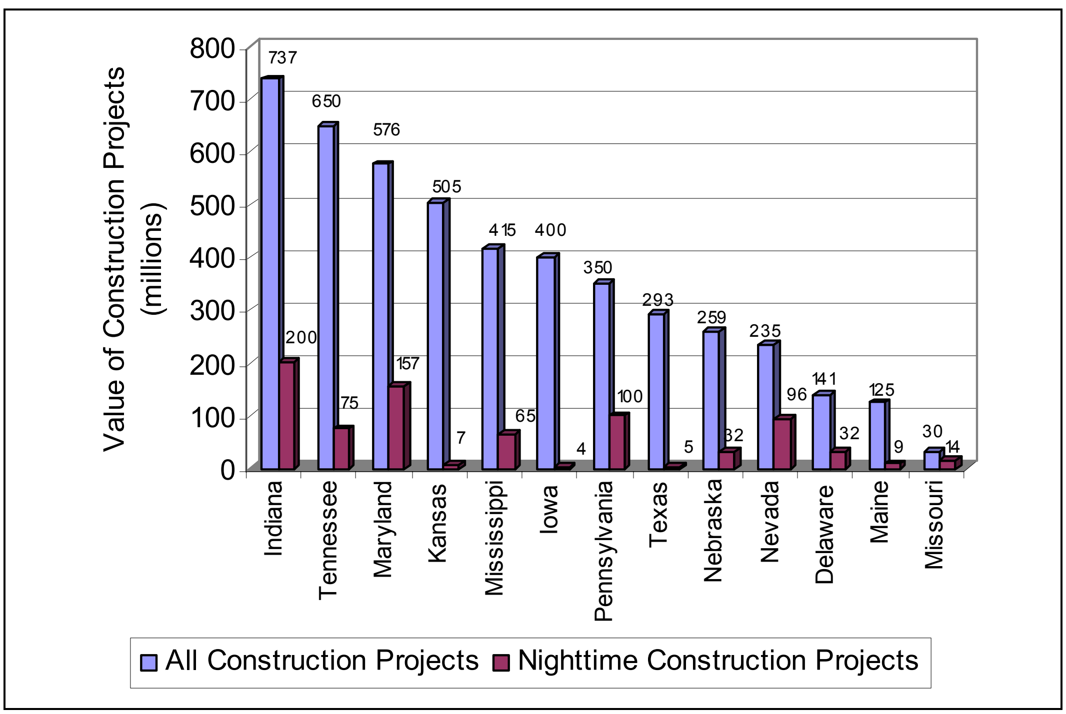


Figure 3.2. Value of Nighttime Construction Projects

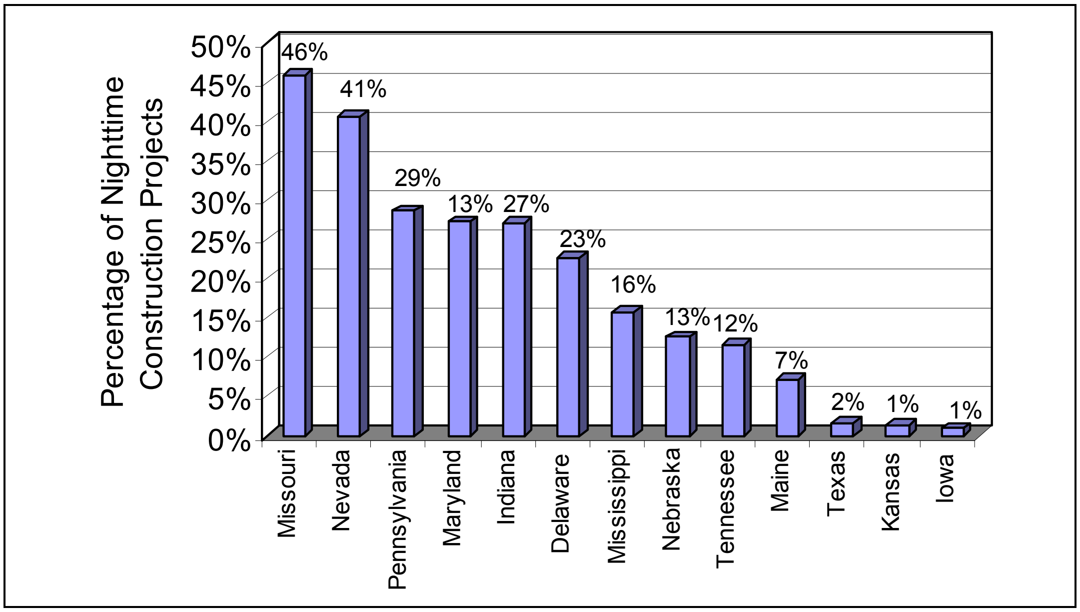


Figure 3.3. Percentage of Nighttime Construction Projects.

As shown in Figure 3.3, the percentage of nighttime construction projects, in terms of the value of these projects, ranged from 1% in Iowa to 46.00% in Missouri. The value of nighttime construction projects provided by the Kansas DOT did not include projects where nighttime construction was partially used. The survey results indicate that nighttime construction work in fiscal year 2001 represents a considerable percentage of all the construction work performed by DOTs, with an average of 16.86% of the total construction projects value.

3.3 Advantages of Nighttime Construction

The main reason for the increased acceptance of nighttime work in highway construction is the apparent advantages associated with performing construction projects at nighttime relative to daytime hours. The advantages of nighttime construction projects, as reported in the literature, include: (1) reduced traffic congestion, (2) reduced project duration, (3) reduced impact on surrounding businesses, (4) minimal economic effects due to delay, (5) minimal air pollution from gases emitted by vehicles idling in traffic congestions, (6) increased freedom to plan lane closures, (7) enhanced work conditions at night, and (8) faster delivery of material at night (Shepard & Cottrell 1985, McCall 1999, and Price 1986).

DOT Personnel were asked to evaluate the relative importance of each of the above listed advantages on a scale ranging from “1” to “5”, where “1” indicates “not important” and “5” indicates “very important.” The participants were also asked to list any further advantages; these are enumerated in Appendix E. Figure 3.4 offers a summary of the average relative importance that respondents attributed to each of the identified advantages of nighttime construction. Reduced traffic congestion and increased freedom in planning lane closures were reported to be the most important advantages in nighttime construction projects. This result concurs with the literature, and confirms that reducing congestion and increasing safety were the main motivations for nighttime construction projects (Shepard & Cottrell 1985, McCall 1999, and Price 1986). The least important advantage was reported to be minimizing air pollution.

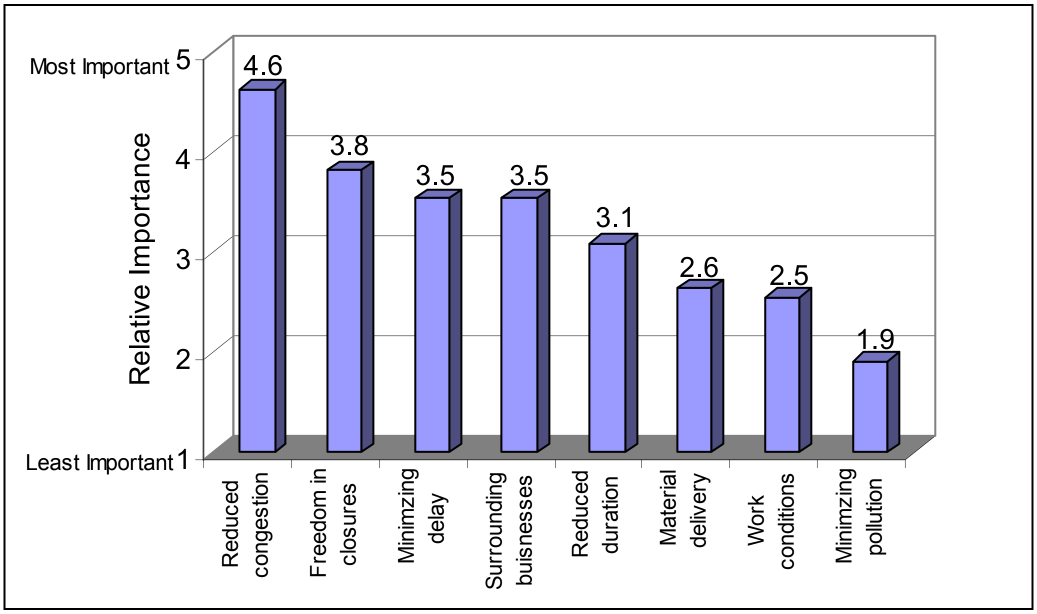


Figure 3.4. Average Importance Ranking by DOTs Personnel.

3.4 Challenges of Nighttime Construction

Despite the reported advantages of nighttime construction, the results of the survey have indicated that a number of challenges also exist. The following sections provide a summary of various problems associated with nighttime construction.

3.4.1 Nighttime Construction Problems

The results of the survey indicate that a number of problems were often encountered in nighttime construction operations, including: (1) accidents to road users; (2) accidents to workers; (3) lower quality; (4) reduced productivity; (5) complaints from neighboring properties; (6) difficulty in quality inspection; (7) difficulty of inspecting lighting conditions; and (8) difficulty in personnel coordination. The participants in the three surveys (i.e., resident engineers, contractors, and DOTs) were asked to identify the problems they faced from the aforementioned list and to add any additional problems they encountered in their previous projects. These additional problems are listed in Appendix E. Figures 3.5, 3.6, and 3.7 show the percentage of respondents who indicated that they have faced problems one through eight in their previous projects. The results show that 76% of the surveyed resident engineers reported difficulties in quality inspection, while 78% of the surveyed contractors reported that they received complaints from neighboring properties. Finally, 75% of DOTs reported problems with the provision of adequate lighting and difficulties in quality inspection.

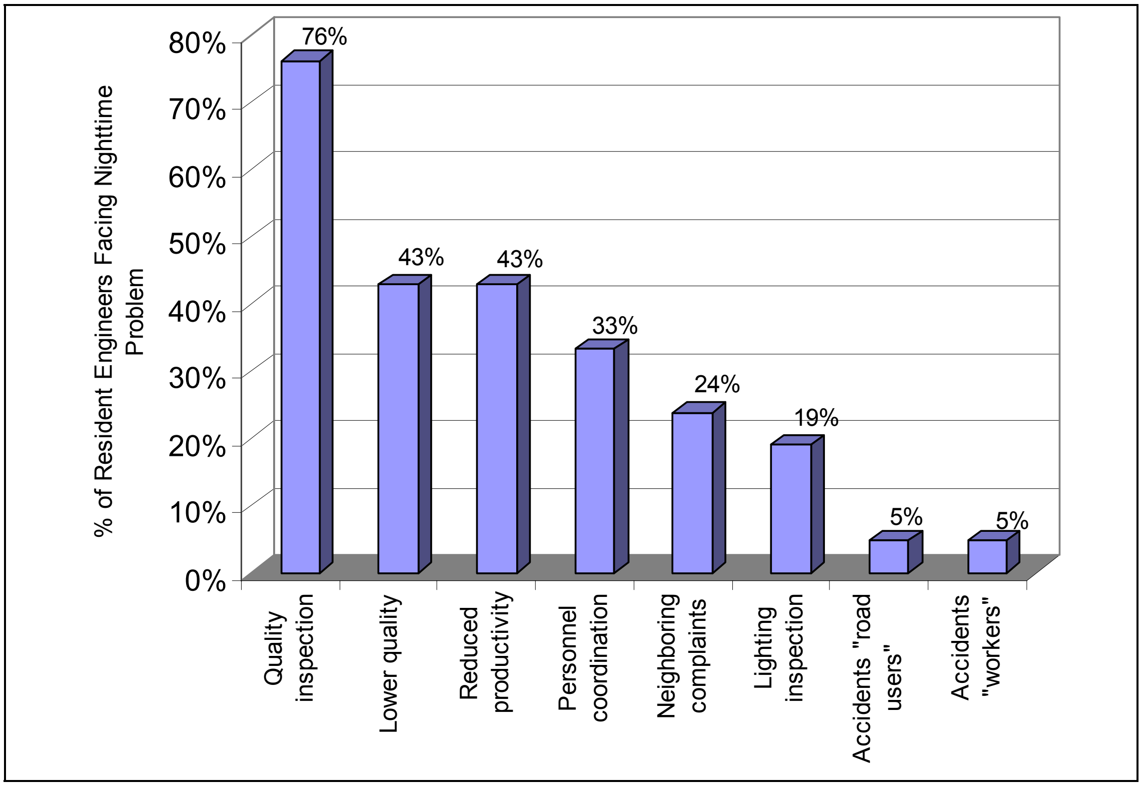


Figure 3.5. Nighttime Construction Problems Faced by Resident Engineers.

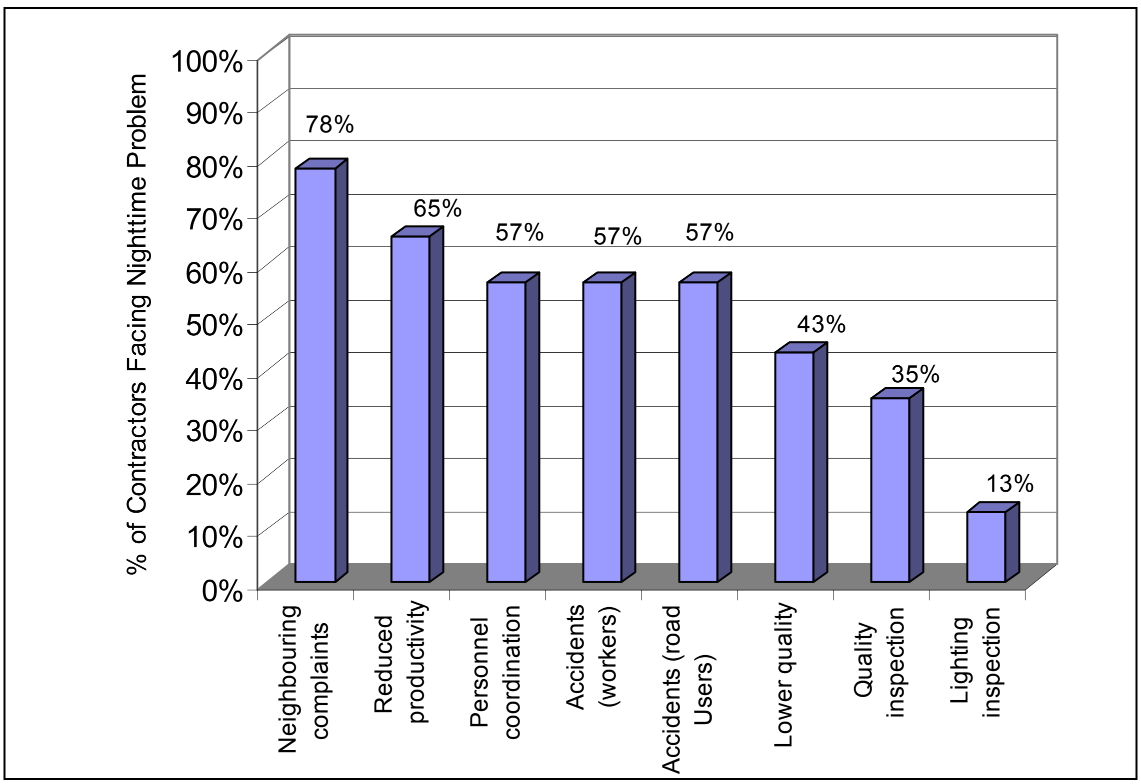


Figure 3.6. Nighttime Construction Problems Faced by Contractors.

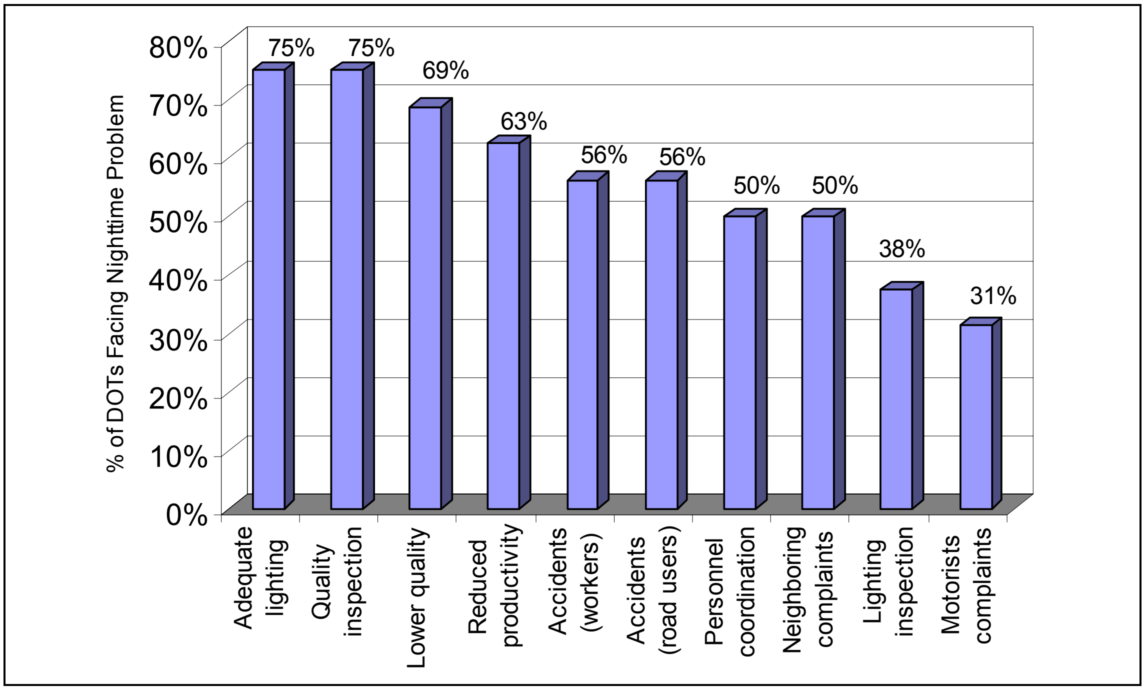


Figure 3.7. Nighttime Construction Problems Faced by DOTs.

The surveyed resident engineers reported difficulties in quality inspection as the most frequent problem they encountered, while contractors emphasized complaints from neighboring properties. DOTs named quality problems and difficulties in providing adequate lighting levels as the central challenges. From the results of these three surveys, then, we see a diverse set of problems perceived or experienced by the three groups. The relative ranking of these problems is important, as these groups' priorities play a key role in shaping new policies and procedures for lighting nighttime construction operations.

3.4.2 Lighting Problems

Participating DOTs identified the difficulty of providing adequate lighting levels as the most frequently encountered problem in nighttime construction, as shown in Figure

3.7. The difficulties associated with this problem were reported to include: (1) insufficient lighting levels, (2) glare to workers, (3) glare to road users, (4) non-uniformity of lighting levels, (5) light trespass to adjacent facilities, (6) availability of suitable lighting equipment, (7) reliability of lighting equipment, (8) difficulty retrofitting construction equipment with additional lighting equipment, (9) placement of lighting equipment, (10) mobility of lighting equipment, (11) lack of experience in lighting design, (12) lack of lighting design guidelines, and (13) cost of lighting equipment. Figures 3.8 to 3.10 show the percentage of respondents in the three surveys who indicated that they encountered these lighting problems in their previous projects. For example, 75% of surveyed resident engineers reported encountering problems due to insufficient lighting, and 70% of them thought lighting uniformity was an issue.

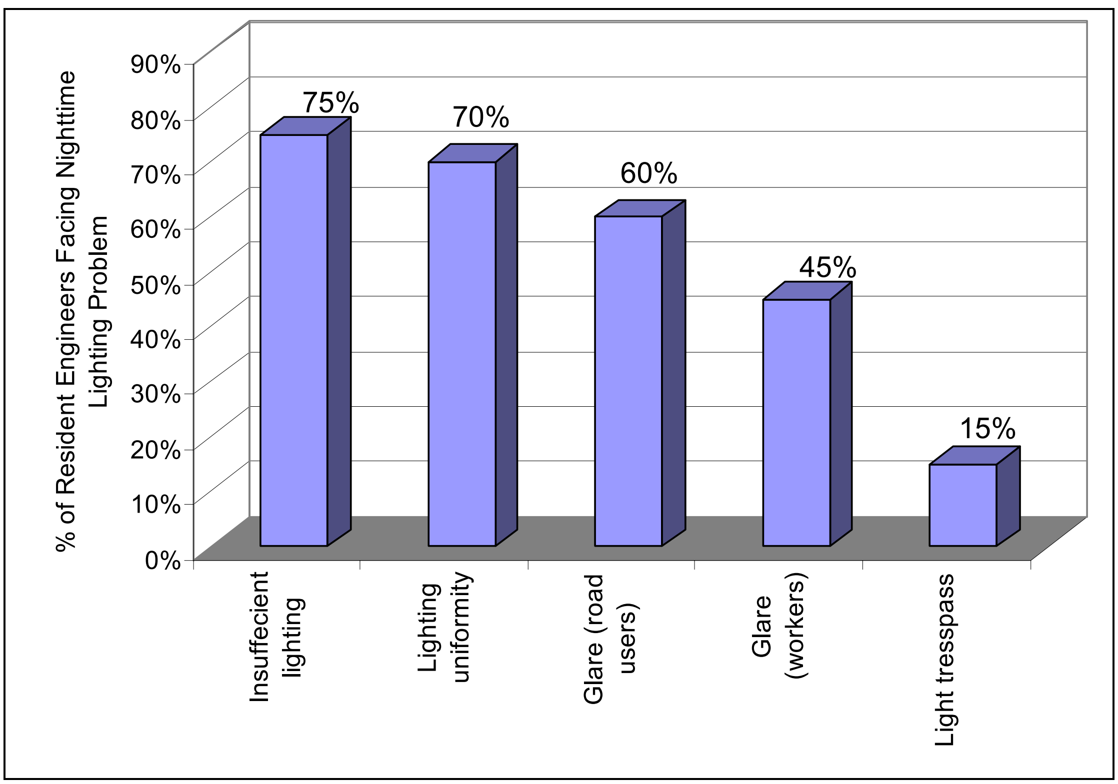


Figure 3.8. Lighting Problems Encountered by Resident Engineers.

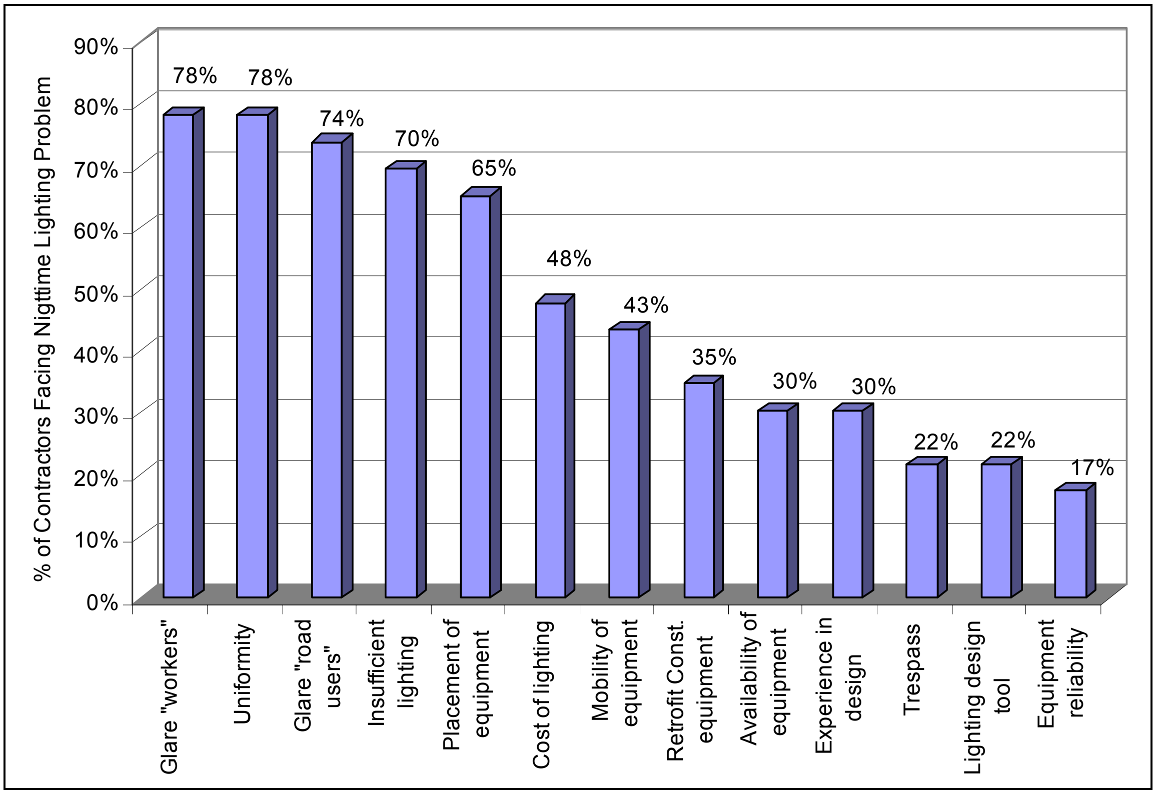


Figure 3.9. Lighting Problems Encountered by Contractors

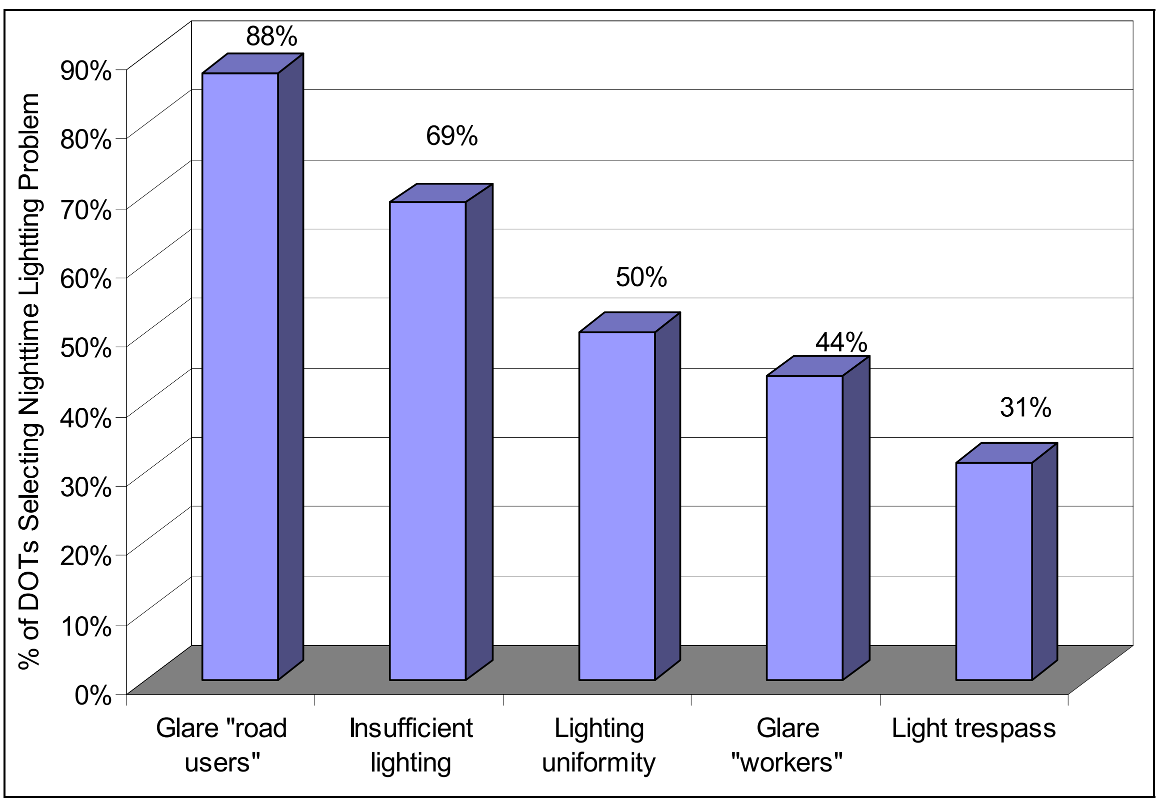


Figure 3.10. Lighting Problems Reported by DOTs in Nighttime Construction.

Contractors encountered more lighting problems than the other groups due to the fact that they are the party providing lighting on site. The most important problems associated with lighting nighttime construction, as reported in the three surveys, were: (1) glare to road users, (2) insufficient lighting levels, (3) glare to workers, and (4) non-uniformity in the distribution of the provided lighting. Light trespass and reliability of lighting equipment were the least frequent problems associated with lighting nighttime construction. The identification of the lighting problems in nighttime construction by the involved parties should serve as a guideline for research efforts that address lighting nighttime construction in that such efforts should give higher priority to the most frequent problems.

3.5 Design Criteria

The purpose of nighttime construction lighting design is to satisfy a number of design criteria. Section 3.5.1 presents the lighting level requirements that need to be satisfied in lighting design for various construction activities. Section 3.5.2 summarizes the available standards for lighting nighttime construction from DOTs that have established guidelines.

3.5.1 Requirements for Lighting Levels

Construction activities performed at night have varying levels of complexity and hazard, which makes each activity unique in its lighting requirements. A list of 27 possible nighttime highway construction activities was compiled from activities reported in the literature, and in conformity with the IDOT standard specifications for road and bridge construction. The respondents were asked to assign the required lighting level for each of these activities by selecting from three possibilities: high, medium, or low. To ensure the soundness of the respondents' judgment about the required lighting level, they were given the option to state that they had no past experience with any particular activity. The results obtained from the resident engineer survey are shown in Figure 3.11. The vertical axis of this graph shows different activities, while the horizontal axis shows the percentage of respondents selecting a specific lighting requirement for each activity. Similarly, Figure 3.12 shows the lighting level requirements for different activities, as identified by participating contractors. The percentages shown in both Figures 3.11 and 3.12 were obtained after excluding the responses that indicated no experience in those activities.

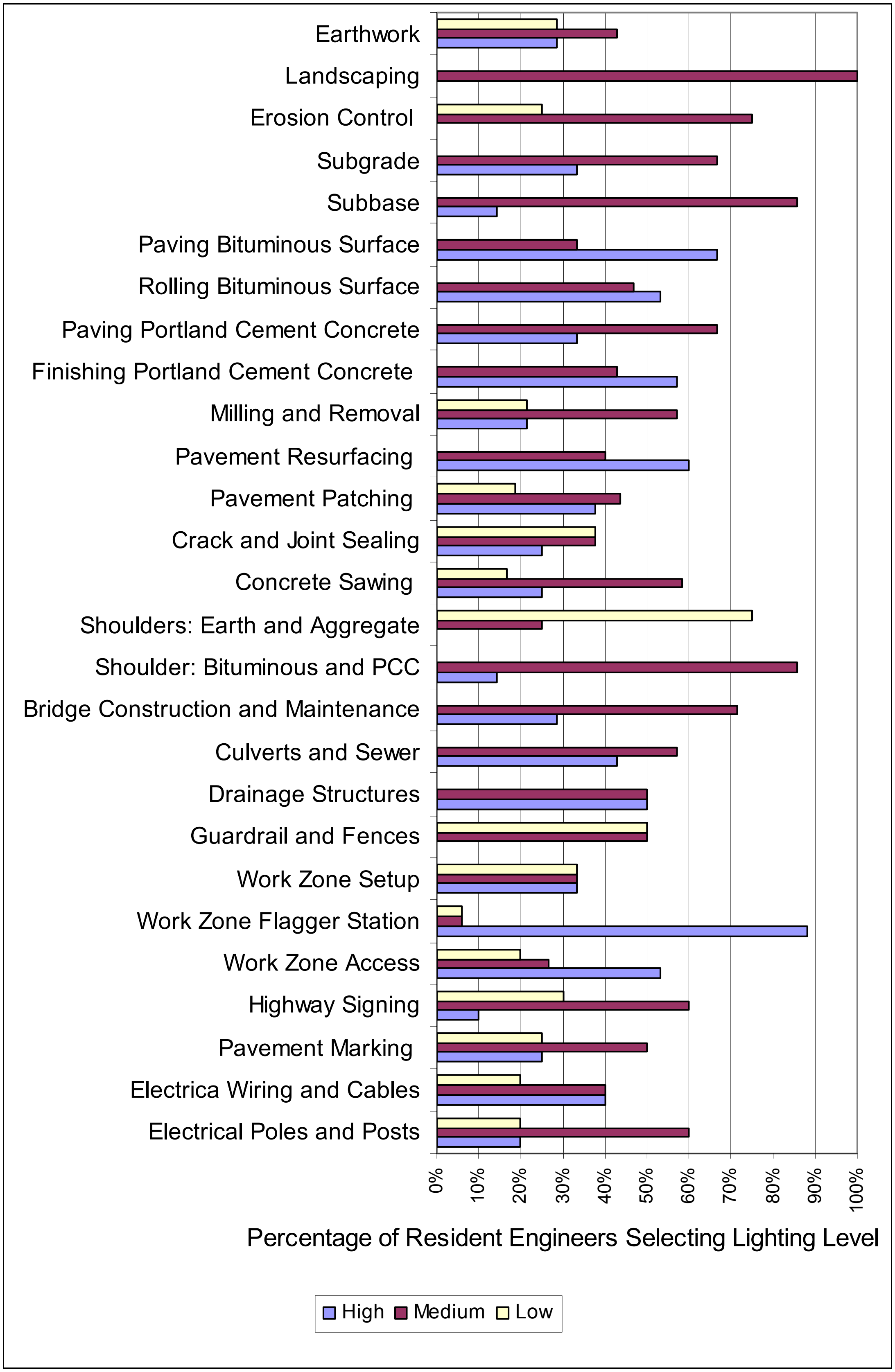


Figure 3.11. Distribution of Lighting Level Requirements- Resident Engineers.

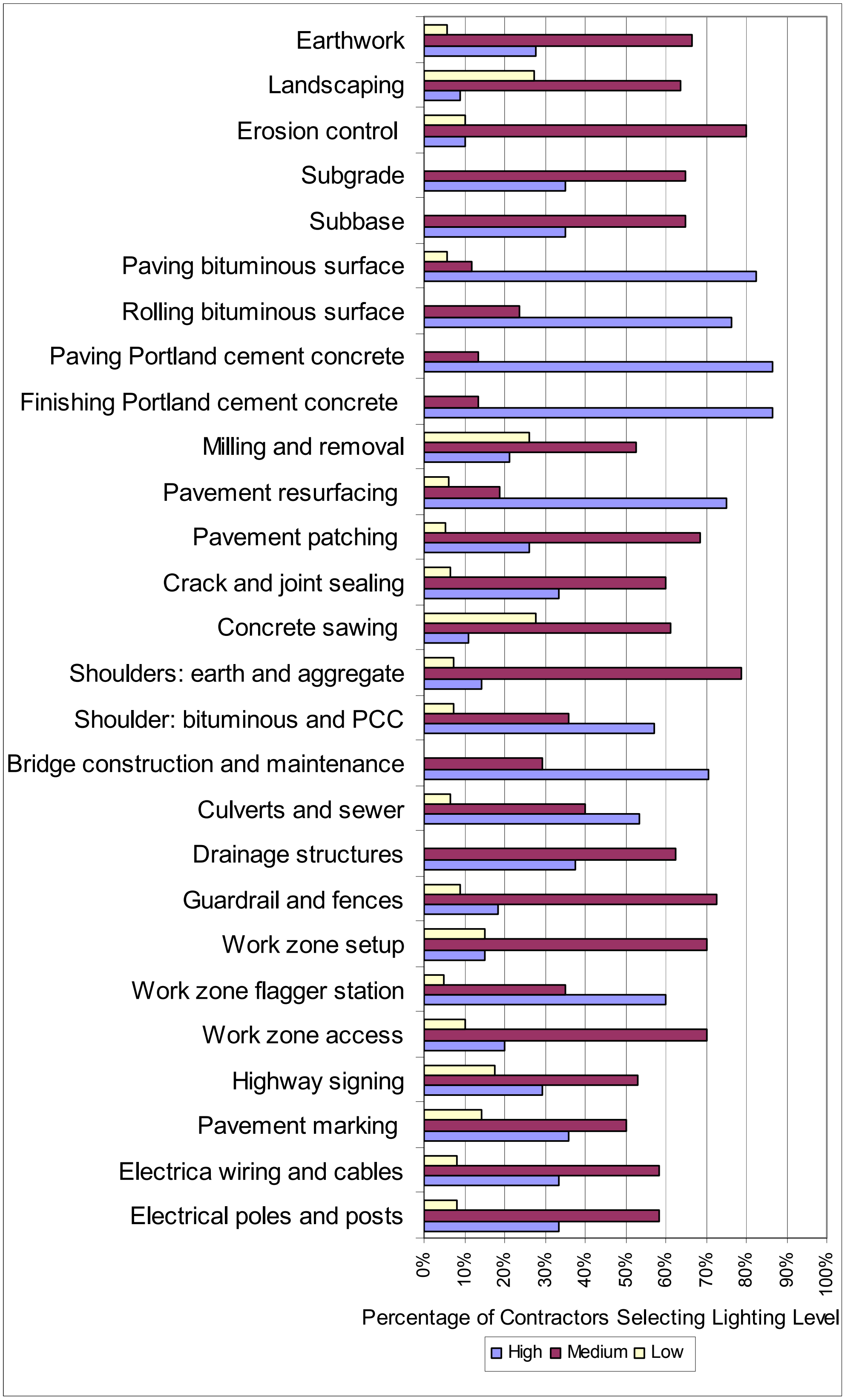


Figure 3.12. Distribution of Lighting Level Requirements- Contractors.

3.5.2 DOT Standards for Lighting Nighttime Construction

The responses from different state DOTs revealed that the available standards for lighting in nighttime construction are limited. Only 8 respondents out of 20 states indicated that their DOT has provisions for lighting nighttime construction. These eight states are Florida, Missouri, Oregon, Washington, New York, Maryland, Mississippi, and Michigan. The complete documents obtained from these states can be found in Appendix E.

3.5.2.1 Florida DOT

The Florida DOT's standards state that lighting should be provided during active nighttime operations for proper workmanship and inspection. The standards further specify the following requirements for lighting nighttime construction activities:

- A minimum light intensity of 54 lux (5 fc) should be provided.
- Lighting should be arranged to prevent interference with traffic and minimize unnecessary glare to adjacent properties.
- Lighting should be operated only during active nighttime construction operations.
- Lighting meters should be provided for inspection of lighting levels.
- The required lighting levels may be achieved through the use of portable floodlights, standard equipment lights, existing roadway lighting, or any other lighting method approved by the engineer.
- A lighting plan must be submitted for engineer approval before nighttime work can begin.

- Variable message signs should be used to alert approaching road users of lighted construction zones. Those signs should be operated only during active nighttime construction operations.
- The cost of lighting arrangements should be included in the price of the contract.

3.5.2.2 Missouri DOT

The Missouri DOT has a limited standard that includes only a single provision for lighting nighttime construction operations. This standard states that "If work is performed during nighttime hours, the contractor shall provide the necessary lighting and take the necessary precautions to protect the workers from harm."

3.5.2.3 Oregon DOT

The Oregon DOT's standards offer some general provisions for temporary lighting during nighttime construction. These provisions include the following:

- For nighttime flaggers, temporary illumination should be provided to illuminate an area of at least 12 m (40 ft) diameter at ground level. Portable illumination should be equivalent to 200w to 250w high-pressure sodium luminarie.
- Shielding should be provided to prevent lighting from adversely affecting traffic.
- The item "temporary illumination" should be included in the lump sum amount of the contract, and should cover all materials required by the

plans and specifications, and for minor adjustments not requiring disassembly.

3.5.2.4 Washington DOT

The Washington DOT does not have specifications for nighttime construction lighting arrangements. Special clauses of some contracts supplement the standard specifications and establish some requirements for temporary lighting systems. These requirements, however, are intended for fixed lighting at detours and temporary roads during construction, and not for lighting nighttime construction areas.

3.5.2.5 New York DOT

In 1995, the State of New York DOT developed specifications for lighting nighttime construction operations. The specifications provide recommendations for: (1) lighting plans, (2) inspection procedures, (3) illuminance levels, (4) lighting equipment, and (5) glare control.

A Lighting Plan

The specifications require that the contractor submit a lighting plan to the DOT engineer 30 days before the start of nighttime construction that includes: (1) a layout of light towers indicating both their spacing and lateral placement; (2) specifications of light towers and their electrical power source; (3) technical specifications for all lighting fixtures, including power rating and photometric charts; (4) lighting calculations demonstrating that the illuminance requirements will be met by the plan;

(5) details of any supplemental hardware needed for glare control; and (6) details of lights to be attached to construction equipment.

Inspection Procedures

In all operations involving nighttime construction, contractors are responsible for providing the DOT engineer with a photometer to measure the illuminance levels for compliance with the required levels throughout the nighttime operations. The DOT engineer must measure the illuminance levels by taking readings spaced approximately 3 m (10 ft) throughout the area tested. The engineer must inspect and evaluate any severe glare that may impair driver visibility in any path open to the public.

Illuminance Levels

The minimum average illuminance levels required for various construction activities within the work zone are grouped into three categories as shown in Table 3.2, according to the level of accuracy required to perform the task. For asphalt paving, milling operations, and bridge decks, level II illuminance levels must be provided 15 m (50 ft) ahead of and 30 m (100 ft) behind the paving or milling machine in addition to providing level I illuminance for a minimum of 120 m (400 ft) ahead of and 240 m (800 ft) behind the machine.

Table 3.2. NYSDOT Requirements for Minimum Illuminance Levels.

Application	Level	Minimum Average Illuminance Level Requirements
• General construction operations, including: excavation, cleaning and sweeping, landscaping, and planting and seeding. • Lane and/or road closures continuously throughout the period of closure, including the setup and removal of the closures.	I	54 lux (5 fc)
• Asphalt paving, milling, and concrete placement and/or removal.	II	108 lux (10 fc)
• Pavement or structural crack filling, joint repair, pavement patching and repairs, installation of signal equipment or other electrical/ mechanical equipment. • Tasks involving fine details or intricate parts and equipment.	III	216 lux (20 fc)
* The illuminance levels uniformity ratio (average illuminance levels to minimum illuminance levels) over the work area shall not exceed 5:1.		

Lighting Equipment

Lighting fixtures recommended in this specification consist of: (1) ground-mounted or trailer-mounted light towers, (2) light towers attached to construction equipment, and (3) flood lights mounted on construction equipment. The source of power for some of these fixtures is recommended to be a portable generator provided by the contractor with adequate output and fuel tank capacity to ensure continuous lighting.

Ground-mounted or trailer-mounted light towers are recommended for use as the primary means of lighting, providing level I illuminance of 54 lux (5 fc) all over the work zone. These towers are to be supplemented by lighting fixtures mounted on construction equipment to provide higher levels of illuminance where required.

Light towers were recommended for attachment to large highway construction equipment (e.g., paving machines, finishing machines, and milling machines) to provide the required level of illuminance for the tasks to be performed. These towers should not exceed a height of 4 m (13 ft) above the ground, and should provide the required illuminance level for the specified distance in front of and behind the equipment. The maximum allowable illuminance uniformity ratio in the areas lighted by these towers is 5:1.

Floodlights are to be mounted on all other construction equipment not requiring lighting towers. These lights should consist of a minimum of two 500w floods facing in each direction of travel of the equipment to provide a minimum of 10 lux (1 fc) measured 18 m (60 ft) in front of and behind the equipment.

3.5.2.6 Michigan DOT

The Michigan DOT has a special provision that supplements its standard specifications, last revised in 1996. The following is a summary of this provision:

- Contractors should furnish, install, and maintain adequate lighting for workers to perform nighttime operations and for inspectors to perform their work.
- The lighting systems can be fixed, portable, or equipment-mounted.
- The contractor should also provide a power source of adequate capacity.
- Lighting fixtures should conform to the Michigan Manual on Uniform Traffic Control Devices (MMUTCD), which states that “In no case shall floodlighting be permitted to glare, shine, or be directed into the eyes of

oncoming drivers. The adequacy of floodlight placement and elimination of potential glare can best be determined by driving through and observing the floodlight area from each direction on the main roadway after initial floodlight setup."

- Pavers should be mounted with lighting equipment that provides a minimum illuminance of 108 lux (10 fc) for a distance of 30 to 60 m (100 to 200 ft) behind the paver. Paver-mounted lighting towers should be of adjustable height and rotatable horizontally, and they should be mounted at least 2 m (6 ft) above the paver.
- Rollers should be provided with four headlights, two facing in each direction of travel and lighting a distance of 15 to 30 m (50 to 100 ft) in front of and behind the roller. Roller-mounted lighting towers should be mounted at least 1.2 m (4 ft) above the roller.
- Sufficient lighting should be provided for all bituminous paving operations from pavement preparation to finish rolling and areas where nighttime removal, replacement or repair of pavement and crack cleaning and sealing is taking place.
- Backup lighting should be provided to replace any failed lighting equipment.
- The engineer can suspend all night work except for traffic control if lighting is inadequate on any nighttime work.
- Payment for lighting for the entire project should be made in a lump sum item.

3.5.2.7 Mississippi DOT

The Mississippi DOT has special standards for lighting nighttime construction. Those standards include the following:

- The Contractor shall submit, for the Engineer's review and approval, a lighting plan showing the type and location of lights proposed for use during night work.
- The Contractor may be required to take lighting level measurements in the presence of the Engineer at locations designated by the Engineer to verify compliance with the approved lighting layout submittals. Field light level measurements shall be equal to or exceed light levels on the submittals
- Tower lights shall be of sufficient wattage and/or quantity to provide an average maintained horizontal illuminance greater than 216 lux (20 fc) over the work area.
- The machine light fixtures shall be of sufficient wattage and/or quantity to provide an average maintained horizontal illuminance greater than 108 lux (10 fc) on the machine and the surrounding work area. Machine lights are in addition to conventional type headlights, which are necessary for maneuverability.

3.5.2.8 Maryland DOT

The Maryland Department of Transportation has a standard that addresses nighttime construction lighting. This standard specifies that floodlighting should be used when the average horizontal illuminance production by the existing lighting system is less than 216 lux (20 fc) over the construction area. The standard further requires the submission of a lighting plan to the Engineer showing the aiming and locations of the floodlights. After the plan is approved, the Engineer shall inspect the floodlighting to ensure that it provides 216 lux (20 fc) without producing glare to the traveling public. If portable generators are used, the standard requires the availability of backup power sources at all times on the job site. Another section of the standard specifications requires the reduction of the lighting produced by traffic control device such as arrow panels to prevent glare to road users from these devices.

3.6 Design Parameters

A designer must set design parameters that satisfy certain lighting criteria. This section presents current practices concerning lighting sources, lighting equipment positioning on site, and glare control measures, as reported by the surveyed contractors and resident engineers.

3.6.1 Lighting Sources

In lighting design, several parameters related to the lighting source should be selected. These parameters include: (1) types of lamps, (2) number of lighting towers, (3) power source for lighting towers, and (4) ownership of these lighting sources. The following sections outline some of the survey findings concerning these parameters.

3.6.1.1 Types of Lamps

A number of lamp types can be used for exterior lighting. These types have varying operational characteristics that should be considered in selecting light sources for nighttime construction. Contractors participating in the survey were asked to name the types of lamps they used in nighttime construction. Figure 3.13 shows the percentage of respondents using each type of lamp in their previous projects. The results indicate that 30% of contractors did not know the types of lamps they were using. The answers of those who knew, ranged over a wide variety of lamp types. It was, therefore, not possible to distinguish with statistical significance which lamp types are most commonly used. This impossibility, combined with the high percentage of “not sure” answers, indicates that the contractors really did not care or know too much about the lamp types and their effects.

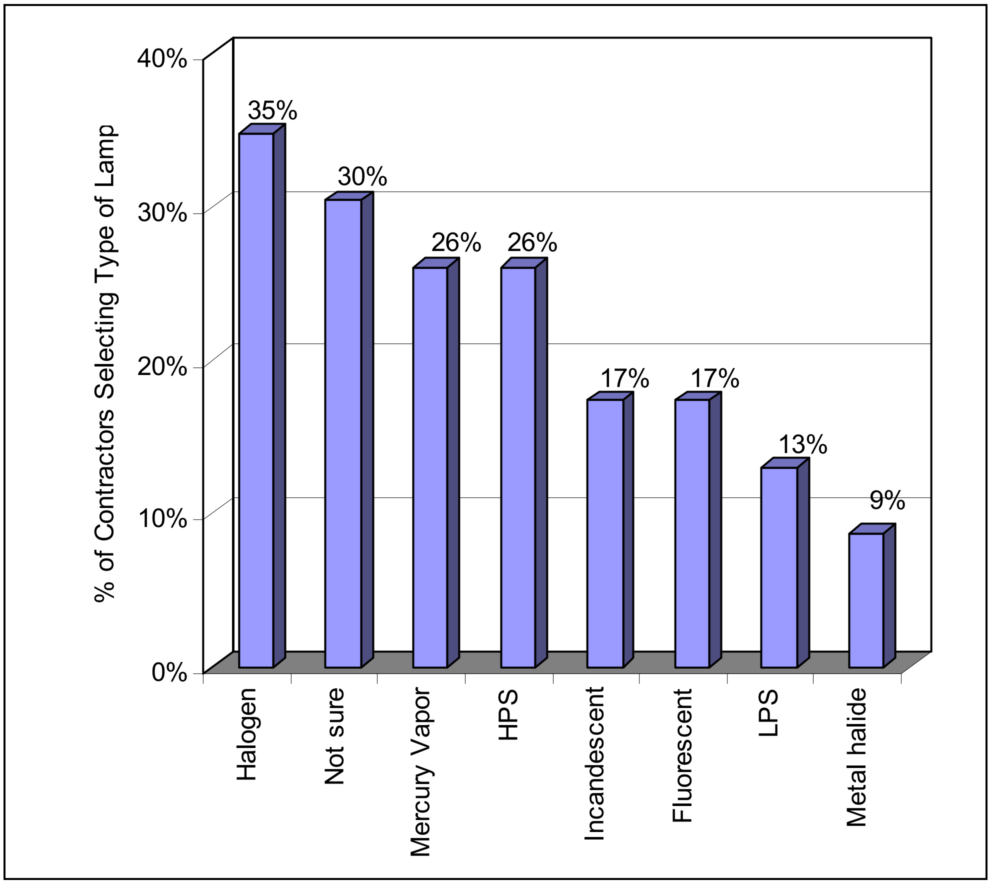


Figure 3.13. Types of Lamps

3.6.1.2 Number of Lighting Towers

Lighting towers are the main source of temporary lighting in work zones. The number of lighting towers used in such zones determines the spacing and configuration of lighting sources. This is why participants in the contractors’ survey were asked to indicate the number of lighting towers they usually use in nighttime construction operations. Their responses are shown in Figure 3.14.

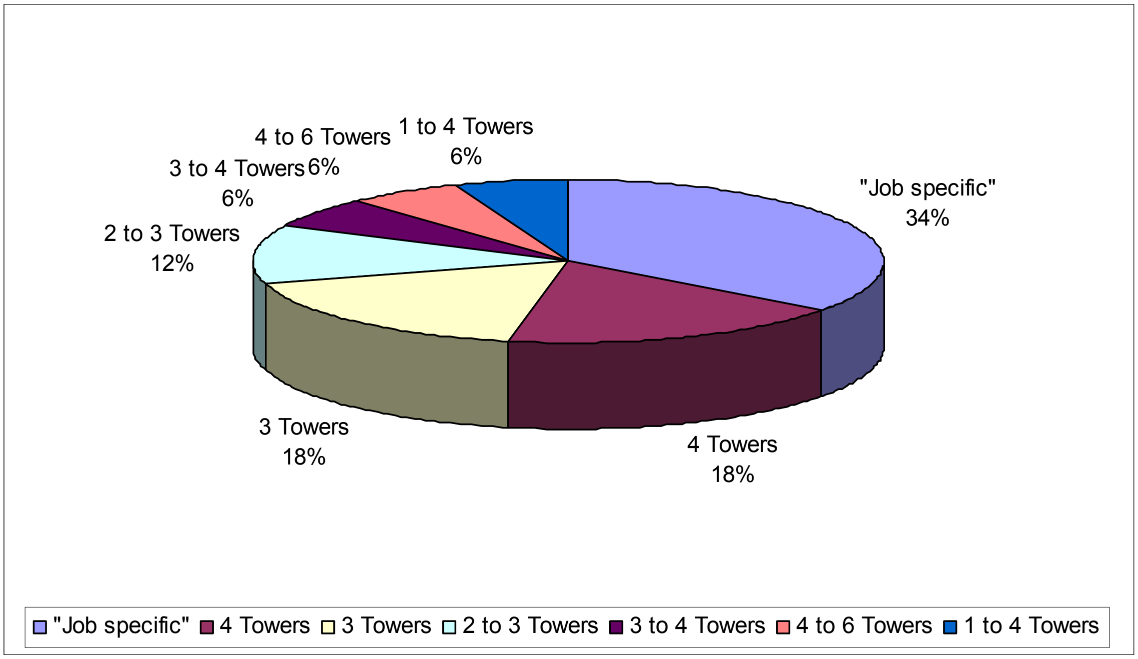


Figure 3.14. Number of Lighting Towers.

34% of the participants indicated that the number of lighting towers is job-specific, and depends on the type of work performed. The majority of the remaining respondents use three to four lighting towers in nighttime construction regardless of the work being performed.

3.6.1.3 Electric Power Sources

The electrical power sources used for lighting equipment can be either separate portable generators or built-in generators. The majority of the surveyed contractors indicated that they use separate portable generators, as shown in Figure 3.15. Fixed power supply sources were used by only 14% of the respondents; this can be attributed to the mobile nature of highway construction operations. The main reason for the popularity of portable generators is that they are shared with other equipment, and would be needed by the contractor apart from lighting measures.

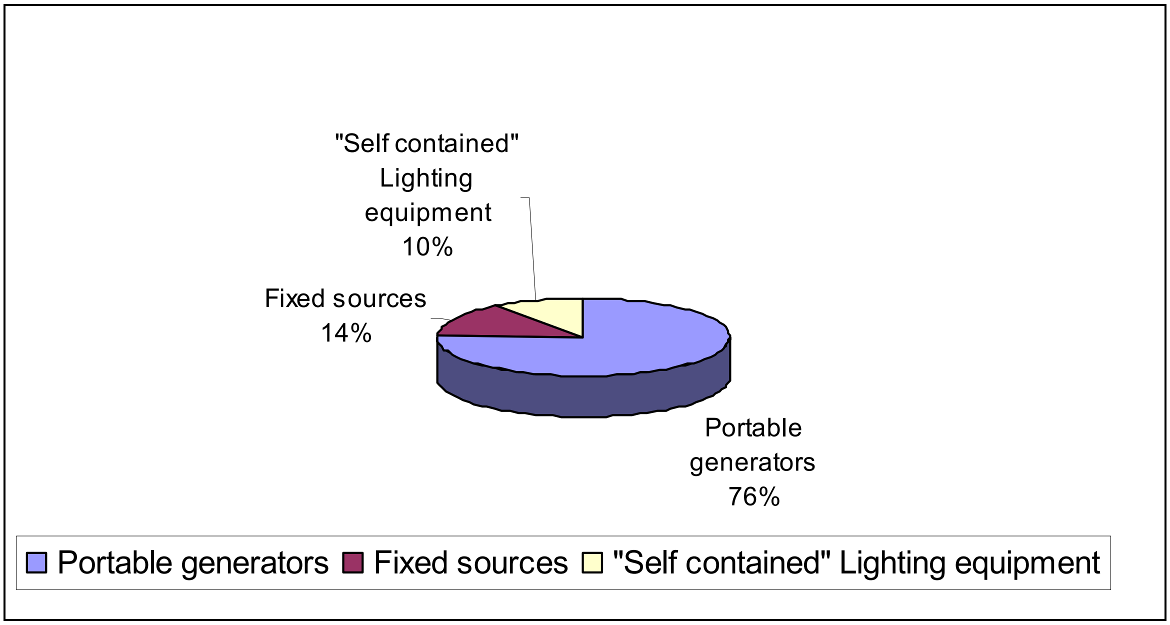


Figure 3.15. Electrical Power Sources.

3.6.1.4 Lighting Equipment Ownership

In response to a question about the ownership of lighting equipment, the percentage of contractors who indicated that they rent, own, or lease this equipment was 50%, 35%, and 15% respectively, as shown in Figure 3.16.

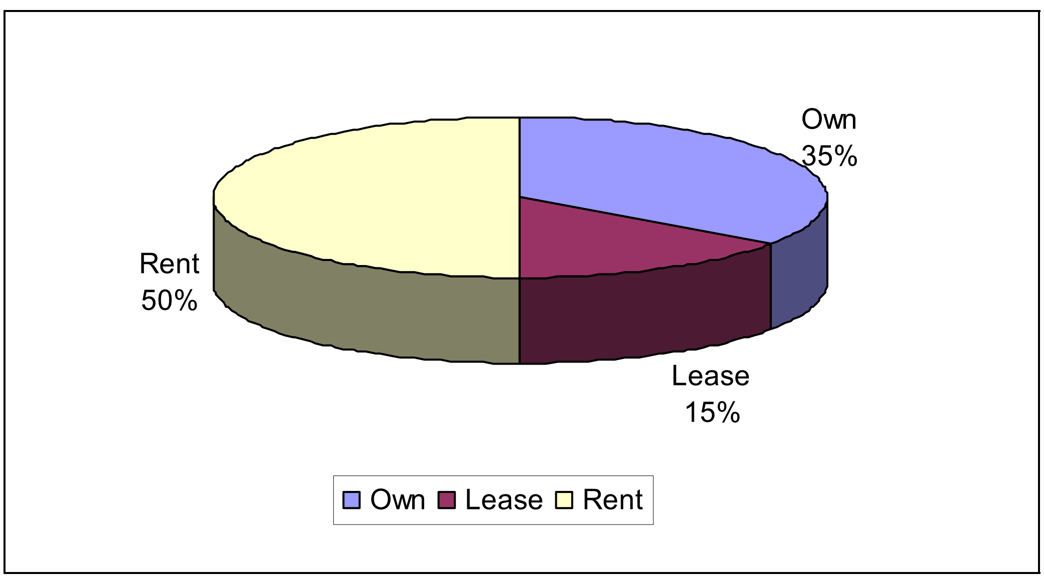


Figure 3.16. Lighting Equipment Ownership

3.6.2 Lighting Tower Positioning

The positioning of lighting equipment in nighttime construction projects is constrained by characteristics particular to nighttime construction operations. Participants in the contractor survey were asked to indicate the relative importance of a set of factors that affect lighting tower positioning, namely: (1) construction equipment movement, (2) road user movement, (3) lighting tower mobility, and (4) light trespass. The respondents were also asked to list any other factors that they might consider in their decision making. Figure 3.17 shows the average relative importance of the four identified factors, as reported by the contractors. The movement of construction equipment and road user movement were reported as the most important factors to ensure and maintain safety during nighttime work.

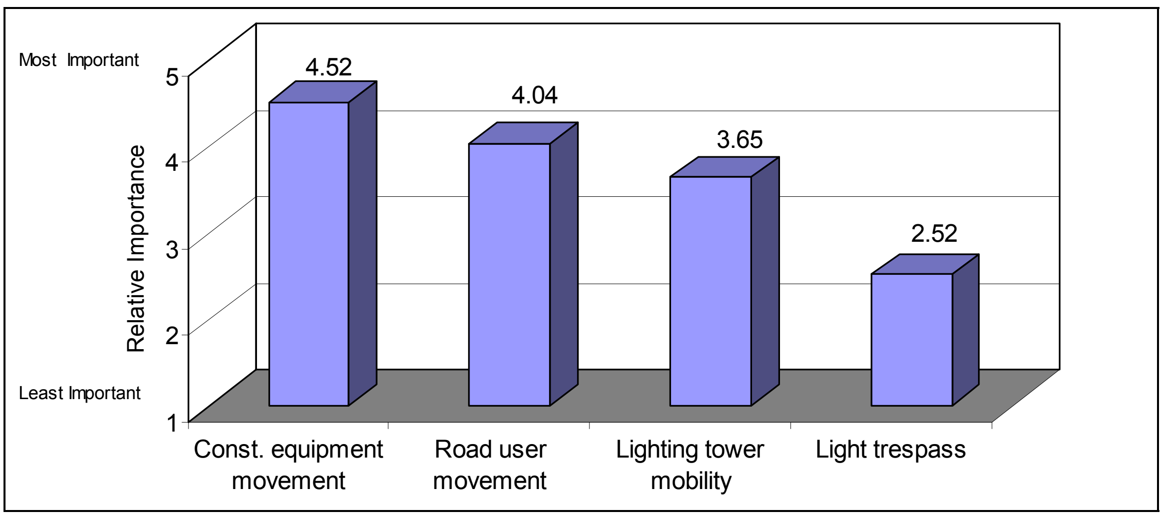


Figure 3.17. Factors Affecting Positioning of Lighting Equipment

3.6.3 Glare Control Measures

Glare to road users was reported to be one of the most significant problems associated with nighttime construction lighting, as shown in Figures 3.18 and 3.19. Glare control measures for nighttime construction lighting include: (1) reducing lighting levels, (2) cutoff luminaries, (3) glare screens, (4) louvers, (5) visors, and (6) repositioning lighting equipment. These six measures are considered effective in reducing glare to travelers and workers. Glare screens are meshes affixed in the direction of traffic flow to prevent light from affecting the visual ability of road users. Louvers and visors are fixtures attached to luminaries to direct light to desired areas and prevent light emission at high angles, which causes both glare and light trespass. The surveyed contractors were asked to select the measures from the above list that they usually use to control glare, and to add any others that they might use. Figures 3.18 and 3.19 show the percentage of participants who indicated they used the identified glare control measures in their previous projects. Repositioning lighting towers was the most frequently used measure of glare control followed by reducing lighting levels. Few projects utilized louvers. Only 10% of resident engineers reported that contractors use glare screens, and 5% reported them employing louvers as a glare control measure. These statistics indicate that contractors rely heavily on repositioning for glare control.

The above statistics confirm the conclusions drawn from the resident engineer surveys. Glare is potentially dangerous to travelers and workers because of its temporary blinding effect. Effective means of measuring and mitigating glare effects are important when developing criteria for lighting design and inspections.

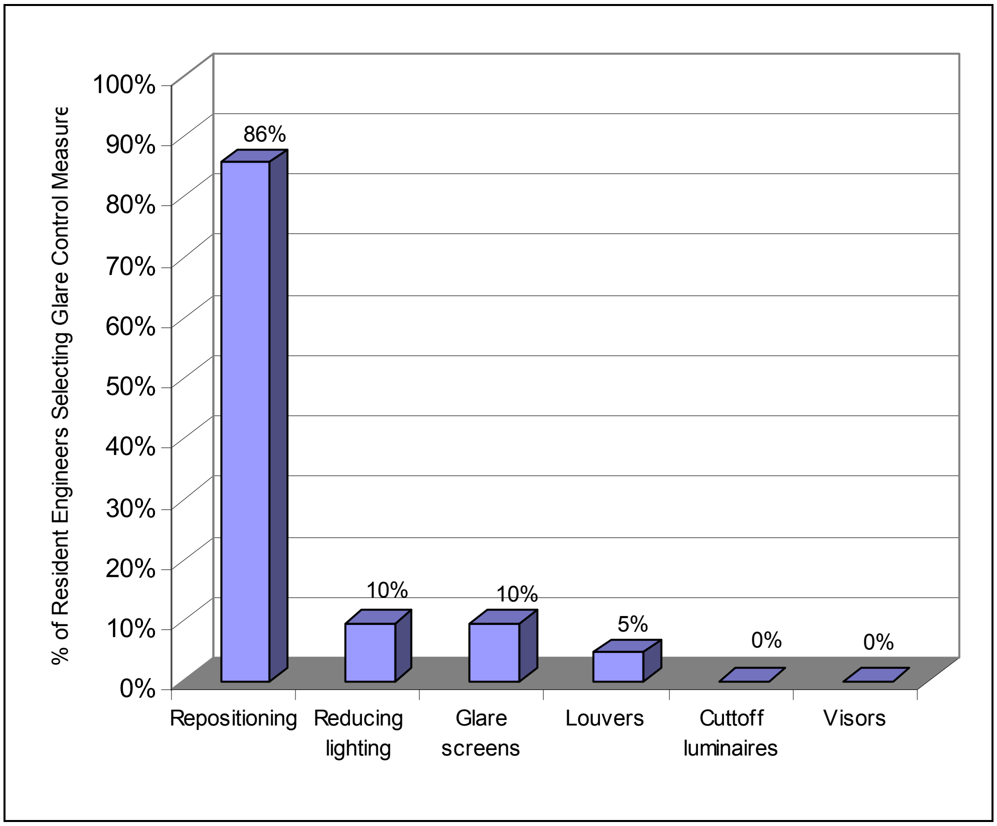


Figure 3.18. Glare Control Measures (Resident Engineer Survey)

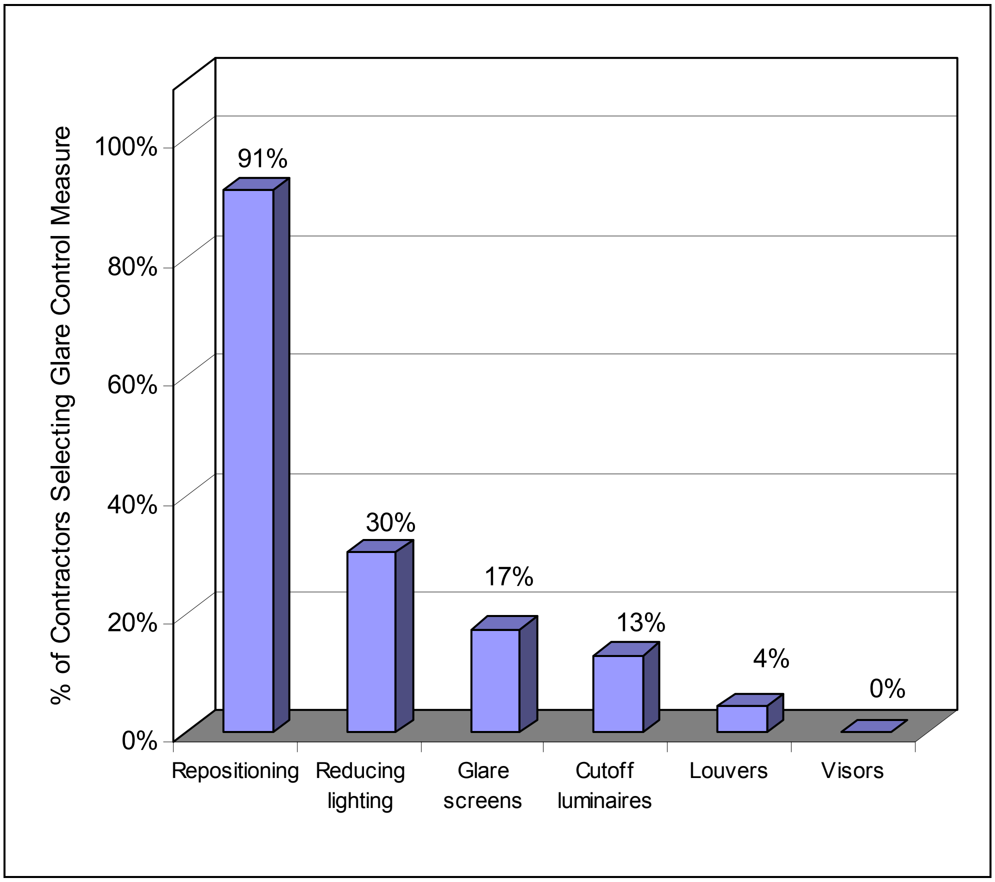


Figure 3.19. Glare Control Measures (Contractor Survey)

3.7 Design Procedures

Design procedures for lighting nighttime construction must develop a lighting plan with an appropriate arrangement of lighting equipment on site. This section presents findings concerning lighting plans and site arrangements of lighting equipment.

3.7.1 Lighting Plan

Although operational aspects of nighttime construction lighting require the participation of resident engineers and contractors, the responsibilities for providing lighting arrangements and for judging their suitability should be clearly defined in advance. A lighting plan is needed before starting nighttime construction to ensure that the lighting arrangements are properly designed and not arbitrarily chosen on site. In a question regarding the measures used to ensure the conformity of the lighting arrangements provided on site, only 5% of the resident engineer respondents indicated the use of a lighting plan for that purpose. The participants in the survey were asked to indicate which party should prepare the lighting plan for nighttime construction projects. As shown in Figure 3.20, 44% of the resident engineers indicated that contractors should be the party who prepares a lighting plan, and 39% indicated that IDOT engineers should prepare it. A considerable percentage of surveyed contractors (46%) indicated that they were responsible for developing a lighting plan in their previous projects. The responsibilities for lighting plan preparation and approval should be clearly stated and accepted by all of the involved parties.

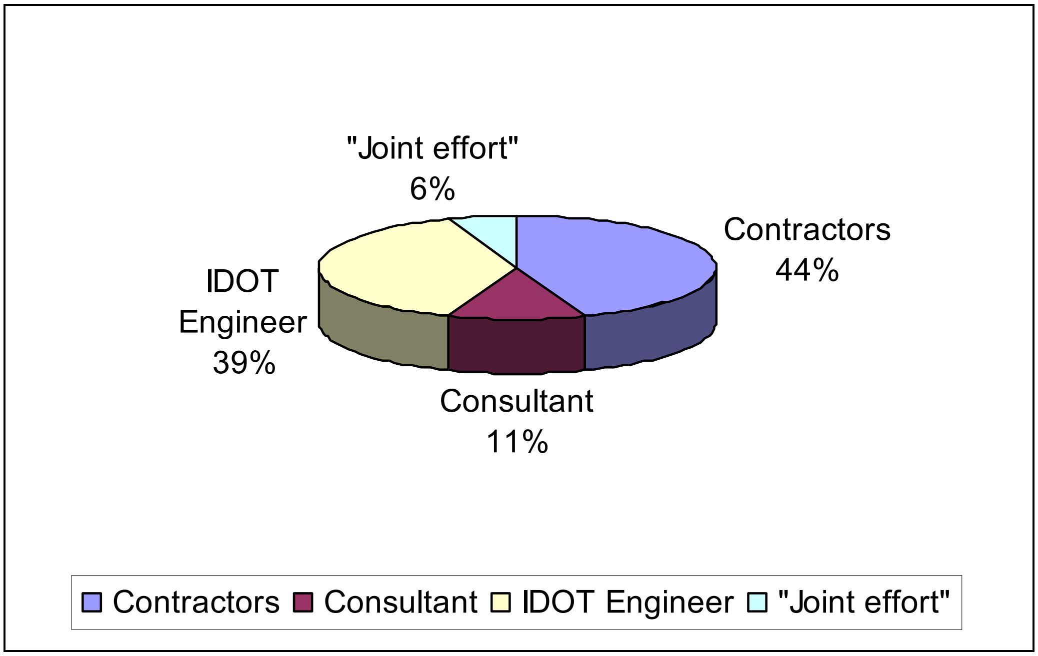


Figure 3.20. Lighting Plan Responsibility (Resident Engineer Survey)

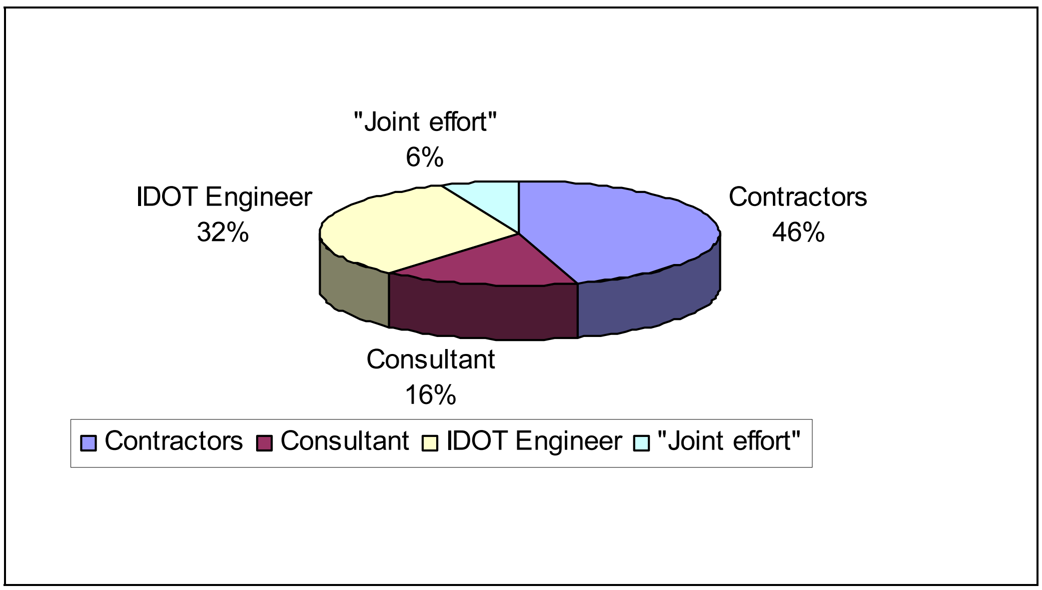


Figure 3.21. Lighting Plan Responsibility (Contractor Survey)

3.7.2 Site Arrangement of Lighting Equipment

Nighttime construction usually involves activities with different lighting requirements. Field personnel need to manage the available lighting sources to satisfy the requirements of the construction activities. This may require the application of measures such as reducing lighting or modifying luminaries' mounting heights, spacing, and/or aiming angles. Participants in the contractor survey were asked to select the measures that they usually use. Figure 3.22 shows the percentage of contractors who indicated that they used each of these measures to adjust lighting levels in their previous projects.

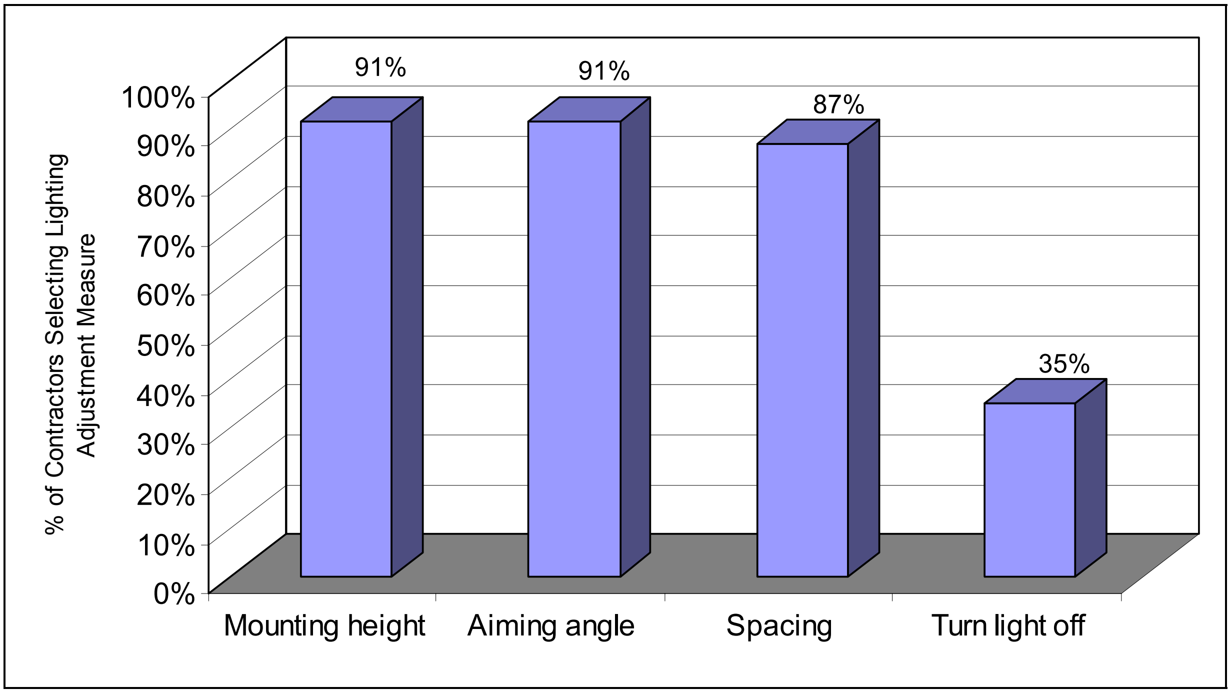


Figure 3.22. Measures to Adjust Lighting Levels

As shown in Figure 3.22, contractors change the mounting height of luminaries, aiming angle of luminaries, and lighting tower spacing according to the needs of construction activities. The least-used measure is turning some lights off, and this can be understood since field personnel usually utilize lighting equipment to increase lighting levels or increase the area covered by lighting sources.

3.8 Lighting Inspection

The previous sections outlined responses concerning lighting design criteria, parameters, and measures. This section presents a discussion of the methods often used to inspect lighting conditions on nighttime construction sites. The participants in the resident engineer survey were asked to indicate the measures they usually use to ensure the conformity of the lighting arrangements on site to the lighting requirements of IDOT. The measures include: (1) a lighting plan and calculations which need to be submitted by contractors before construction, (2) field inspection of lighting levels, (3) field inspection of glare, and (4) field inspection of light trespass. Figure 3.23 shows the percentage of the resident engineer respondents who indicated that they used each of these measures in their previous projects. The most-used inspection measure is the inspection of lighting levels followed by that of glare levels, i.e. 67% of resident engineers checked the lighting levels, and 52% conducted field inspection of glare.

The surveyed resident engineers and contractors were asked to indicate the method used to inspect lighting levels, glare, and light trespass. The resident engineer survey showed that almost all participants use engineering judgment to inspect lighting levels, glare, and light trespass. None of the resident engineers used a light meter for lighting inspection.

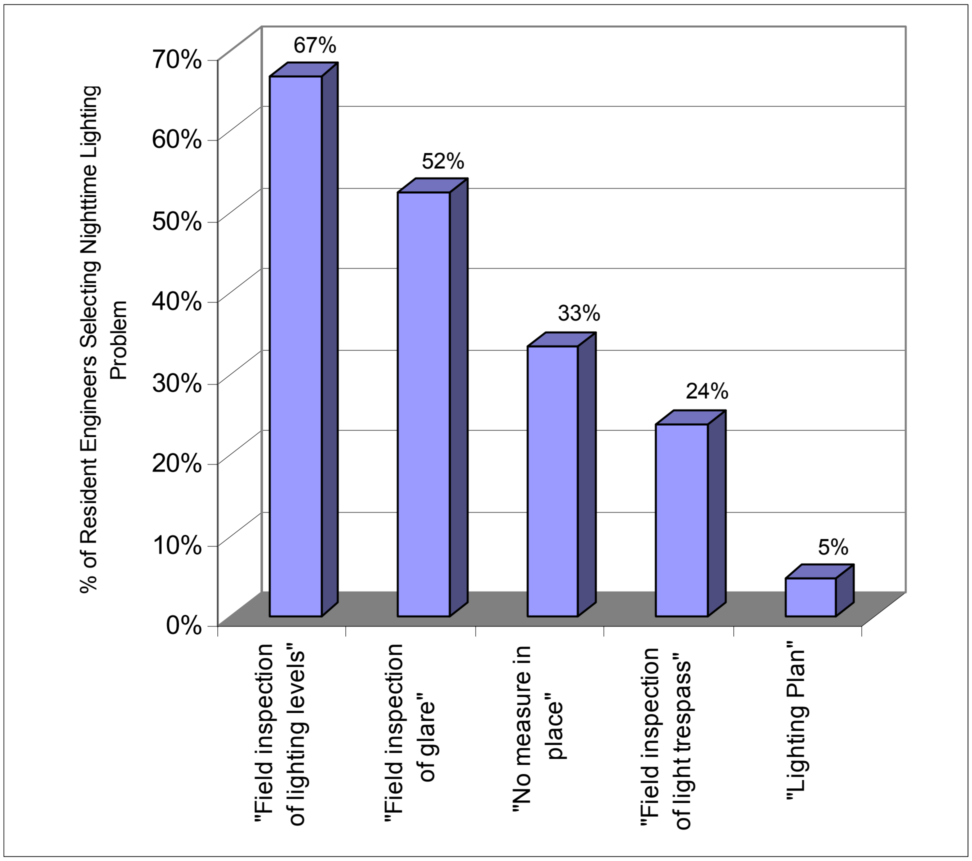


Figure 3.23. Inspection Measures in Nighttime Construction Lighting

90% of the contractor respondents reported relying on engineering judgment to inspect lighting levels, and 5% of them indicated they used light measuring equipment. For glare inspection, 86% of respondents indicated they used engineering judgment, while 9% indicated that they do not inspect glare at all. For light trespass, 95% of contractors also reported the use of engineering judgment to inspect light trespass, while 5% indicated that they do not inspect light trespass.

91% of the contractor respondents indicated that they do not use any standards or guidelines for lighting arrangements in nighttime construction, and only 56% of them indicated that guidelines for nighttime construction lighting would help them in their work. A full 75% of the resident engineer respondents indicated that guidelines for nighttime construction lighting would help in their work. The difference between the viewpoints of contractors and resident engineers on this issue can be understood since contractors see guidelines as an additional requirement that they will need to satisfy, while resident engineers view them as a helpful tool for ensuring adequate lighting levels on nighttime construction sites.

To identify the preference of the field personnel in design and/or inspection tools that would be most helpful in their work, the surveyed resident engineers and contractors were asked to select between light measuring equipment, paper-based manual, or software. Figures 3.24 and 3.25 show the preferences of both resident engineers and contractors. The Figures show that 48% of the resident engineer respondents preferred light measuring equipment, while 39% preferred a paper-based manual, and 13% preferred software. The contractors showed the same tendencies, with 39% preferring light measuring equipment, 32% a paper-based manual, and 29% software. These two statistics show that both resident engineers and contractors desire a light measuring device that is easy to use.

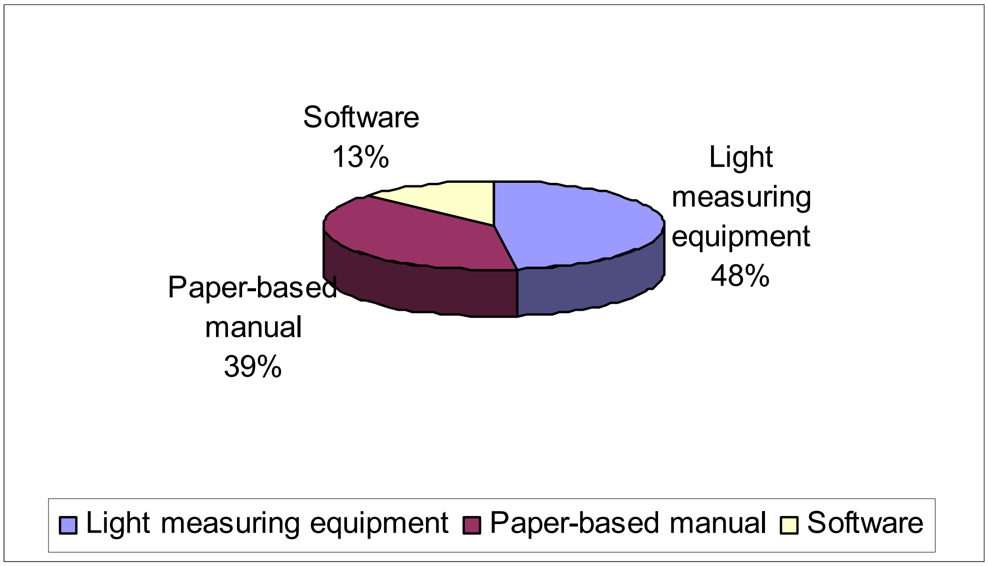


Figure 3.24. Resident Engineers' Inspection Tool Preference

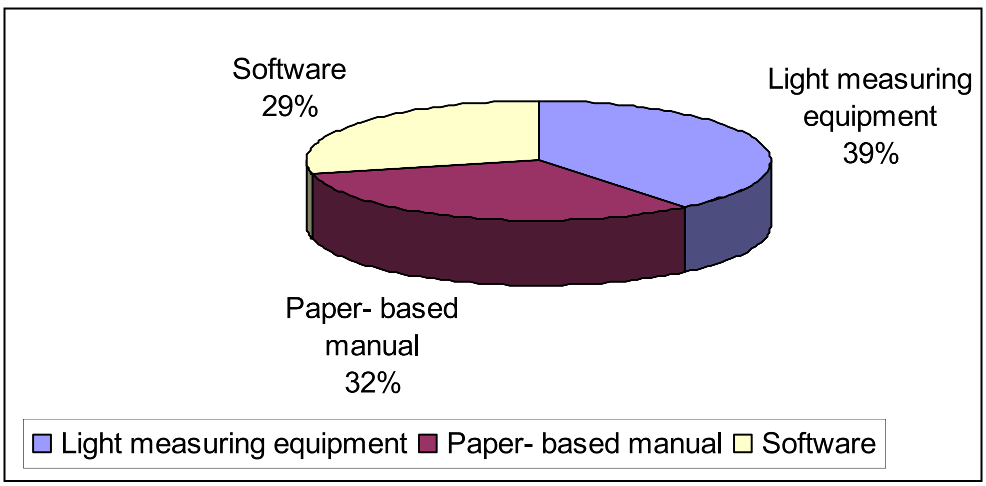


Figure 3.25. Contractors' Design Tool Preference.

3.9 Summary

The conducted surveys have demonstrated that nighttime construction is gaining acceptance and popularity among construction professionals. The advantages and challenges of nighttime construction were examined and evaluated by professionals in the field. The main advantages of nighttime construction can be summarized as follows:

- Reduced traffic congestion.
- Reduced project duration.
- Reduced impact on surrounding businesses.
- Minimal economic effect due to delay.
- Minimal air pollution from gases emitted by idling vehicles in traffic congestion.
- Increased freedom to plan lane closures.
- Enhanced work conditions at night.
- Faster delivery of material at night.

The main challenges of the practice on the other hand can be summarized as follows:

- Accidents involving road users.
- Accidents involving workers.
- Lower quality.
- Reduced productivity.
- Complaints from neighboring properties.
- Difficulty in quality inspection.
- Difficulty in inspecting lighting conditions.
- Difficulty in personnel coordination.

Among the main reported challenges were nighttime lighting problems, which were also examined in this study by surveying the current lighting design criteria, parameters, and methods. The results show that there are limited available standards to regulate lighting design in other states. The results also show that guidelines for lighting design and inspection are not well established, despite the urgent need for such guidelines, as expressed by both contractors and resident engineers. One surveyed contractor stated that "*the burden of approving a contractor's night lighting plan is often placed on the CM/CE without guidelines for evaluating the quality of a plan or without specifications and specific light levels that the contractor needs to develop a plan to meet; 'as needed' or 'as determined by the engineer" are too open to judgment to be enforceable.*" Another resident engineer emphasized that "*specific wording that would be part of the contract documents on the actual amount of light (lumens) required for a given work task would be helpful.*" The survey results further demonstrate that most contractors rely on repositioning lighting towers for glare control, which may not be adequate due to special constraints related to the construction activity. The survey also shows that easy-to-use light measuring devices are needed for assuring the quality of the lighting arrangements provided. In conclusion, the survey has provided useful information on the practices and needs of nighttime highway construction.

CHAPTER 4
DESIGN CRITERIA FOR LIGHTING NIGHTTIME CONSTRUCTION OPERATIONS

4.1 Introduction

The results of the surveys presented in the preceding chapter indicated that nighttime construction is gaining acceptance among many state Departments of Transportation (DOTs) in the United States. This increase in the volume of nighttime work was attributed by DOTs officials to a number of advantages that can be realized by adopting this practice including: (1) reduced construction related traffic congestions; (2) increased freedom in planning lane closures; and (3) reduced project duration. In order to ensure quality and safety in these nighttime construction projects, proper and adequate lighting conditions need to be provided on site. Lighting was reported to be one of the most important factors affecting quality, safety, cost and productivity of nighttime construction projects (Kumar 1994). Providing adequate lighting conditions on site entails establishing proper and practical lighting design criteria that can be satisfied by contractors and enforced by DOTs' officials in nighttime highway construction projects.

This chapter presents the development of design criteria for lighting nighttime construction operations. These design criteria are developed by analyzing and synthesizing available standards and recommendations acquired from a number of sources including: (1) professional organizations; (2) state DOTs; and (3) surveyed contractors and resident engineers.

4.2 Lighting Design Criteria

In order to ensure the availability of adequate lighting conditions during nighttime highway construction operations, a number of design criteria need to be satisfied on site including: (1) illuminance; (2) uniformity; (3) glare; and (4) light trespass (IESNA 1999; CIE 1986; and ILE 2000).

4.2.1 Illuminance

Illuminance is an important criterion in lighting design since it represents the quantity of lighting and significantly affects other lighting criteria (e.g. luminance). It can be defined as the density of luminous flux incident on a certain surface, and can be measured in lux or fc (Kaufman 1981). Illuminance is used as a design criterion for many exterior lighting applications (CIE 1986, IESNA 1999). The use of illuminance as an important design criterion in roadway lighting has shown to be beneficial in reducing pedestrian accidents, reducing fear of crime, and promoting business and public usage of roads at night (IESNA 2000).

4.2.2 Lighting Uniformity

Lighting Uniformity is a design criterion that identifies how evenly light reaches different parts of a target area. It can be measured and quantified using one of two ratios: (1) an average-to-minimum ratio which represents the ratio of the average illuminance at all points to the minimum illuminance in the studied area; and (2) a maximum-to-minimum ratio which represents the ratio of the maximum illuminance at any point to the minimum illuminance in the studied area (IESNA 2000).

4.2.3 Glare

Glare is a term used to describe the sensation of annoyance, discomfort or loss of visual performance and visibility produced by experiencing luminance in the visual field significantly greater than that to which the eyes of the observer are adapted (Triaster 1982). Disability glare is the most severe type of glare and can be defined as the veiling effect produced by bright sources or areas in the visual field that result in decreased visual performance and visibility (Kaufman 1981). Disability glare is also known as veiling luminance (L_v), and can be calculated at a particular point P due to a certain light source as shown in Figure 4.1 using Equations 4.1 to 4.3 (IESNA 2000). Veiling luminance due to all light sources at a certain point P ($\sum L_v$) can be calculated by summing up the veiling luminance from all individual contributing sources.

$$L_v = \frac{K}{\theta^n} \tag{4.1}$$

$$K = 10 * E_v \tag{4.2}$$

$$n = 2.3 - 0.7 * \log_{10}(\theta) \quad \text{for} \quad \theta < 2 \tag{4.3}$$
$$n = 2 \quad \text{for} \quad \theta >= 2$$

Where,

L_v = veiling luminance from one individual luminaire;

K = a variable that can be calculated using Equation 4.2;

θ = angle between the line of sight and the luminaire in degrees, as shown in Figure 36;

n = a variable which can be calculated using Equation 4.3; and

E_v = vertical illuminance at the plane of the observer's eye.

Veiling luminance can be quantified using Equations 4.1 to 4.3 in order to control glare during nighttime hours. For example, in roadway lighting design, glare is controlled by specifying a maximum allowable ratio of the maximum veiling luminance (max $\sum L_v$) to the average pavement luminance. This maximum allowable ratio is considered as a control measure of glare in roadway lighting, and it ranges from 0.3 to 0.4 depending on the category of road (IESNA 2000).

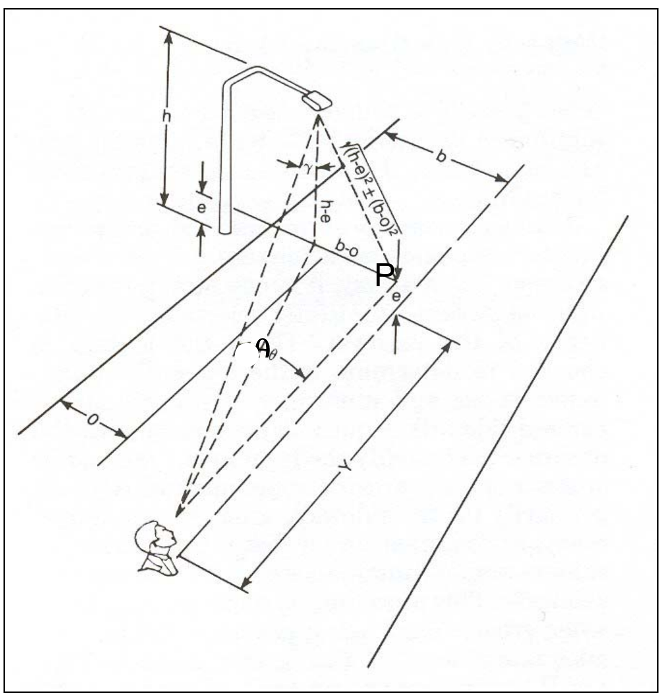


Figure 4.1. Angle between Line of Sight and Luminaire θ (IESNA 2000)

4.2.4 Light Trespass

Light trespass can be defined as “light from an artificial light source that is intruding into an area where it is not wanted or does not belong” (Connecticut Municipal Regulation 2001). This light may enter the boundaries of a privately owned property causing nuisance to its owners, and leading to a waste of energy (ILE 2000). Many municipal authorities have developed ordinances with quantifiable limits for light trespass. For example, the San Diego county in California limits stray light entering a property to 0.21 lux (0.021 fc), which is equivalent to the amount of illuminance from moon light, in both the horizontal and vertical planes at a point 1.5 m (5 ft) inside the owner’s property line. Another ordinance was developed in the village of Skokie, llinois, which defines the light trespass to be light from a roadway lighting system falling on adjacent properties with intensity more than 3 lux (0.3 fc) (Schaflik 1997). Milford county in Connecticut also developed an ordinance, which limits the maximum allowable illuminance on the edge of a property line to 1 lux (0.1 fc) and 5 lux (0.5 fc) for residentially and commercially zoned properties respectively. Watertown county in Connecticut on the other hand prevents the location of any lighting within five feet of any property lines (Connecticut Municipal Regulation 2001).

In another research study, the Illuminating Engineering Society of North America (IESNA) provided recommendations to control the impact of light trespass on adjoining properties (IESNA TM-2000). As shown in Table 4.1, the study recommended maximum allowable vertical illuminance limits to control light trespass that are dependant on: (1) ambient brightness of the area under consideration where higher limits are allowed for bright areas such as commercial zones and lower limits are permitted for dark areas such as rural residential zones; and (2) time of night, assuming that local authorities may set a curfew that imposes additional restrictions for light trespass during late-night hours (IESNA TM-2000). These limits for light trespass represent the maximum allowed vertical illuminance in the plane of an observer's eye at possible viewing locations of the light source, which are recommended to be measured at the edge of the property line (IESNA TM 2000).

Table 4.1. Recommended Light Trespass Limitations (IESNA TM-2000)

Environmental Zone	**Pre-Curfew Limitations***	**Post-Curfew Limitations***
Areas of low ambient brightness (suburban and rural residential areas where roadway lighting may be lighted to typical residential standards)	3.0 (0.30)	1.0 (0.10)
Areas of medium ambient brightness (e.g. urban residential areas where roadway lighting will normally be traffic route standards)	8.0 (0.80)	3.0 (0.30)
Areas of high ambient brightness (e.g. dense urban areas with mixed residential and commercial use with a high level of nighttime activity)	15.0 (1.50)	6.0 (0.60)

*Lux (foot candles) values on a plane perpendicular to the line of sight to the luminaire (s).

4.3 Professional Organizations Standards

A number of professional organizations have developed standards and recommendations to specify the lighting requirements for external work areas. This section provides a review of these available standards, especially those that focus on construction areas, including: (1) OSHA regulations; (2) ANSI standards; (3) NCHRP recommendations; (4) IESNA recommendations; (5) CIE recommendations; (6) Australian recommendations; and (7) FAA specifications.

4.3.1 OSHA Regulations

The Occupational Safety and Health Administration (OSHA) regulations for lighting requirements in nighttime construction were limited to the illuminance criterion and did not address the remaining criteria of lighting uniformity, glare and light trespass. OSHA specifies the minimum illuminance levels for different construction operations, as shown in Table 4.2 (Hutchings 1998).

Table 4.2. Minimum Illuminance Levels (Hutchings 1998).

Area of operation	Minimum Illuminance lux (fc)
General construction area lighting low activity	32 (3)
Outdoor active construction areas, concrete placement, excavation and waste areas, access ways, active storage areas, loading platforms, refueling and field maintenance area	54 (5)
Indoors: warehouses, corridors, hallways, stairways and exit ways	54 (5)
General construction plant and shops (e.g., batch plants, screening plants, mechanical and electrical equipment rooms, carpenter shops, rigging lofts and active storerooms, barracks, living quarters, locker or dressing rooms, mess halls, indoor toilets, and workrooms)	108 (10)
First aid stations, infirmaries and offices	324 (30)

4.3.2 ANSI Standards

The American National Standards Institute (ANSI) published "*Practice for Industrial Lighting*" that covers lighting requirements for four hundred and fifty five industrial activities. These lighting requirements were limited to the illuminance criterion, and did not address the remaining criteria of lighting uniformity, glare and light trespass. ANSI standards of minimum illuminance levels for construction activities are shown in Table 4.3 (ANSI 1973).

Table 4.3 Lighting Requirements of Industrial Activities (ANSI 1973).

Activity	Minimum Illuminance Level in lux (fc)
Building construction-general	108 (10)
Materials-loading, trucking	216 (20)
Woodworking- rough sawing	324 (30)
Inspection-ordinary	540 (50)
Paint dipping, spraying	540 (50)
Welding-general	540 (50)
Inspection-highly difficult	2160 (200)

4.3.3 NCHRP Recommendations

Despite the availability of lighting standards for various work activities (CIE 1986; ANSI 1973), there are limited lighting standards for highway construction activities in the literature. A recent research study was conducted by Ellis et. al. (1995) and published as a Highway Research Digest in 1996 to establish lighting requirements for nighttime highway construction. The study provides lighting recommendations for: (1) minimum level of illuminance for various construction activities; (2) uniformity ratio in the work area; and (3) suggested glare control measures.

4.3.3.1 Illuminance

The NCHRP study provides recommended illuminance levels for twenty seven highway construction and maintenance tasks as shown in Table 4.4 (Ellis and Amos 1996). These recommended illuminance levels are assigned from one of the following categories:

(1) Category I, with a minimum illuminance requirement of 54 lux (5 fc), which is recommended as the general illuminance level for the safety of crew movements in work zones, and for tasks where low accuracy is acceptable such as visual tasks with large objects.

(2) Category II, with a minimum illuminance requirement of 108 lux (10 fc), which is recommended for tasks that utilize various construction equipment.

(3) Category III, with a minimum Illuminance requirement of 218 lux (20 fc), which is recommended for certain tasks that require efficient visual performance such as: crack filling and traffic signals (Ellis and Amos 1996).

The three categories of illuminance levels were established based on: (1) required illuminance levels for comparable non-highway tasks; (2) required illuminance standards and regulations for construction; (3) state requirements for illuminance of highway nighttime construction; and (4) researchers' observations of current practices on nighttime highway construction (Ellis et. al. 1995).

Table 4.4. Suggested Illuminance Levels for Typical Construction and Maintenance Tasks (Ellis and Amos 1996).

Task No	Task Description (Construction)	Suggested Illuminance	
		Category	Level lux (fc)
1	Excavation-regular, lateral ditch, channel	I	54 (5)
2	Embankment, Fill and Compaction	I	54 (5)
3	Barrier Walls, Traffic Separators	II	108 (10)
4	Milling, Removal of Pavement	II	108 (10)
5	Resurfacing	II	108 (10)
6	Concrete Pavement	II	108 (10)
7	Subgrade Stabilization and Construction	I	54 (5)
8	Base Course Construction	II	108 (10)
9	Surface Treatment	II	108 (10)
10	Waterproofing and Sealing	II	108 (10)
11	Sidewalks	II	108 (10)
12	Sweeping and Cleaning	II	108 (10)
13	Guardrails, Fencing	II	108 (10)
14	Painting stripes/markers/metal buttons	II	108 (10)
15	Landscaping, grassing, sodding	I	54 (5)
16	Highway signing	II	108 (10)
17	Traffic signals	III	216 (20)
18	Highway lighting system	III	216 (20)
20	Drainage structures, culverts, storm sewer	II	108 (10)
21	Other concrete structures	II	108 (10)
22	Maintenance of earthwork/embankment	I	54 (5)
23	Reworking shoulders	I	54 (5)
24	Repair of concrete pavement	II	108 (10)
25	Crack filling	III	216 (20)
26	Pot filling	II	108 (10)
27	Resetting guardrail/fencing	II	108 (10)

The study provides a recommendation for the minimum distance that should be illuminated in front and behind construction equipment (Kumar 1994). These distances were established to be at least equal to the equipment stopping distance at its maximum operating speed. Highway construction equipment was divided into two major categories: (1) slow moving equipment with a suggested illuminance level of 108 lux (10 fc) in distances 4.9 m (16 ft) in front and behind the equipment; and (2) fast-moving equipment with a suggested illuminance level of 108 lux (10 fc) in distances of 17.7 m (58 ft) in front and behind the equipment (Kumar 1994).

4.3.3.2 Lighting Uniformity

The NCHRP study suggests a maximum uniformity ratio of 10:1 (i.e. average illuminance to minimum illuminance) in the work area.

4.3.3.3 Glare Control

The NCHRP report suggests a number of measures to control glare in nighttime highway construction work areas, including the control of: (1) vertical beam spread; (2) mounting height; (3) luminaire positioning; (4) aiming of the light source; and (5) supplemental hardware. Table 4.5 provides a summary of these suggested glare control measures (Ellis and Amos 1996).

4.3.3.4 Light Trespass

NCHRP study does not specify requirements to control light trespass.

Table 4.5. Glare Control Measures (Ellis and Amos 1996).

Glare Control Factors	Control Recommendations
1- Beam Spread	Select vertical and horizontal beam spreads to minimize light spillage. Consider using cutoff luminaries.
2- Mounting Height	Coordinate minimum mounting height with source lumens.
3- Location	Luminaire beam axis crosses normal lines of sight between 45 and 90 degrees.
4- Aiming	Angle between main beam axis and nadir less than 60 degrees. Intensity at angles greater than 72 degrees from the vertical less than 20,000 candelas.
5- Supplemental Hardware	Visors Louvers Shields Screens Barriers

4.3.4 IESNA Recommendations

The Illuminating Engineering Society of North America (IESNA) provides recommendations for lighting requirements in construction (Kaufman 1981). These recommendations include illuminance level and uniformity requirements, but do not address the remaining criteria of glare and light trespass.

4.3.4.1 Illuminance

IESNA recommended illuminance levels for construction activities are shown in Table 4.6 (Kaufman 1981).

Table 4.6 Recommend Illuminance Levels (Kaufman 1981).

Activity	Illuminance Level in lux (fc)
Building construction (general)	108 (10)
Excavation work	22 (2)

4.3.4.2 Lighting Uniformity

IESNA recommends a maximum uniformity ratio of 5:1 (i.e. maximum to minimum illuminance in the work area) for construction activities (Kaufman 1981).

4.3.5 CIE Recommendations

The International Commission on Illumination (CIE) has published recommendations for lighting external work areas including building sites (CIE 1986). These recommendations cover illuminance levels and uniformity ratio, and do not address the remaining criteria of glare and light trespass.

4.3.5.1 Illuminance

CIE recommended illuminance levels are shown in Table 4.7. CIE also recommends that illuminance should not be allowed to drop below 1 lux (0.09 fc) in any exterior area on the site (CIE 1986).

4.3.5.2 Lighting Uniformity

CIE recommended uniformity ratios are shown in Table 4.7. Uniformity ratios vary according to the complexity of the visual task.

4.3.6 Australian Recommendations

The Occupational Safety and Health in Australia provides recommendations for exterior lighting of workplaces (1979). These recommendations are limited to the illuminance criterion, and do not address the remaining criteria of lighting uniformity, glare or light trespass. Recommended illuminance levels for various areas and operations on building and civil engineering sites are shown in Table 4.8.

Table 4.7. Recommended Values of Illuminance and Uniformity Ratio (CIE 1986)

Visual task **Operations performed and areas to be lighted**	**Maintained average horizontal illuminance E_{av} in lux (fc)**	**Uniformity ratio E_{av} / E_{min}**
Movement of people, machines and vehicles, walkways and access routes	20 (2)	4:1
Loading and unloading areas, handling of materials	20 (2)	2.5:1
General rough work, site clearance, excavation and soil work	20 (2)	4:1
Reinforcing, concreting, shuttering errection; brick laying (except facings); blockwork; carpentry.	100 (10)	2.5:1
Scaffold erection and dismantling steel structural work.	100 (10)	3:1
Operating circular saws.	300 (28)	2.5:1
Stores and stockyards	20 (2)	4:1

Table 4.8. Recommended Lighting Levels for exterior workplaces - Australia

Purpose	**Operations Performed**	**Illuminance lux (fc)**
Security		10 (1)
Movement and handling	Movement of people, machines and vehicles; unloading and handling of materials; walkways and access routes.	5 (0.5)
Stores and stockyards	Vertical surfaces and racks in stores vertical plane.	5 (0.5)
Site entrance		5 (0.5)
General work areas	General rough work; site clearance, excavations and soil work.	20 (2)
Trade work	Reinforcing, concreting, shuttering erection; brick laying (excepting facings); blockwork; scaffold erection and dismantling.	50 (5)
Fine craft work	Joinery; all work with circular saws; plastering, screeding and terrazzo; dry finishing; ordinary painting; electrical and plumbing work; shop fitting, brick work facings, masonry	200 (20)

4.3.7 FAA Specifications

The Federal Aviation Administration (FAA) specifies requirements for lighting arrangements while asphalt overlay operations are taking place. The specification focuses on the required illuminance level, and does not address the remaining criteria of lighting uniformity, glare and light trespass. The average illuminance level that should be maintained throughout the working area is 54 lux (5 fc). This illuminance level should be maintained in the following work areas (Wills 1982):

- An area 7.5 m (25 ft) wide and 3.6 m (12 ft) long behind operating asphalt spreader.
- An area 3.6 m (12 ft) wide and 9 m (30 ft) long in front of all rolling equipment.
- An area 3.6 m (12 ft) wide and 3.6 m (12 ft) long where tack coat is being placed.
- An area 3.6 m (12 ft) wide and 6 m (20 ft) long in front of the cold milling machine.
- An area 3.6 m (12 ft) wide and 9 m (30ft) long in front of the heater scarifier and heater planning machine.
- An area 3.6 m (12 ft) wide and 9 m (30 ft) long in front of the rubber asphalt distributor and spreading equipment.
- An area 3.6 m (12 ft) wide and 3.6 m (12 ft) long where joint sealing operations area taking place.

4.3.8 Summary of Professional Organizations Standards

4.3.8.1 Illuminance

Table 4.9 below shows a summary of the illuminance requirements for nighttime highway construction. Only the requirements listed in the NCHRP study are developed specifically for highway nighttime construction, while others are intended for general construction but still can be considered applicable for highway construction.

4.3.8.2 Lighting Uniformity

Among the lighting requirements listed in this section, limits for uniformity ratio can be found only in the NCHRP study, IESNA recommendations, and CIE recommendations. Table 4.10 provides a summary of lighting uniformity requirements provided by these organizations.

Table 4.9. Illuminance Requirements in Professional Organizations Standards

	Highway Construction Activity	Lighting Level Requirements in fc						
		OSHA	IESNA	ANSI	FAA	NCHRP	CIE	AUSTRALIA
1	Earthwork: excavation/ embankment/ backfill	Outdoor active construction areas, concrete placement, excavation, access ways, loading: 5 fc	Building construction: 10 fc. Excavation: 2 fc.	Building construction-general: 10 fc. Materials loading-trucking: 20 fc.		5	2	Movement of people and machines, handling of materials, access routes: 0.5 fc. General rough work: 2 fc. Trade work (concreting): 5 fc. Fine craftwork: 20 fc.
2	Landscaping: seeding/ mulch/ sodding/ planting					5	2	
3	Erosion control: riprap/ ditch lining					5		
4	Sub grade					5		
5	Sub base / Base courses					10		
6	Paving bituminous surfaces				5	10		
7	Rolling bituminous surfaces and pavements				5			
8	Paving PCC surfaces					10	10	
9	Finishing PCC pavements					10	10	
10	Milling and removal				5	10	General rough work, movement of people, machines and vehicles, loading, handling of materials, walkways and access routes: 2 fc.	
11	Pavement resurfacing				5	10		
12	Pavement patching				5	10		
13	Crack and joint sealing				5	20		
14	Concrete sawing							
15	Shoulders: earth and aggregate					5		
16	Shoulders: bituminous and PCC					5		
17	Bridge construction and maintenance					10		
18	Culverts and sewers					10		
19	Drainage structures					10		
20	Guardrail and fences					10		
21	Work zone setup, take down and revision					10		
22	Work zone flagger station							
23	Work zone access and material handling							
24	Highway signing					10		
25	Pavement marking: striping and markers					10		
26	Electrical wiring and cables					20		
27	Electrical poles and posts: lighting/ traffic signals					20		

Table 4.10 Lighting Uniformity Requirements in Professional Organizations Standards

<table>
<tr><th rowspan="2">No.</th><th rowspan="2">Highway Construction Activity</th><th colspan="7">Maximum Lighting Uniformity Ratio</th></tr>
<tr><th>OSHA</th><th>IESNA</th><th>ANSI</th><th>CIE (average to minimum)</th><th>NCHRP</th><th>AUSTRALIA</th><th>FAA</th></tr>
<tr><td>1</td><td>Earthwork: excavation/ embankment/ backfill</td><td rowspan="27">N/A</td><td rowspan="27">5:1 maximum to minimum</td><td rowspan="27">N/A</td><td>4:1</td><td rowspan="27">10:1 maximum to minimum</td><td rowspan="27">N/A</td><td rowspan="27">N/A</td></tr>
<tr><td>2</td><td>Landscaping: seeding/ mulch/ sodding/ planting</td><td>4:1</td></tr>
<tr><td>3</td><td>Erosion control: riprap/ ditch lining</td><td></td></tr>
<tr><td>4</td><td>Sub grade</td><td></td></tr>
<tr><td>5</td><td>Sub base / Base courses</td><td></td></tr>
<tr><td>6</td><td>Paving bituminous surfaces</td><td></td></tr>
<tr><td>7</td><td>Rolling bituminous surfaces and pavements</td><td></td></tr>
<tr><td>8</td><td>Paving PCC surfaces</td><td>2.5:1</td></tr>
<tr><td>9</td><td>Finishing PCC pavements</td><td>2.5:1</td></tr>
<tr><td>10</td><td>Milling and removal</td><td></td></tr>
<tr><td>11</td><td>Pavement resurfacing</td><td></td></tr>
<tr><td>12</td><td>Pavement patching</td><td></td></tr>
<tr><td>13</td><td>Crack and joint sealing</td><td></td></tr>
<tr><td>14</td><td>Concrete sawing</td><td>2.5:1</td></tr>
<tr><td>15</td><td>Shoulders: earth and aggregate</td><td>4:1</td></tr>
<tr><td>16</td><td>Shoulders: bituminous and PCC</td><td rowspan="12">Movement of people, and machines. Stores and stockyards: (4:1)
Loading and unloading: (2.5:1)
Steel structural work: (3:1)</td></tr>
<tr><td>17</td><td>Bridge construction and maintenance</td></tr>
<tr><td>18</td><td>Culverts and sewers</td></tr>
<tr><td>19</td><td>Drainage structures</td></tr>
<tr><td>20</td><td>Guardrail and fences</td></tr>
<tr><td>21</td><td>Work zone setup, take down and revision</td></tr>
<tr><td>22</td><td>Work zone flagger station</td></tr>
<tr><td>23</td><td>Work zone access and material handling</td></tr>
<tr><td>24</td><td>Highway signing</td></tr>
<tr><td>25</td><td>Pavement marking: striping and markers</td></tr>
<tr><td>26</td><td>Electrical wiring and cables</td></tr>
<tr><td>27</td><td>Electrical poles and posts: lighting/ traffic signals</td></tr>
</table>

4.3.8.3 Glare

Provisions for glare control in nighttime construction lighting can be found only in the NCHRP study. Those requirements are qualitative and are listed in Table 4.5 above.

4.3.8.4 Light Trespass

None of the above researched professional organizations provide requirements for light trespass in nighttime construction.

4.4 State Department of Transportation Standards

Despite the recent increase in the volume of nighttime highway construction projects, the survey results indicated that there are limited lighting standards and guidelines for this type of construction. Only 8 state DOTs out of the 22 respondents reported that they have lighting requirement provisions for nighttime construction in their standards. The following sections provide a summary of the available lighting standards in these eight states (i.e. New York, California, Florida, Maryland, Michigan, Mississippi, North Carolina, and Oregon).

4.4.1 New York DOT

In 1995, New York DOT developed specifications for lighting nighttime construction operations. The specifications provide recommendations for illuminance levels, uniformity ratio, and glare control.

4.4.1.1 Illuminance Levels

The standards specify minimum illuminance levels for various construction activities within the work zone. These specified illuminance levels are grouped into three categories, according to the level of accuracy required to perform the construction task, as shown in Table 4.11.

Table 4.11 Illuminance Level Requirements - New York DOT

Application	Level	Minimum Average Illuminance lux (fc)
• General construction operations, including: excavation, cleaning and sweeping, landscaping, and planting and seeding. • Lane and/or road closures continuously throughout the period of closure, including the setup and removal of the closures.	I	54 (5)
• Asphalt paving, milling, and concrete placement and/or removal.	II	108 (10)
• Pavement or structural crack filling, joint repair, pavement patching and repairs, installation of signal equipment or other electrical/ mechanical equipment. • Tasks involving fine details or intricate parts and equipment.	III	216 (20)
* The illuminance levels uniformity ratio (average illuminance levels to minimum illuminance levels) over the work area shall not exceed 5:1.		

The standard recommends the attachment of light towers to large highway construction equipment (e.g., paving machines, finishing machines, and milling machines) in order to provide the required level of illuminance for each specific task. These towers should not exceed a height of 4 m (13 ft) above the ground, and should provide the required illuminance level for a specified distance in front of and behind the equipment. For example, an illuminance of 108 lux (10 fc) (i.e. level II) should be provided 15 m (50 ft) in front of and 30 m (100 ft) behind paving and milling equipment. The standard also recommends the mounting of floodlights on all other construction equipment not requiring lighting towers. These lights should consist of a minimum of two 500w floods facing in each direction of travel of the equipment to provide a minimum of 10 lux (1 fc) measured 18 m (60 ft) in front of and behind the equipment.

4.4.1.2 Lighting Uniformity

The allowable uniformity ratio (i.e. average to minimum illuminance levels in the lighted areas) is specified to be less than or equal 5:1.

4.4.1.3 Glare Control

The following minimum requirements should be met to avoid objectionable levels of glare:

- All luminaires should be aimed so that the center of the beam axis is no greater than 60 degrees from the vertical.
- No luminaires that provide luminance intensity greater than 20,000 candelas at an angle 72 degree above the vertical should be permitted.
- The contractor should be responsible for providing shields, visors, or louvers on luminaires when necessary to reduce objectionable levels of glare.

4.4.1.4 Light Trespass

The New York DOT standards do not include provisions for controlling light trespass during nighttime construction operations.

4.4.2 California DOT

The Night Work Guide provided by the California Department of Transportation requires that lighting in all construction areas should satisfy the minimum Illuminance levels shown in Table 4.12. The guide also requires providing a minimum of 54 lux (5 fc) in all work sites. The California DOT guide does not address the remaining criteria of lighting uniformity, glare, and light trespass.

Table 4.12 Illuminance Level Requirements - California DOT

Area or Operation	**Minimum Illuminance Levels Lux (fc)**
General construction area lighting low activity.	32 (3)
Outdoor active construction areas, concrete placement, excavation and waste areas, access ways, active storage areas, loading platforms, refueling, and field maintenance areas.	54 (5)
Indoors: warehouses, corridors, hallways, stairways, and exit-ways.	54 (5)
General construction plant and shops (e.g., batch plants, screening plants, mechanical and electrical equipment rooms, carpenter shops, rigging lofts and active storerooms, barracks or living quarters, locker or dressing rooms, mess halls and indoor toilets and workrooms).	108 (10)
First-aid stations, infirmaries, and offices.	324 (30)
Note: For areas or operations not covered above, refer to the American National Standards A11.1-1973, Practice for Industrial Lighting, for recommended values of Illuminance.	

4.4.3 Florida DOT

Florida DOT's standards state that lighting should be provided during active nighttime operations for proper workmanship and inspection. The standards specify that a minimum illuminance level of 54 lux (5 fc) should be provided for lighting nighttime construction activities. The standards do not address the remaining criteria of lighting uniformity, glare, and light trespass.

4.4.4 Maryland DOT

Maryland Department of Transportation has a standard that addresses nighttime construction lighting. This standard specifies that floodlighting should be used when the average horizontal illuminance produced by the existing lighting system is less than 216 lux (20 fc) over the construction area. Maryland DOT standards do not address the remaining criteria of lighting uniformity, glare and light trespass.

4.4.5 Michigan DOT

Michigan DOT has a special provision for lighting requirements that supplements its standard specifications. The provision focuses only on illuminance requirements for nighttime highway construction tasks and does not address the remaining criteria of lighting uniformity, glare, and light trespass. The following is a summary of illuminance requirements:

- Pavers should be mounted with lighting equipment that provides a minimum illuminance of 108 lux (10 fc) for a distance of 30 to 60 m (100 to 200 ft). Paver-mounted lighting towers should be of adjustable height and rotatable horizontally, and they should be mounted at least 2 meters (7 ft) above the paver.
- Rollers should be provided with four headlights, two facing in each direction of travel and lighting a distance of 15 to 30 m (50 to 100 ft) in front of and behind the roller. Roller-mounted lighting towers should be mounted at least 1.2 m (4 ft) above the roller.

- Sufficient lighting should be provided for all bituminous paving operations from pavement preparation to finish rolling and areas where nighttime removal, replacement or repair of pavement and crack cleaning and sealing is taking place.

4.4.6 Mississippi DOT

Mississippi DOT has special standards for Illuminance requirements in nighttime construction that specify the following requirements:

- Tower lights shall be of sufficient wattage and/or quantity to provide an average maintained horizontal illuminance greater than 216 lux (20 fc) over the work area.
- The machine light fixtures shall be of sufficient wattage and/or quantity to provide an average maintained horizontal illuminance greater than 108 lux (10 fc) on the machine and the surrounding work area. Machine lights are in addition to conventional type headlights, which are necessary for maneuverability.

Mississippi DOT standards do not address the remaining criteria of lighting uniformity, glare, and light trespass.

4.4.7 North Carolina DOT

Illuminance requirements for night work in the standard specification of North Carolina Department of Transportation are divided into two categories as shown in

Table 4.13. The standard does not address the remaining criteria of lighting uniformity, glare, and light trespass.

Table 4.13. Illuminance Level Requirements - North Carolina DOT

Operation	Illuminance Levels lux (fc)
Stationery construction operation: when the night work is confined to a fairly small area and is essentially a stationery operation, tower lights may be used.	216 (20) over the work area
Moving construction operation: when the night work is not confined to a small area and is essentially a continuous moving construction operation, machine lights may be used.	108 (10) on the machine and the surrounding work area

4.4.8 Oregon DOT

Oregon DOT's standards for lighting nighttime construction focus on nighttime flaggers. Oregon standards for nighttime flaggers require that temporary lighting should be provided to illuminate an area of at least 12 m (40 ft) diameter at ground level. Portable lighting should be equivalent to 200w to 250w high-pressure sodium luminaire. The standard does not address illuminance requirements for other construction activities as well as the remaining criteria of lighting uniformity, glare, and light trespass.

4.4.9 Summary of DOTs Standards

4.4.9.1 Illuminance Levels

The survey results indicate that there are limited lighting standards and guidelines for nighttime construction operations. Only 8 out of the 22 responding state DOTs reported the availability of limited nighttime construction lighting provisions in their standards. A comparison of these limited provisions (see Table 4.14) reveals that there is a lack of consensus among state DOTs on the lighting requirements for nighttime highway construction operations. For example, California, Florida, and Maryland DOTs have a single unified minimum lighting level of 54 lux (5 fc) in the entire work area, while Mississippi and North Carolina DOTs divides lighting level requirements into two categories of 108 lux (10 fc) for moving operations and 216 lux (20 fc) for stationery operations. New York DOT, on the other hand, provides lighting level requirements according to the construction activity being performed and divides lighting level requirements into three categories of 54, 108, and 216 lux (5, 10, and 20 fc). It should be noted also that Oregon DOT standards focus only on lighting requirements for flagger stations.

4.4.9.2 Lighting Uniformity

Among the above listed DOTs standards, lighting uniformity requirements exist only in New York DOT standards, which require a maximum average illuminance to minimum illuminance ratio of 5:1.

4.4.9.3 Glare

Among the above listed DOTs standards, requirements for glare control in nighttime construction exist only in New York standards as discussed earlier in section 4.4.1.3.

4.4.9.4 Light Trespass

Provisions for controlling light trespass from nighttime construction lighting do not exist in any of the abovementioned DOTs standards.

Table 4.14 Illuminance Requirements in DOTs Standards

<table>
<tr><th rowspan="2">No.</th><th rowspan="2">Highway Construction Activity</th><th colspan="8">Lighting Level Requirements fc</th></tr>
<tr><th>California</th><th>Florida</th><th>Maryland</th><th>Michigan</th><th>Mississippi</th><th>New York*</th><th>North Carolina</th><th>Oregon</th></tr>
<tr><td>1</td><td>Earthwork: excavation/ embankment/ backfill</td><td rowspan="27">Outdoor active construction areas, concrete placement, excavation, access ways, loading: 5 fc</td><td rowspan="27">A minimum of 5 fc for lighting nighttime construction activities</td><td rowspan="27">A minimum of 5 fc over the construction area</td><td></td><td rowspan="27">Tower lights: 20 fc over the work area, Machine operations: 10 fc on and around the machine</td><td>5</td><td rowspan="27">Tower lights: 20 fc over the work area, Machine operations: 10 fc on and around the machine</td><td></td></tr>
<tr><td>2</td><td>Landscaping: seeding/ mulch/ sodding/ planting</td><td></td><td>5</td><td></td></tr>
<tr><td>3</td><td>Erosion control: riprap/ ditch lining</td><td></td><td></td><td></td></tr>
<tr><td>4</td><td>Sub grade</td><td></td><td></td><td></td></tr>
<tr><td>5</td><td>Sub base / Base courses</td><td></td><td></td><td></td></tr>
<tr><td>6</td><td>Paving bituminous surfaces</td><td>10</td><td>10</td><td></td></tr>
<tr><td>7</td><td>Rolling bituminous surfaces and pavements</td><td></td><td></td><td></td></tr>
<tr><td>8</td><td>Paving PCC surfaces</td><td></td><td>10</td><td></td></tr>
<tr><td>9</td><td>Finishing PCC pavements</td><td></td><td></td><td></td></tr>
<tr><td>10</td><td>Milling and removal</td><td></td><td>10</td><td></td></tr>
<tr><td>11</td><td>Pavement resurfacing</td><td></td><td>10</td><td></td></tr>
<tr><td>12</td><td>Pavement patching</td><td></td><td>20</td><td></td></tr>
<tr><td>13</td><td>Crack and joint sealing</td><td></td><td>20</td><td></td></tr>
<tr><td>14</td><td>Concrete sawing</td><td></td><td></td><td></td></tr>
<tr><td>15</td><td>Shoulders: earth and aggregate</td><td></td><td></td><td></td></tr>
<tr><td>16</td><td>Shoulders: bituminous and PCC</td><td></td><td></td><td></td></tr>
<tr><td>17</td><td>Bridge construction and maintenance</td><td></td><td></td><td></td></tr>
<tr><td>18</td><td>Culverts and sewers</td><td></td><td></td><td></td></tr>
<tr><td>19</td><td>Drainage structures</td><td></td><td></td><td></td></tr>
<tr><td>20</td><td>Guardrail and fences</td><td></td><td></td><td></td></tr>
<tr><td>21</td><td>Work zone setup, take down and revision</td><td></td><td>5</td><td></td></tr>
<tr><td>22</td><td>Work zone flagger station</td><td></td><td></td><td>**</td></tr>
<tr><td>23</td><td>Work zone access and material handling</td><td></td><td></td><td></td></tr>
<tr><td>24</td><td>Highway signing</td><td></td><td></td><td></td></tr>
<tr><td>25</td><td>Pavement marking: striping and markers</td><td></td><td></td><td></td></tr>
<tr><td>26</td><td>Electrical wiring and cables</td><td></td><td>20</td><td></td></tr>
<tr><td>27</td><td>Electrical poles and posts: lighting/ traffic signals</td><td></td><td>20</td><td></td></tr>
</table>

* General construction operations in NY standards are required to have a minimum of 5 fc.

** For nighttime flaggers, Portable illumination should be provided to illuminate an area of at least 12 m (40 ft) diameter at ground level. Temporary lighting should be equivalent to 200w to 250w high-pressure sodium luminaire.

4.5 Surveyed Resident Engineers and Contractors Recommendations

The conducted surveys included questions to obtain field personnel perception regarding the required lighting levels for a list of 27 construction activities. As illustrated in Chapter 3, Figures 3.11 and 3.12 show the percentages of respondents (i.e. resident engineers and contractors) selecting a specific lighting requirement for each activity. These percentages are combined into a weighted average score (A_{ij}) for each activity as shown in Equation (4.4) to represent the average reported lighting requirements by respondent group j for construction activity i.

$$A_{ij} = 1 * L_{ij} + 2 * M_{ij} + 3 * H_{ij} \qquad (4.4)$$

Where,

A_{ij} = weighted average score that represents the average lighting level requirements by respondent group j for construction activity i;

L_{ij} = percentage of group j respondents selecting low lighting level for activity i;

M_{ij} = percentage of group j respondents selecting medium lighting level for activity i;

H_{ij} = percentage of group j respondents selecting high lighting level for activity i.

i = construction activity, where i = 1 to 27; and

j = respondent group, where j = 1 for resident engineers and j = 2 for contractors.

As shown in Equation (4.4), the calculated weighted averages (A_{ij}) can range from 1 to 3. Accordingly, A_{ij} can be used to categorize the average lighting requirements for each activity into three major categories: (1) low lighting which includes A_{ij} values ranging from 1 to 1.5; (2) medium lighting which includes A_{ij} values ranging from 1.5 to 2.5; and (3) high lighting which includes A_{ij} values ranging from 2.5 to 3.

A comparative analysis was conducted between the results obtained from resident engineers and those provided by contractors as shown in Figure 4.2 and Table 4.15. The analysis showed relatively high agreement between resident engineers and contractors on the required lighting levels for the majority of activities such as erosion control, work zone flagger station, landscaping, paving bituminous surfaces, and sub grade. It should also be noted that the reported results showed few disagreements between resident engineers and contractors for a limited number of activities such as crack and joint filling, and paving PCC surfaces. This expected disparity can be attributed to the fact that the lighting requirements for tasks performed by resident engineers on site (e.g. inspection of quality) can be different from those carried out by contractors (e.g. cracks and joints filling).

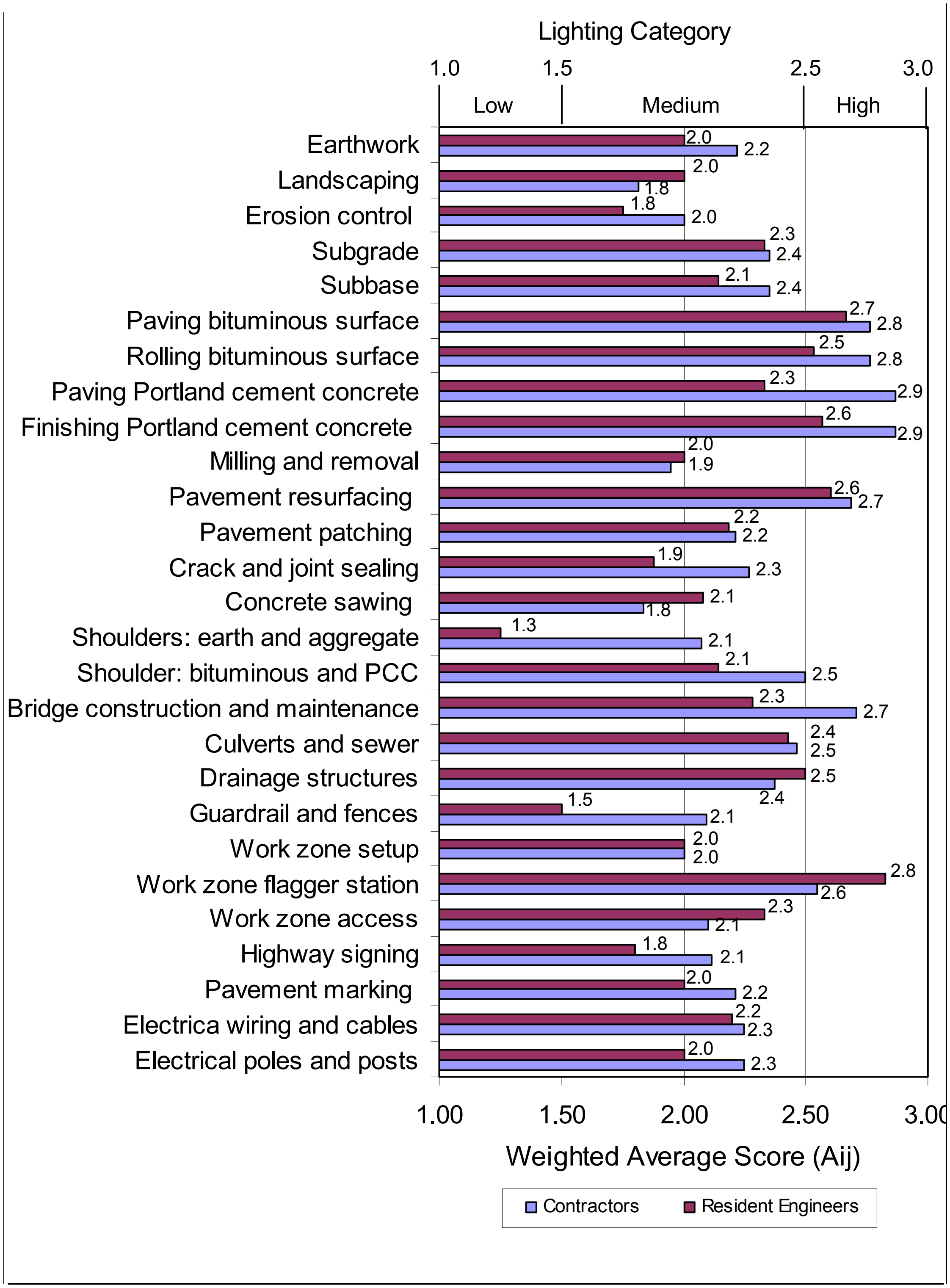


Figure 4.2. Weighted Average of Lighting Level Requirements Identified by Resident Engineers and Contractors

Table 4.15-Weighted Average of Lighting Level Requirements

No. (i)	Highway Construction Activity	Weighted Average Score for Lighting Level Requirements (A_{ij})					
		Resident Engineers j = 1	Category*	Contractors j = 2	Category*	Average of Resident Engineers and Contractors	Category*
1	Earthwork: excavation/ embankment/ backfill	2.0	M	2.2	M	2.1	M
2	Landscaping: seeding/ mulch/ sodding/ planting	2.0	M	1.8	M	1.9	M
3	Erosion control: riprap/ ditch lining	1.8	M	2.0	M	1.9	M
4	Sub grade	2.3	M	2.3	M	2.3	M
5	Sub base / Base courses	2.1	M	2.4	M	2.25	M
6	Paving bituminous surfaces	2.7	H	2.8	H	2.75	H
7	Rolling bituminous surfaces and pavements	2.5	H	2.6	H	2.55	H
8	Paving PCC surfaces	2.3	M	2.9	H	2.6	H
9	Finishing PCC pavements	2.6	H	2.9	H	2.75	H
10	Milling and removal	2.0	M	1.9	M	1.95	M
11	Pavement resurfacing	2.6	H	2.7	H	2.65	H
12	Pavement patching	2.2	M	2.2	M	2.2	M
13	Crack and joint sealing	1.9	M	2.3	M	2.1	M
14	Concrete sawing	2.1	M	1.8	M	1.95	M
15	Shoulders: earth and aggregate	1.3	L	2.0	M	1.65	M
16	Shoulders: bituminous and PCC	2.1	M	2.5	H	2.3	M
17	Bridge construction and maintenance	2.3	M	2.7	H	2.5	H
18	Culverts and sewers	2.4	M	2.5	H	2.45	M
19	Drainage structures	2.5	H	2.4	M	2.45	M
20	Guardrail and fences	1.5	M	2.2	M	1.85	M
21	Work zone setup, take down and revision	2.0	M	2.0	M	2.0	M
22	Work zone flagger station	2.8	H	2.6	H	2.7	H
23	Work zone access and material handling	2.3	M	2.0	M	2.15	M
24	Highway signing	1.8	M	2.1	M	1.95	M
25	Pavement marking: striping and markers	2.0	M	2.2	M	2.1	M
26	Electrical wiring and cables	2.2	M	2.3	M	2.25	M
27	Electrical poles and posts: lighting/ traffic signals	2.0	M	2.3	M	2.15	M

*L = low, M = medium, H = high

4.6 Recommended Lighting Design Criteria

The lighting standards and recommendations discussed earlier were analyzed in order to develop design criteria for lighting nighttime highway construction operations. The recommended criteria are developed using data and information acquired from various sources including: (1) professional organizations; (2) state DOTs; and (3) surveyed contractors and resident engineers.

4.6.1 Recommended Illuminance Levels

A summary of the available standards and recommendations for illuminance levels for each of the 27 construction activities is shown in Table 4.16. These available illuminance levels were analyzed and compared to the survey results and the researchers observations of the actual lighting levels in nighttime construction sites in order to develop a recommended minimum illuminance levels for each of the 27 highway construction activities. The recommended illuminance levels for different construction activities were divided into three categories, as shown in Table 4.16.

Our approach in developing these criteria is to ensure that the standards comply with recommended minimum illuminance levels suggested by professional societies such as IESNA, CIE and OSHA. Adjustments were made to the criteria based on the results obtained from surveyed resident engineers and contractors, available standards of other DOTs, and field experiments.

Although illuminance criterion is defined in terms of horizontal illuminance, some tasks also need to maintain the required illuminance level in the vertical level (vertical illuminance), such as bridge construction and maintenance, and work on overhead signs and sign structures (Bryden and Mace 2002).

4.6.1.1 Low Illuminance Category

The recommended illuminance level for this category is 54 lux (5 fc). This relatively low illuminance level is recommended for the following eight major activities: (1) earthwork (excavation/embankment/backfill); (2) landscaping (seeding/mulch/sodding/planting); (3) erosion control (riprap/ditch lining); (4) subgrade; (5) sub base/base courses; (6) shoulders (earth and aggregate); (7) work zone access and materials handling; and (8) work zone setup, take down and revision. The rationale for including these 8 activities in the low illuminance category can be summarized as follows:

(1) The recommended illuminance for these activities in the analyzed standards and guidelines ranged from 5 to 108 lux (0.5 to 10 fc).

(2) Surveyed resident engineers and contractors recommended relatively low scores for illuminance levels for these tasks ranging from 1.6 to 2.3 (see Table 4.16).

(3) Site visits indicated that most of these activities involve little details, and therefore they require relatively low illuminance levels.

This level should be maintained in all work zone areas including the lane closure tapers. Illuminating lane closure tapers is required for several reasons including: (1)

providing safe environment for workers movement in this area during setup and takedown; (2) lane closure tapers are associated with the greatest traffic risks because of drivers uncertainty about the route since diversion of traffic occurs along these tapers; and (3) taper is a transitional area for the driver where drivers eye adaptation to the change in lighting levels reduces visibility of objects (Bryden and Mace 2002).

4.6.1.2 Medium Illuminance Category

The recommended illuminance level for this category is 108 lux (10 fc). This medium illuminance level is recommended for the majority of activities, as follows: (1) paving bituminous surfaces; (2) rolling bituminous surfaces and pavements; (3) milling and removal; (4) pavement resurfacing; (5) shoulders (bituminous and PCC); (6) paving PCC surfaces; (7) finishing PCC pavements; (8) concrete sawing; (9) bridge construction and maintenance; (10) culverts and sewers; (11) drainage structures; (12) guardrail and fences; (13) highway signing; (14) pavement marking (stripping and markers); and (15) work zone flagger station. The rationale for including these 15 activities in the medium illuminance category can be summarized as follows:

(1) The recommended illuminance level for these activities in the analyzed standards and guidelines ranged from 54 to 108 lux (5 to 10 fc).
(2) Surveyed resident engineers and contractors recommended relatively medium scores for illuminance levels for these tasks.

(3) Site visits indicated that most of these activities involve medium details comparable to the “general building construction” and therefore they require relatively medium illuminance levels.

(4) A consensus was found in the analyzed standards on the recommendation of 108 lux (10 fc) for concreting activities that include: paving PCC surfaces, and finishing PCC pavements.

(5) Workers in flagger stations are exposed to a relatively high risk due to their forefront location in the work zone, which requires providing adequate lighting conditions to improve the visibility of flagger stations.

4.6.1.3 High Illuminance Category

The recommended illuminance level for this category is 216 lux (20 fc). This high illuminance level is recommended for the following activities: (1) electrical wiring and cables; (2) electrical poles and posts (lighting and traffic signals); (3) pavement patching; and (4) crack and joint sealing. The rationale for including these 4 activities in the high illuminance category can be summarized as follows:

(1) The recommended illuminance level for these activities in the analyzed standards and guidelines ranged from 54 to 216 lux (5 to 20 fc).

(2) Surveyed resident engineers and contractors recommended relatively high scores for illuminance levels for these tasks.

(3) These activities are generally confined to small areas, which makes it easier to provide this illuminance level.

(4) These activities are considered to be fine craftworks that require a high level of detail.

4.6.2 Recommended Uniformity Ratio

A summary of the available limits for uniformity ratios in nighttime work is shown in Table 4.17. The lighting uniformity can be represented using two ratios:

(1) a ratio of maximum to minimum illuminance levels similar to the ratio of 5:1 recommended by IESNA; and

(2) a ratio of average to minimum illuminance levels similar to those recommended by CIE, NCHRP study, and New York DOT standards, which ranged from 2.5:1 to 10:1.

The average to minimum ratio is considered more practical for highway construction work areas because lighting tower luminaires are usually directed towards pavement surfaces to avoid causing glare to road users, which creates a highly illuminated area under these light towers. These highly illuminated areas can lead to higher maximum to minimum ratios that do not practically represent the uniformity of lighting in nighttime construction zones. Accordingly, this report recommends an average to minimum lighting uniformity ratio of 6:1 be maintained in the work area. This ratio is selected to provide contractors with flexibility in meeting uniformity requirements to consider the practical limitations imposed by the positioning requirements of lighting sources on site.

4.6.3 Recommended Glare Control Measures

To quantify glare in nighttime highway construction, this report recommends the use of the ratio of maximum veiling luminance to the average pavement luminance as a control measure of glare. This ratio is recommended by IESNA in roadway lighting design, and is considered to be applicable to highway work zones due to the similarities in design criteria, parameters, and designers concerns in both cases. The maximum allowable glare ratio in roadway lighting (i.e. 0.4) can be used to control glare in nighttime construction. This ratio can be relaxed to account for the temporary nature of work zone lighting, and can be implemented in the design of lighting arrangements.

4.6.4 Recommended Light Trespass Control

The effect of lighting trespass encountered from nighttime construction lighting is similar to the effect of other external lighting sources. The only difference is the temporary nature of work zone lighting arrangement. Available standards for light trespass (see section 4.2.4) can also be applicable for lighting nighttime work. Accordingly, this study proposes adopting the IESNA recommendations (IESNA TM-2000) for controlling light trespass from nighttime construction lighting. The IESNA recommendations set maximum allowed vertical illuminance limits (see Table 4.1) that should be measured at the edge of the property line in the plane of an observer's eye at possible viewing locations of the light source (IESNA TM-2000). It should be pointed out that IESNA recommended limits are intended for permanent outdoor lighting, and therefore they can be slightly relaxed for temporary nighttime construction lighting that is provided for a short period of time (IESNA TM-2000).

Table 4.16. Summary of Illuminance Requirements

No.	Highway Construction Activity	Professional Organizations: OSHA	ANSI	IESNA	AUSTRALIA	CIE	FAA	NCHRP	DOTs Standards: New York	Michigan	California	Florida	Maryland	Mississippi	North Carolina	Surveys: W weighted Average	Category	Illuminance Level Range	**Recommended Illuminance Level**
1	Earthwork: excavation/ embankment/ backfill	Outdoor active construction areas, concrete placement, excavation, access ways: **5 fc**	Building construction-general: **10 fc**, Excavation: **2 fc**.	Building construction-general: 10 fc, Materials loading-trucking: **2 fc**.	Movement of people, machines and vehicles, handling of materials, access routes: **0.5 fc** General rough work: **2 fc**. Trade work (concreting): **5 fc**. Fine craftwork: **20 fc**.	2		5	5		Active construction areas, concrete placement, excavation, access ways, loading: **5 fc**	A minimum of **5 fc** for lighting nighttime construction activities	A minimum of **5 fc** over the construction area	Tower lights: **20 fc** over the work area, Machine operations: **10 fc**	Tower lights: **20 fc** over the work area, Machine operations: **10 fc**	2.1	M	2-5	**5**
2	Landscaping: seeding/ mulch/ sodding/ planting					2		5	5							1.9	M	2-5	**5**
3	Erosion control: riprap/ ditch lining							5								1.9	M	5	**5**
4	Sub grade							5								2.3	M	5	**5**
5	Sub base / Base courses							10								2.2	M	5-10	**5**
6	Paving bituminous surfaces						5	10	10	10						2.8	H	5-10	**10**
7	Rolling bituminous surfaces and pavements						5									2.6	H	5-10	**10**
8	Paving PCC surfaces					10		10	10							2.6	H	5-10	**10**
9	Finishing PCC pavements					10		10								2.8	H	5-10	**10**
10	Milling and removal					General rough work, movement of people and machines, handling of materials, walkways and access routes: **2 fc**.		10	10							2.0	M	10	**10**
11	Pavement resurfacing						5	10	10							2.6	H	5-10	**10**
12	Pavement patching							10	20							2.2	M	10-20	**20**
13	Crack and joint sealing						5	20	20							2.1	M	5-20	**20**
14	Concrete sawing															2.0	M		**10**
15	Shoulders: earth and aggregate							5								1.6	M	5	**5**
16	Shoulders: bituminous and PCC							5								2.3	M	5-10	**10**
17	Bridge construction and maintenance							10								2.5	H	10	**10**
18	Culverts and sewers							10								2.4	M	10	**10**
19	Drainage structures							10								2.4	M	10	**10**
20	Guardrail and fences							10								1.8	M	10	**10**
21	Work zone setup, take down and revision							10	5							2.0	M	5-10	**5**
22	Work zone flagger station															2.7	H		**10**
23	Work zone access and material handling															2.2	M	0.5-2	**5**
24	Highway signing							10								2.0	M	10	**10**
25	Pavement marking: striping and markers							10								2.1	M	10	**10**
26	Electrical wiring and cables							20	20							2.2	M	20	**20**
27	Electrical poles and posts: lighting/ traffic signals							20	20							2.2	M	20	**20**

*L = low, M = medium, H = high

Table 4.17 Summary of Lighting Uniformity Requirements

<table>
<tr><th rowspan="2">No.</th><th rowspan="2">Highway Construction Activity</th><th colspan="4">Uniformity Requirements</th></tr>
<tr><th>IESNA</th><th>CIE (avg. to min.)</th><th>NCHRP</th><th>New York DOT</th></tr>
<tr><td>1</td><td>Earthwork: excavation/ embankment/ backfill</td><td rowspan="28">5:1 maximum to minimum</td><td>4:1</td><td rowspan="28">10:1 average to minimum</td><td rowspan="28">5:1 average. to minimum.</td></tr>
<tr><td>2</td><td>Landscaping: seeding/ mulch/ sodding/ planting</td><td>4:1</td></tr>
<tr><td>3</td><td>Erosion control: riprap/ ditch lining</td><td></td></tr>
<tr><td>4</td><td>Sub grade</td><td></td></tr>
<tr><td>5</td><td>Sub base / Base courses</td><td></td></tr>
<tr><td>6</td><td>Paving bituminous surfaces</td><td></td></tr>
<tr><td>7</td><td>Rolling bituminous surfaces and pavements</td><td></td></tr>
<tr><td>8</td><td>Paving PCC surfaces</td><td>2.5:1</td></tr>
<tr><td>9</td><td>Finishing PCC pavements</td><td>2.5:1</td></tr>
<tr><td>10</td><td>Milling and removal</td><td></td></tr>
<tr><td>11</td><td>Pavement resurfacing</td><td></td></tr>
<tr><td>12</td><td>Pavement patching</td><td></td></tr>
<tr><td>13</td><td>Crack and joint sealing</td><td></td></tr>
<tr><td>14</td><td>Concrete sawing</td><td>2.5:1</td></tr>
<tr><td>15</td><td>Shoulders: earth and aggregate</td><td>4:1</td></tr>
<tr><td>16</td><td>Shoulders: bituminous and PCC</td><td rowspan="13">Movement of people and machines, stores and stockyards: 4:1.
Loading and unloading: 2.5:1
Steel structural work: 3:1.</td></tr>
<tr><td>17</td><td>Bridge construction and maintenance</td></tr>
<tr><td>18</td><td>Culverts and sewers</td></tr>
<tr><td>19</td><td>Drainage structures</td></tr>
<tr><td>20</td><td>Guardrail and fences</td></tr>
<tr><td>21</td><td>Work zone setup, take down and revision</td></tr>
<tr><td>22</td><td>Work zone flagger station</td></tr>
<tr><td>23</td><td>Work zone access and material handling</td></tr>
<tr><td>24</td><td>Highway signing</td></tr>
<tr><td>25</td><td>Pavement marking: striping and markers</td></tr>
<tr><td>26</td><td>Electrical wiring and cables</td></tr>
<tr><td>27</td><td>Electrical poles and posts: lighting/ traffic signals</td></tr>
</table>

CHAPTER 5
EVALUATION OF SELECTED LIGHTING ARRANGEMENTS

5.1 Introduction

This chapter presents the results of field experiments which were conducted to study and evaluate selected lighting arrangements for nighttime construction. The objective of these experiments is to provide a practical set of example arrangements that utilize commonly used lighting equipment and meet the recommended lighting design criteria. These example arrangements are intended to (1) provide a practical sample of possible arrangements that are capable of satisfying the recommended lighting design criteria; and (2) illustrate that the design criteria are attainable using commonly available lighting equipment.

The field experiments were conducted to evaluate the performance of four major types of lighting arrangements, namely: (1) fixed lighting arrangements; (2) mobile lighting arrangements; (3) flagger station arrangements; and (4) transition zone arrangements. The following sections provide a brief description of the conducted experiments and their performance for each of these four types of lighting arrangements. It should be noted that these example arrangements and their measured performance should be used as guidance only since actual lighting levels may vary due to different work zone characteristics and the lighting equipment used.

5.2 Fixed Lighting Arrangements

In this report, the term “fixed lighting arrangements” is used to describe the utilization of portable lighting towers in nighttime construction sites. This type of lighting arrangement was evaluated using a set of experiments that were conducted at the Advanced Transportation Research and Engineering Laboratory (ATREL) at the University of Illinois at Urbana-Champaign. The location of the experiments was selected in an area which was not equipped with any type of street lighting in order to study the lighting requirements for the most demanding (i.e. least illuminated) construction site at night, as shown in Figure 5.1.

Figure 5.1. Experimental Site

In this experimental site, various layouts were set up and examined to study the lighting requirements for work zones in two-lane and four-lane roads. Each work zone layout was divided into a grid of equally spaced points that were marked on the pavement surface to enable a uniform pattern of measurements of illuminance in order to facilitate the calculation of lighting uniformity ratio. Furthermore, each work zone was set up in a way that enabled driving through the work zone in both directions in order to evaluate and calculate glare levels (i.e. veiling luminance ratio).

5.2.1 Utilized Equipment

The following equipment were utilized in the field experiments:

- Light Towers: Three light towers were utilized in the experiments. Each light tower is equipped with four 1000-watt metal halide luminaries, as shown in Figures 5.2. Aiming and rotation angles of all luminaries are adjustable in all directions, and mounting height of luminaries can be extended up to 7.8 m, as shown in Figure 5.3.

Figure 5.2. Preparing Lighting Towers for Experiments

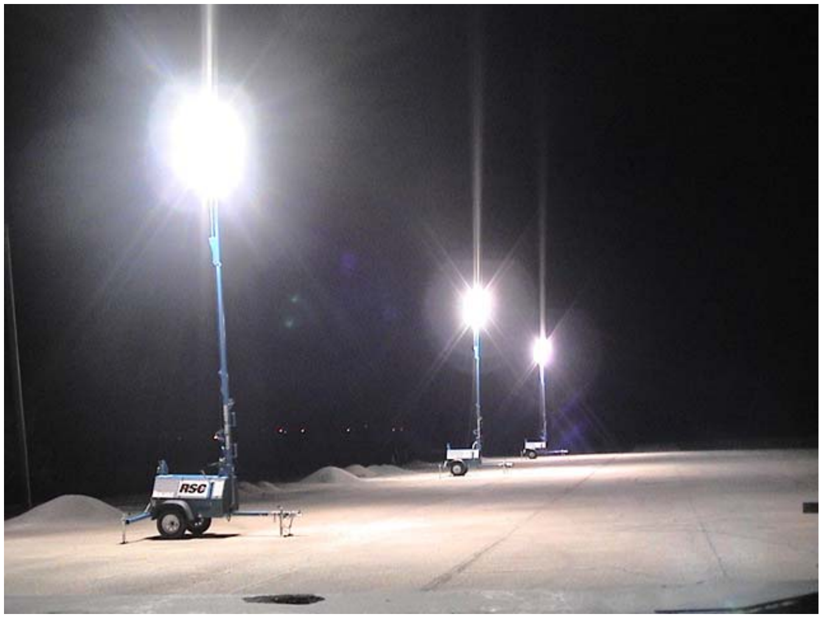


Figure 5.3. Lighting Towers at Night

- Light meter: A light meter was used to measure both horizontal and vertical illuminance during the field tests. The meter shown in Figure 5.4 has a range of illuminance measurements from 0 to 50,000 lux. This meter is a cosine corrected and color corrected light meter. It can be used to measure illuminance, in both lux or foot candles, under different types of lamps.

Figure 5.4. Utilized Light Meter

- Luminance Meter: A Minolta LS-100 luminance meter was used to measure pavement luminance in order to facilitate the evaluation and computation of glare (i.e. veiling luminance) during the field tests. This meter can measure luminance levels from 0.001 to 299,900 cd/m^2 and has a one-degree acceptance angle, as shown in Figure 5.5.

Figure 5.5. Utilized Luminance Meter

- Angle Locator: A magnetic angle locator was used in the experiments to measure and identify the aiming and rotation angles of each luminaire in the light tower. The magnetic angle locator shown in Figure 5.6 is capable of measuring the angle of any surface from the horizontal or vertical plane.
- Surveying Equipment: A total station was used in combination with tapes to mark a grid of points on the pavement to facilitate the measurements of illuminance at the predetermined grid points during the experiments, as shown in Figure 5.7.

Figure 5.6. Angle Locator Used to Measure Aiming and Rotation Angles

Figure 5.7. Using Surveying Equipment to Mark Grid Points

5.2.2 Examined Work Zones

In this field study, the conducted experiments were designed to cover a wide range of nighttime work zones that are typically found in (1) two-lane roads; and (2) four-lane highways.

5.2.2.1 Typical Work Zones in Two-lane Roads

For this type of road, the field tests examined various lighting arrangements in order to satisfy the lighting requirements for two typical sizes of nighttime work zones: (case 1.1) 20 ft x 100 ft zone; and (case 1.2) 20 ft x 250 ft zone, as shown in Figure 5.8. These two cases were suggested by IDOT operation engineers. In order to study the produced light trespass in this setup, it was assumed that a house is located at a distance of 100 ft from the edge of the work zone.

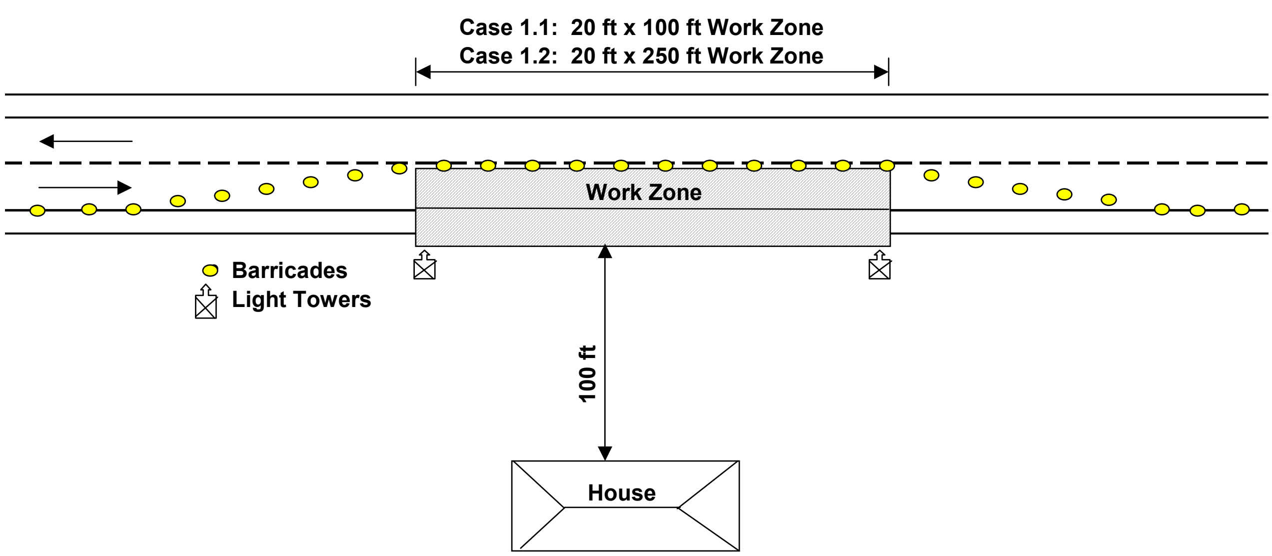


Figure 5.8. Examined Work Zone Layouts for Two-Lane Roads

Case 1.1: 20 ft x 100 ft Work Zone

In this example work zone, lighting arrangement needs to be provided for a stationary work zone on a two-lane road. The work will be carried out in the right lane and will extend to a distance of 100 ft, as shown in Figure 5.8. In this example, it is assumed that a house is located at a distance of 100 ft from the edge of the work zone which imposes additional constraints on the maximum allowable light trespass at that location. Field experiments were performed to evaluate a number of lighting arrangements for this example work zone and to examine the performance of these arrangements in terms of satisfying the lighting design criteria (i.e. average horizontal illuminance, uniformity ratio, glare, and light trespass). The following two sections provide two example lighting arrangements that were found to provide varying degrees of satisfaction to the lighting design criteria for this size of work zone.

Example 1.1.1: First Example Arrangement for 20 ft x 100 ft Work Zone

The experiments showed that the lighting requirements for this work zone layout can be satisfied using two light towers. The specific arrangements and adjustments of the two light towers along with their measured performance in illuminance, uniformity, glare and light trespass are shown in Table 5.1. Figure 5.9 also shows the distribution of the measured horizontal illuminance for this example lighting arrangement. Zero in the x-axis in Figure 5.9 represents the edge of the work area, and the negative value represents the lateral distance between light towers and the outer edge of the work area (i.e. light towers are located at a lateral distance of 2 meters from the edge of the work area in the shown example).

Table 5.1 Lighting Arrangements and Performance for 20 ft x 100 ft Work Zone

Lighting Arrangements		**Measured Performance in Design Criteria**	
Number of Light Towers	2	Average Illuminance	669 lux (Entire work zone)
Spacing	30 m (at both ends of the work zone) 2 m from the work zone edge	Uniformity Ratio (Average to Minimum)	5.4 (Entire work zone)
Mounting Height	7.8 m	Glare (Maximum Veiling Luminance Ratio)	0.11 (Maximum obtained value)
Rotation Angle	Three luminaries at 45^o towards the work zone. One luminaire at 45^o towards the transition zone	Light Trespass (House located at 100 ft from the edge of the work zone)	Maximum. Vertical illuminance: 20 lux (measured 1.5 m above ground at the edge of property line)
Aiming Angle	20^o upward for all luminaries		
Tower Orientation	Each tower is pointed perpendicular to the traffic flow and located at a lateral distance of 2 meters from the edge of the work area		

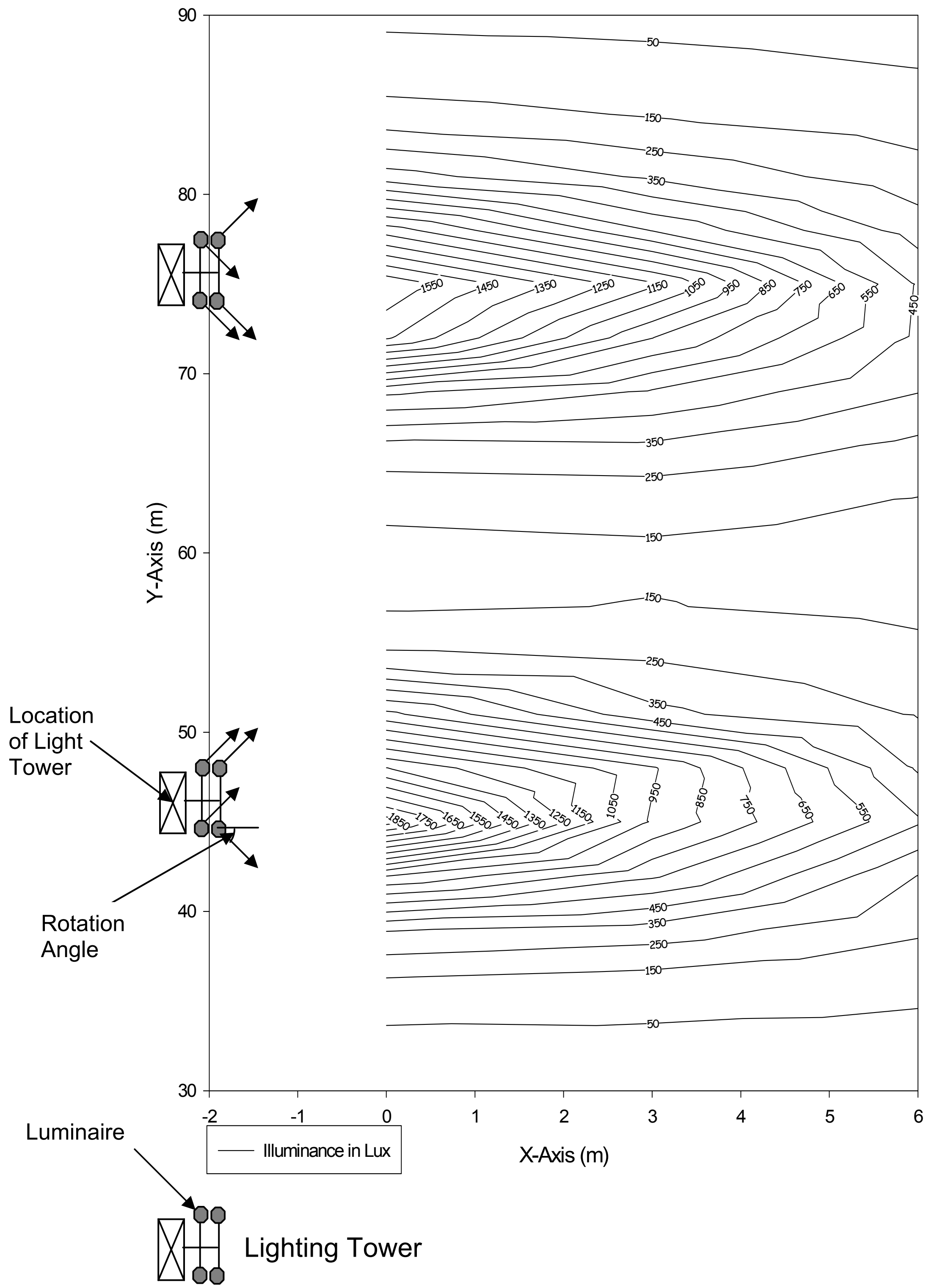


Figure 5.9. Work Zone Illuminance Distribution for 20 ft x 100 ft Work Zone

Example 1.1.2: Second Example Arrangement for 20 ft x 100 ft Work Zone

This example arrangement is similar to the previous one (example 1.1.1 on page 130) in terms of the type and size of the considered work zone. The main difference between the two examples is that this experiment places a higher priority on minimizing light trespass. As such, this example arrangement can be preferred over the previous one where light trespass is expected to be a major concern during nighttime construction. In this example arrangement, light trespass was reduced in both sides of the road while satisfying all the remaining requirements of the lighting design criteria by minimizing aiming angles and locating lighting towers at a closer spacing.

This example configuration clearly illustrates the trade-offs in nighttime construction lighting design. Lower light trespass can be achieved, in this example, by increasing the cost of lighting equipment due to the closer spacing of light towers (20 m instead of 30 m). The specific arrangements and adjustments of the two light towers along with their measured performance in illuminance, uniformity, glare and light trespass are shown in Table 5.2.

Table 5.2 Lighting Arrangement for 20 ft x 100 ft Work Zone with Light Trespass Constraints

Lighting Arrangements		**Measured Performance in Design Criteria**	
Spacing	20 m	Average Illuminance	611 lux (Entire work zone)
Mounting Height	7.8 m		
Rotation Angle	Two luminaires at 0 °, and one luminaire at 45 ° in both directions	Uniformity Ratio (Average to Minimum)	2.75 (Entire work zone)
Aiming Angle	0 ° for all luminaires	Glare (Maximum Veiling Luminance Ratio)	0.04 (Maximum obtained value)
Tower Orientation	Each tower is pointed perpendicular to the traffic flow and located at a lateral distance of 2 meters from the edge of the work area	Light Trespass (House located at 100 ft from the edge of the work zone)	Maximum vertical illuminance: 5 lux at both sides of the road (measured 1.5 m above ground at the edge of the property line)

Case 1.2: 20 ft x 250 ft Work Zone

In this example work zone, lighting arrangement needs to be provided for a stationary work zone in a two-lane road. The work will be carried out in the right lane and will extend to a distance of 250 ft, as shown in Figure 5.8. In this example, it is assumed that a house is located at a distance of 100 ft from the edge of the work zone which imposes additional constraints on the maximum allowable light trespass at that location. Field experiments were performed to evaluate the performance of various lighting arrangements for this example work zone. The following two sections provide two example lighting arrangements that were found to provide varying degrees of satisfaction to the lighting design criteria for this size of work zone.

Example 1.2.1: First Example Arrangement for 20 ft x 250 ft Work Zone

The experiments showed that the lighting requirements for this size of work zone can be satisfied using three light towers. The specific arrangements and adjustments of the three light towers along with their measured performance in illuminance, uniformity, glare and light trespass are shown in Table 5.3. Figure 5.10 also shows the distribution of the measured horizontal illuminance for this example lighting arrangement. It should be noted that this example lighting arrangement is a modular one that can be expanded to accommodate longer work zones, by simply increasing the number of lighting towers while keeping the spacing among towers and the other parameters unchanged.

Table 5.3 Lighting Arrangements and Performance for 250 ft long Work Zone

Lighting Arrangements		**Measured Performance in Design Criteria**	
Number of Light Towers	3	Average illuminance	552 lux (Entire work zone)
Spacing	30 m	Uniformity Ratio (Average to Minimum)	4.83 (Entire work zone)
Mounting Height	7.8 m	Glare (Maximum Veiling Luminance Ratio)	0.12 (Maximum obtained value)
Rotation Angle	For the edge Lighting towers: three luminaries at 45° towards the work zone, and one luminaire at 45° towards the transition zone For the middle lighting tower: one luminaire at 45° for each direction.	Light Trespass (House located at 100 ft from the edge of the work zone)	Maximum vertical Illuminance: 2 lux (Measured 1.5 m above ground at the edge of the property line)
Aiming Angle	20° for all luminaires		
Tower Orientation	Each tower is pointed perpendicular to the traffic flow and located at a lateral distance of 2 meters from the edge of the work area		

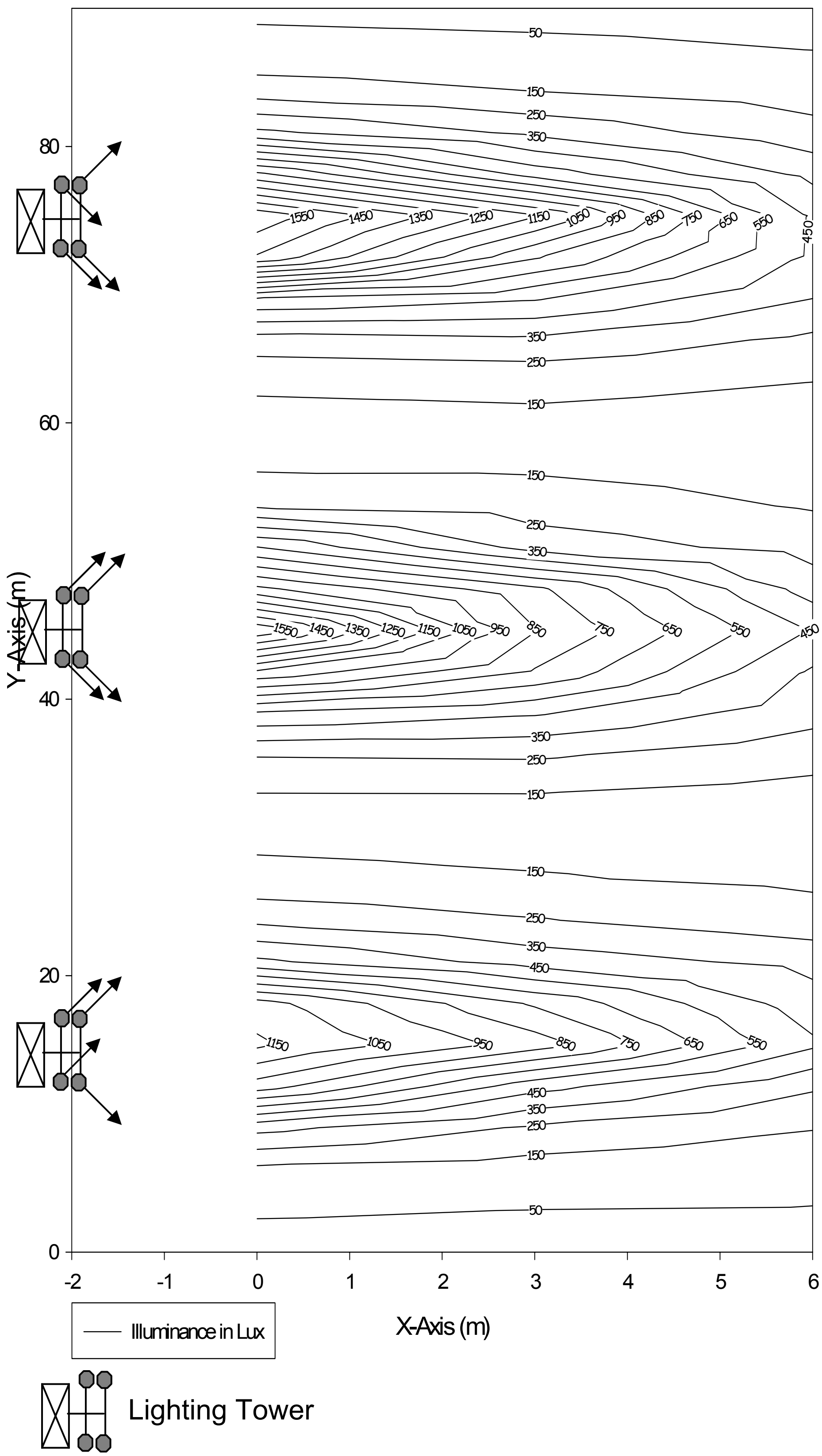


Figure 5.10. Work Zone Illuminance Distribution for 250 ft long Work Zone

Example 1.2.2: Second Example Arrangement for 20 ft x 250 ft Work Zone

The tested arrangement in this example is similar to the previous one (example 1.2.1) in terms of spacing and mounting height. The main difference between the two is that the aiming angles were increased to 45 degrees in this arrangement. As shown in Table 5.4, this led to increased glare levels to a veiling luminance ratio of 0.2 as compared to 0.12 in the previous example. Surprisingly, this increase in glare was not accompanied by improvement in any other design criteria. This illustrates clearly that higher aiming angles do not necessarily produce better results for lighting levels or uniformity.

Table 5.4 Lighting Arrangement and Performance for 250ft long Work Zone

Lighting Arrangements		**Measured Performance in Design Criteria**	
Number of Light Towers	3	Average Illuminance	413 lux (Entire work zone)
Spacing	30 m	Uniformity Ratio (Avg. to Minimum)	4.3 (Entire work zone)
Mounting Height	7.8 m	Glare (Maximum Veiling Luminance Ratio)	0.2 (Maximum obtained value)
Rotation Angle	Two luminaries at 45° and two luminaires at -45° (2 luminaires at 45° for each direction).	Light Trespass (House located at 100 ft from the edge of the work zone)	Maximum Vertical illuminance: 1 lux (Measured 1.5 m above ground at the edge of the property line)
Aiming Angle	45° for all luminaires		
Tower Orientation	Each tower is pointed perpendicular to the traffic flow and located at a lateral distance of 2 meters from the edge of the work area		

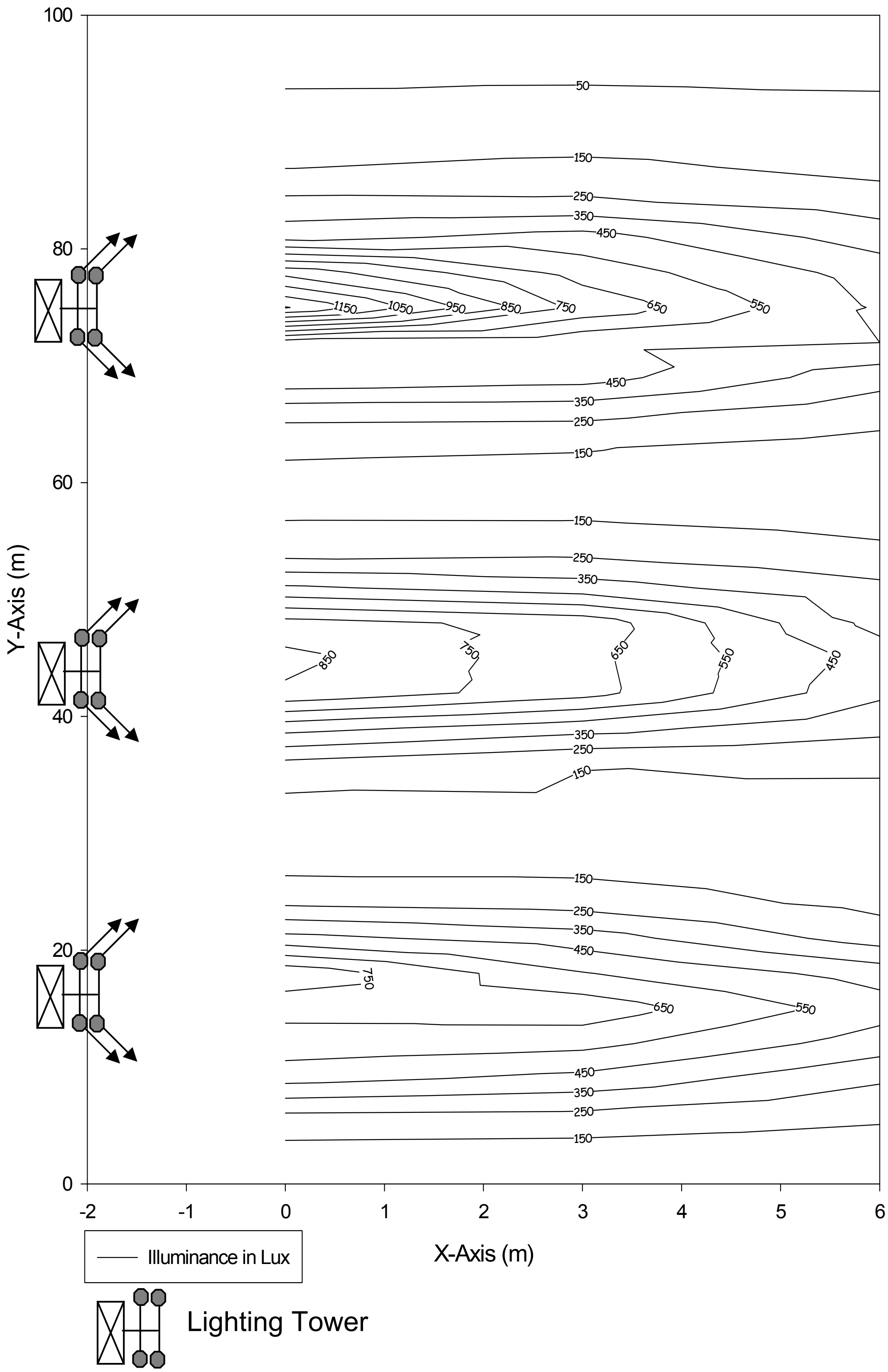


Figure 5.11. Work Zone Illuminance Distribution for Example 1.2.2

5.2.2.2 Work Zones in Four-lane Highways

For this type of highways, the field tests examined a number of lighting arrangements for two typical sizes of nighttime work zones: (2.1) 24 ft x 250 ft zone; and (2.2) 24 ft x 500 ft zone, as shown in Figure 5.12.

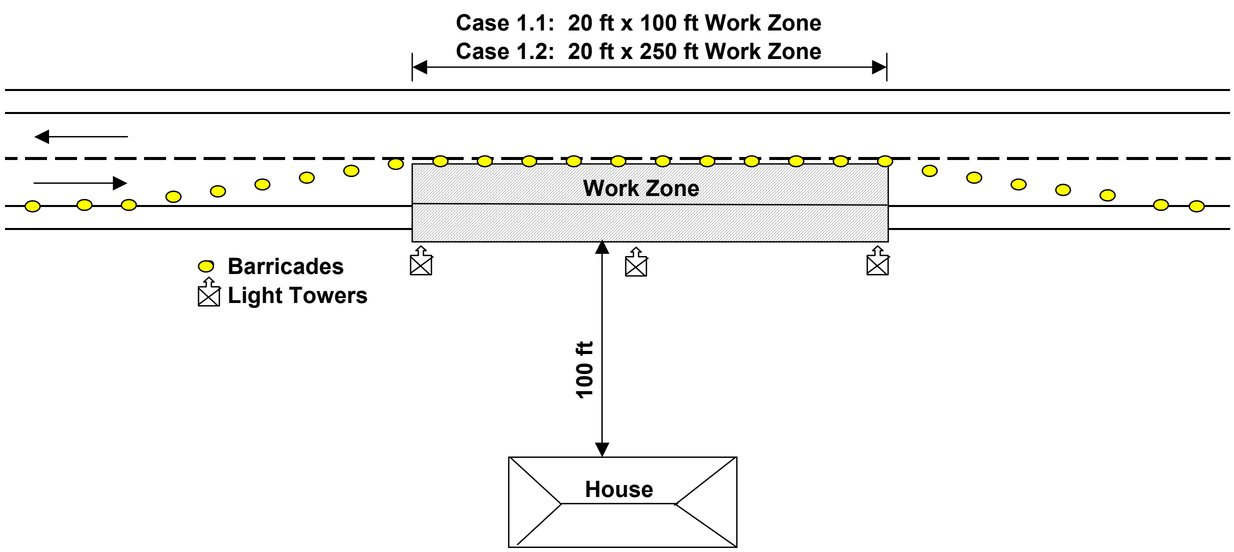


Figure 5.12. Examined Work Zone Layouts for Four-Lane Highways

In these experiments, it was found that the previous example arrangements that utilized three light towers for 250+ ft long two-way roads (example 1.2.1 in page 136) provided better or similar lighting performance in a four-lane highway of the same length. The only difference between the two is the levels of glare experienced by traffic. In four-lane divided highways, it was found that the traffic in the opposite direction was exposed to lower levels of glare than those experienced in two-lane roads because of the median which increases the offset distance between the light sources and the driver's line of sight. As such, the earlier described modular and expandable lighting arrangements in example 1.2.1 (see page 136) was found to satisfy all lighting design requirements for the two work zone sizes considered in this type of four-lane highway.

5.3 Mobile Arrangements

In the case of mobile lighting systems, lighting arrangements should be designed to provide the required lighting levels and satisfy the requirements of other lighting design criteria. This includes the specified areas that need to be illuminated in front of and behind the equipment depending on the speed of movement of the equipment (see section 4.3.3.1 in Chapter 4). Providing construction equipment with additional lighting to satisfy design criteria should be performed by lighting professional personnel to ensure that the selected lighting arrangement satisfies the required design criteria, and to ensure that installations conform to the applicable safety codes. This section provides example mobile lighting arrangements for equipment commonly used in paving and resurfacing operations. These example arrangements were obtained from (1) field tests conducted for paving equipment; and (2) available recommendations in the literature.

5.3.1 Field Tests for Paving Equipment

Field tests were carried out at Mattoon, Illinois by Ingersoll-Rand Inc, which manufactures paving equipment, to study the performance of selected lighting arrangements for this type of equipment. The arrangement in these tests utilized four 1000-watt metal halide luminaries (NEMA 6 distribution). Two of these luminaries were mounted to illuminate the area in front of the equipment, while the other two were positioned to illuminate the area behind it, as shown in Figure 5.13. The aiming angles of these luminaries were set at 30°.

Figure 5.13. Lighting Arrangement for Paving Equipment

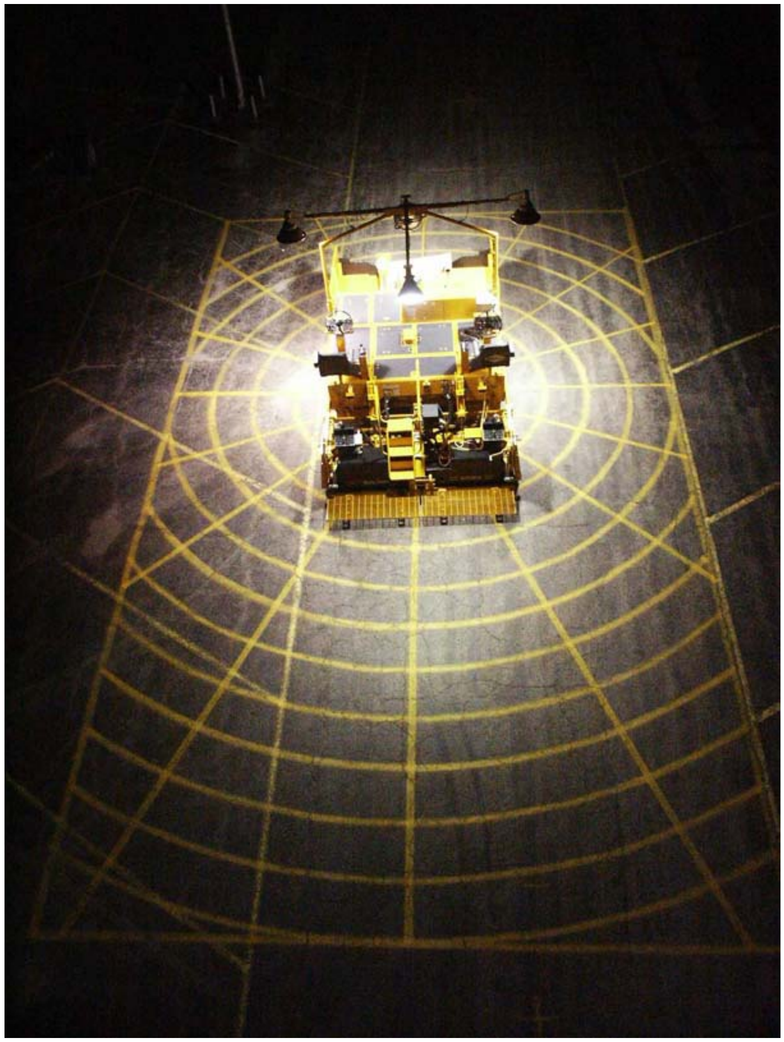


Figure 5.14. Polar Grid for Illuminance Readings

As shown in Figure 5.14, a polar grid was created to facilitate the measurement of illuminance readings in front and behind the paving equipment. In this example arrangement, the measured average illuminance readings for an area that extends 9 m (30 ft) in front and behind the equipment were found to be 421 lux (39 fc) with an average to minimum uniformity ratio of 4.4. As such, this example lighting arrangement was found to satisfy the earlier recommended illuminance requirements for paving operations.

5.3.2 Available Recommendations in the Literature

A study conducted by Amos (1994) provided recommended lighting arrangements for five types of construction equipment: (1) milling machine; (2) front loader; (3) sweeper; (4) paver; and (5) roller. The required illuminance level and the areas that need to be illuminated in front of and/or behind the equipment are illustrated in Table 5.5.

Table 5.5. Requirements for Utilized Equipment and Lighting Levels

Type	Area to be Illuminated			Illuminance Level lux (fc)
	Dimensions	Area m^2	Location	
Milling Machine	4.9m x 3.3m (16 ft x 11 ft)	16.2	Front & Rear	108 (10)
Front Loader	17.7m x 3.3m (58 ft x 11 ft)	58.4	Front	54 (5)
Sweeper	17.7m x 3.3m (58 ft x 11 ft)	58.4	Front	54 (5)
Paver	4.9m x 3.3m (16 ft x 11 ft)	16.2	Front & Rear	108 (10)
Roller	17.7m x 3.3m (58 ft x 11 ft)	58.4	Front & Rear	108 (10)

In order to satisfy the lighting requirements specified in Table 5.5, a cluster of 100-watt metal halide luminaries (i.e. 1 to 3 luminaries) can be mounted on the various construction equipment utilized in this example. The exact mounting location of each luminaire is constrained by the physical characteristics of the construction equipment. For each construction equipment in this example, the suggested arrangement of mobile lighting equipment, and the produced lighting conditions are shown in Table 5.6 to 5.9.

Table. 5.6. Lighting Arrangement for Rollers

Recommended Arrangement		**Produced Lighting**	
Three-lamp cluster for the front area, and three-lamp cluster for the rear area.		Average illuminance level	106 lux (9.8 fc)
Lamp	100-watt metal halide (MH100)	Minimum illuminance	14 lux (1.3 fc)
Mounting height	5 m (16 ft)	Uniformity ratio	7.8. (average to minimum).
Aiming angle	60^o		
Rotation angle	0^o		

Table 5.7. Lighting Arrangement for Sweepers and Front-End Loaders

Recommended Arrangement		**Produced Lighting**	
Two-lamp cluster for the front area.		Average illuminance level	66 lux (6.11 fc)
Lamp	100-watt metal halide (MH100)	Minimum illuminance	7 lux (0.65 fc)
Mounting height	5 m (16 ft)	Uniformity ratio	8.9 (average to minimum).
Aiming angle	60^o		
Rotation angle	0^o		

Table 5.8. Lighting Arrangement for Paving Machines

Recommended Arrangement		Produced Lighting	
One lamp for the front area and one lamp for the rear area.		Average illuminance level	104 lux (9.63 fc)
Lamp	100-watt metal halide (MH100)	Minimum illuminance	26 lux (2.4 fc)
Mounting height	3 m (10 ft)	Uniformity ratio	4 (average to minimum).
Aiming angle	60^{o}		
Rotation angle	0^{o}		

Table 5.9. Lighting Arrangement for Milling Machines

Recommended Arrangements		Produced Lighting	
One lamp for the front area and one lamp for the rear area.		Average illuminance level	121 lux (11.2 fc)
Lamp	100-watt metal halide (MH100)	Uniformity ratio	2.6 (average to minimum).
Mounting height	3 m (10 ft)	Minimum illuminance	47.6 lux (4.4 fc)
Aiming angle	60^{o}		
Rotation angle	0^{o}		

5.4 Flagger Station Arrangements

Flagger stations should be illuminated during nighttime work to ensure that all flaggers are clearly visible to traffic and their positions are safe and effective. Since the main purpose of flagger stations is to provide warning to the drivers approaching the work zone, the vertical illuminance in the direction facing the traffic is the most important criterion that should be met by the provided lighting. Lighting arrangements for flagger stations should satisfy the required design criteria (i.e. a minimum average vertical illuminance level of 108 lux, 10 fc), without causing objectionable glare to the traffic approaching the work zone. Field experiments were performed to evaluate an example lighting arrangement for flagger stations using two luminaires positioned above the flagger with 500-watt quartz lamps, as shown in Figure 5.15. The luminaires were ground mounted on a tripod at a height of about 3m (10 ft.). Ground mounted tripods provide flexibility to the flagger in adjusting lights. The provided lighting was capable of satisfying the required lighting level for flagger stations (i.e. 108 lux) without causing objectionable glare. Due to the limited area that should be illuminated in this type of arrangement, the lights should be aimed straight down to avoid causing glare to the traffic approaching the work zone.

Figure 5.15. Example Lighting Arrangement for Flagger Station

5.5 Transition Zone Arrangements

The term transition zone is used here to indicate the area of the road that is immediately before or after the work area. Transition zones should be illuminated to: (1) help drivers become accustomed to the difference in lighting levels between the illuminated work zone area and the rest of the road; and (2) help drivers recognize the work zone from a far enough distance that prepares them to properly respond to the new road conditions (e.g. by lowering speed). The developed design criteria require a minimum average horizontal illuminance of 54 lux (5 fc) to be maintained in transition zones. Although this lighting level can be achieved using the commonly available light towers, the field experiments indicated that they may not be the best choice for transition zones.

The field experiments examined and compared the performance of two selected types of lighting equipment for transition zones, namely portable lighting towers (see Figure 5.3) and ground mounted lighting on tripods (see Figure 5.15). The experiments showed that the use of ground mounted lighting on tripods provides a more efficient and cost effective solution for transition zones than portable light towers, especially when several of these tripods can be connected to a single portable generator. For example, the experiments revealed that a single lighting tower could be used to provide the required lighting levels for a longitudinal length of up to 50 m (165 ft) of the transition zone at a daily rental cost of $110. The alternative utilization of ground-mounted lighting on tripods was found to satisfy the required lighting levels for the same length of the transition zone at a daily rental cost of $48 ($12 per lighting stand).

Furthermore, the utilization of several ground-mounted lighting on tripods was found to provide better lighting uniformity than that achieved using a single light tower. For light towers spaced at 50 m (165 ft) with 7.8 m (26 ft) mounting height, the obtained average illuminance was 300 lux (27.8 fc) and the uniformity ratio was 27. For ground lighting on tripods, at 12 m (39 ft) spacing and 3 m (10 ft) mounting height, the average illuminance was 125 lux (11.5 fc), and the uniformity ratio was 11. Further improvements in uniformity can be achieved if ground mounted lighting on tripods are utilized with higher mounting height. It should be noted that the listed values here are intended for illustrative purposes only to compare the use of multiple lighting sources with lower lumen output (e.g. ground mounted lighting on tripods) to a single light source with higher lumen output (e.g. commonly used lighting towers) in transition zones.

CHAPTER 6
RECOMMENDATIONS FOR LIGHTING ARRANGEMENTS

6.1 Introduction

This chapter presents practical recommendations for lighting arrangements in order to help nighttime construction personnel in complying with the design criteria requirements presented in Chapter 4. Recommendations presented here were developed based on: (1) the conducted field experiments; (2) the latest reported research and developments in lighting and vision science; and (3) the characteristics of available lighting equipment.

This chapter presents recommendations for: (1) providing adequate lighting arrangements for nighttime construction sites, including mobile and fixed systems, and glare control measures; and (2) selecting lighting equipment for nighttime highway construction. It should be noted that the recommended arrangements should be used as guidelines only since actual lighting levels may vary depending on the actual work zone characteristics and the lighting equipment used.

6.2 Lighting Arrangements

Highway construction work zones are typically linear work areas that extend for a relatively long distance and involve construction work in one or more lanes of the highway. Whenever nighttime construction is utilized, adequate lighting conditions need to be maintained in these work zones. The availability of existing street and highway lighting does not guarantee adequate lighting conditions for nighttime construction operations. Additional lighting arrangements must be added during construction operations in order to satisfy lighting requirements on nighttime construction sites. Temporary lighting arrangements can be provided in the form of: (1) fixed lighting arrangements; and/or (2) mobile lighting systems. The factors that should be considered in the selection process of proper lighting arrangements include: (1) work zone size and layout; (2) required mobility; (3) duration of work; (4) required illuminance level and ability to satisfy minimum requirements; (5) existing lighting; (6) cost; (7) power requirements; (8) glare control; and (9) light trespass limitations (Amos 1994; and Bryden and Mace 2002).

6.2.1 Fixed Lighting Arrangements

As mentioned earlier, the term “fixed lighting arrangements” is used to describe the utilization of portable lighting towers in nighttime construction sites. This type of lighting towers is available in the form of a trailer mounted or ground mounted tower (e.g. collapsible tripod portable light stands). Fixed lighting arrangements can be utilized in nighttime construction sites as a stand-alone system or in combination with mobile lighting systems (i.e. equipment mounted lighting). First, fixed lighting arrangements can be used solely in order to satisfy the lighting requirements for all the construction activities in the work zone. Second, a fixed system can also be used to supplement a mobile lighting system in order to ensure safety in the work zone by providing a minimum illuminance level of 54 lux (5 fc) in areas that are not adequately illuminated by the mobile system.

The design of fixed lighting arrangements requires selecting proper values for the lighting design variables, including (1) luminaires' mounting height, which represents the vertical distance between the center of the luminaires and the pavement surface; (2) lighting towers positioning, which represents the location of the lighting towers in the work zone; (3) aiming angle of the luminaries, which is the angle between the center of the luminaires' beam spread and nadir; and (4) rotation angles of the luminaries, which represent the rotation in a horizontal plane. Proper values for these variables need to be selected to improve the performance and quality of the selected lighting arrangement. Several field experiments were conducted to evaluate selected fixed lighting arrangements, as previously described in Chapter 5. The following section presents an example of fixed lighting arrangements that was found to satisfy the required design criteria during field experiments. Additional examples of fixed lighting arrangements and their measured performance during the field tests can be found in section 5.2 of the previous chapter.

This example lighting arrangement was examined during the field tests and was found to provide satisfactory lighting conditions for a four-lane, two-way highway. In this example, it is assumed that (1) the construction work is performed in the right lane and extends a distance of 500 ft.; (2) there is adequate space to position lighting equipment alongside the work zone; (3) a house is located at a distance of

100 ft from the edge of the work zone. The suggested lighting arrangement for this example and the obtained values for design criteria are shown in Table 6.1.

Table 6.1 Lighting Arrangement for 500ft Work Zone

<table>
<tr><th colspan="2">Design Parameters
(Lighting Arrangement)</th><th colspan="2">Design Criteria</th></tr>
<tr><td>Number of Light Towers</td><td>6</td><td rowspan="2">Average Illuminance</td><td rowspan="2">377 lux (Entire work zone)</td></tr>
<tr><td>Spacing</td><td>30 m</td></tr>
<tr><td>Mounting Height</td><td>7.8 m</td><td>Uniformity Ratio
(Average to Minimum)</td><td>3.46
(Entire work zone)</td></tr>
<tr><td rowspan="2">Rotation Angle</td><td rowspan="2">For the edge Lighting towers: three luminaries at 45^{o} towards the work zone, and one luminaire at 45^{o} towards the transition zone
For the middle lighting towers: 2 luminaires at 45^{o} for each direction.</td><td>Glare (Maximum Veiling Luminance Ratio)</td><td>0.12
(Maximum obtained value)</td></tr>
<tr><td rowspan="3">Light Trespass
(House located at 100 ft from the edge of the work zone)</td><td rowspan="3">Maximum Vertical Illuminance: 20 lux (Measured 1.5 m above ground at the edge of the property line)</td></tr>
<tr><td>Aiming Angle</td><td>20^{o} for all luminaires</td></tr>
<tr><td>Tower Orientation</td><td>Each tower is pointed perpendicular to the traffic flow and located at a lateral distance of 2 meters from the edge of the work area</td></tr>
</table>

The advantages of utilizing portable light towers include: (1) flexibility in lighting design, since these towers are self-contained and can be easily moved in the work zone; (2) availability, since these towers can be obtained from most construction equipment rental companies; and (3) reliability and ease of use and maintenance (Amos 1994). Despite these advantages, light towers can potentially cause glare problems in the work zone, especially when they are equipped with high wattage lamps at a low mounting height (Amos 1994; and Bryden and Mace 2002).

6.2.2 Mobile Lighting Arrangements

In this report, the term “mobile lighting arrangements” is used to describe the utilization of luminaires attached to mobile construction equipment during nighttime operations. In a mobile lighting system, luminaires should be designed and installed on construction equipment by a professional in a way that (1) does not obstruct the sight of the equipment operator; and (2) ensures secure connection to the equipment with minimum vibration (Bryden and Mace 2002). The installation should also utilize brackets and fixtures to mount luminaires on construction equipment in order to enable aiming and rotating luminaires in a proper direction that reduces glare and/or directs light where needed (Bryden and Mace 2002).

Mobile lighting systems should be designed to provide the required lighting levels in adequate areas both in front and behind the equipment. The areas that should be illuminated depend on the type of operation and the operating speed of the construction equipment. The minimum distance to be illuminated in front and behind construction equipment should not be lower than the equipment stopping distance at its maximum operating speed (Ellis et al 1995). A study conducted in 1995 categorized highway construction equipment into: (1) slow moving equipment with a stopping distance of 4.9 m (16 ft); and (2) fast-moving equipment with a stopping distance of 17.7 m (58 ft) as shown in Table 6.2 (Ellis et al 1995). Distances obtained, based on the equipment stopping distance at its maximum operating speed, represent a required, but not sufficient, condition that should be met by mobile lighting arrangements. This report recommends a minimum distance of 9 m (30 ft) in front and behind slow moving equipment such as pavers and milling machines, and a minimum distance of 20 m (65 ft) in front and behind faster moving equipment such as backhoes and wheel loaders, scrapers, rollers, and motor graders (see Table 6.3).

Table 6.2. Stopping Distance for Various Construction Equipment (Ellis et al 1995).

Type of Equipment	Working Speed km/h (mph)	Reaction Distance m (ft)	Breaking Distance m (ft)	Stopping Distance m (ft)
Slow-Moving Equipment				
Paver Milling Machine	6.4-8 (4-5)	3.4 (11)	1.5 (5)	4.9 (16)
Fast Moving Equipment				
Backhoe Loader Wheel Tractor Scraper Wheel Loader Compactor/Roller Motor Grader	16.1-24.2 (10-15)	10.1 (33)	4.6-7.6 (15-25)	17.7 (58)

Table 6.3. Recommended Illuminated Distance for Various Construction Equipment

Type of Equipment	Distance to be illuminated in front and behind equipment, m (ft)
Slow-Moving Equipment: (e.g. Paver, Milling Machine)	9 (30)
Fast Moving Equipment (e.g. Backhoe Loader, Wheel Tractor, Scraper, Wheel Loader, Compactor/Roller, Motor Grader)	20 (65)

A survey of nighttime construction practices revealed that mobile lighting arrangements were frequently utilized by the surveyed contractors (Amos 1994). The advantages of these mobile arrangement over the fixed type were reported to include: (1) providing high intensity illumination in the activity work area; (2) eliminating shadows through positioning of lights between operator and task; (3) providing flexibility to the operator to direct light where needed; (4) operating equipment autonomously regardless of the general illumination; (5) reducing the possibility of general shutdown of work due to failure of portable light towers, and (7) minimizing the time and effort needed to reposition and handle portable light towers (Amos 1994). Equipment mounted lighting systems can be used to supplement the fixed arrangements, described earlier in order to increase illuminance levels from the minimum average level of 54 lux (5 fc) to satisfy activity lighting requirements of 108 lux or 216 lux (10 fc or 20 fc) in the area where construction tasks are performed directly in front and behind the construction equipment (Bryden and Mace 2002).

It should be noted that headlamps on various construction equipment are manufactured to satisfy the Society of Automotive Engineering (SAE) lighting criteria. The primary purpose of these criteria is to ensure adequate lighting for the movement and travel of construction equipment on highways. These headlamps are therefore inadequate to satisfy the lighting requirements for various construction tasks during nighttime operations. As such, the headlamps in all construction equipment must be supplemented with dedicated luminaires to provide lighting for construction activities (in the case of selecting a mobile lighting system) for the nighttime construction site (Bryden and Mace 2002).

6.2.3 Glare Control Measures

Glare is a term used to describe the sensation of annoyance, discomfort or loss of visual performance and visibility produced by experiencing luminance in the visual field significantly greater than that to which eyes of the observer are adapted (Triaster 1982). Glare affects both safety and visual comfort of road users and workers. Contractors and resident engineers should exert every possible effort to reduce the glare produced by nighttime lighting equipment. Glare can be controlled during nighttime construction operations using the following three measures: (1) selection of lighting sources that minimize glare on site; (2) proper design and arrangement of lighting equipment (e.g. aiming angle, mounting height) in order to reduce high glare levels on site; and (3) utilizing glare control hardware, if needed.

6.2.3.1 Selection of Lighting Sources

Contractors should be encouraged to use light sources that produce low glare levels. First, proper selection of luminaire type (e.g. cutoff luminaires) can reduce glare by shielding the emitted light above a specified vertical angle in order to direct a greater proportion of candlepower to the work area (Bryden and Mace 2002). Second, a new technology, balloon lights, is available in the market to help control glare produced by nighttime lighting. Balloon lights have been used in several state DOTs such as Caltrans, Minnesota, and Pennsylvania (Lockwood 2000, Caltrans 2000). Balloon lights are inflated with air or helium with a halogen or metal halide electrical system inside (Lockwood 2000). Figures 6.1 to 6.3 show examples of balloon lights on highway projects. Balloon lights reduce the brightness of the lighting source by distributing the luminous flux over a relatively large area, thus reducing the glare to a great extent.

Figure 6.1. Balloon Lighting

Figure 6.2. Balloon Lighting

Figure 6.3. Balloon Lighting

6.2.3.2 Design and Arrangement of Lighting Equipment

In order to avoid objectionable glare to road users, the following guidelines should be adopted during the design and arrangement of lighting equipment in nighttime highway construction: (1) luminaires should be positioned so that the axis of maximum candlepower of the luminaires is directed away from the motorists' line of sight by a minimum angle of 45°; (2) the vertical aiming angle of all luminaires should be kept to a minimum and should not exceed 60° between the center of the beam axis and nadir; (3) luminous intensity of all luminaires should provide less than 20,000 candela at an angle of 72° from nadir; and (4) light towers should be fully extended to their maximum mounting height (Bryden and Mace 2002).

6.2.3.3 Hardware Measures

Supplemental hardware can be used whenever needed to control glare, especially when lighting tower locations are restricted by the physical constraints of the work zone or where sufficient mounting height cannot be obtained. In these cases, additional hardware such as visors, louvers, shields, screens and barriers can be used to reduce glare. A visor is essentially a piece of aluminum bent to the shape or curve of the fixture to capture excess reflected light and direct it both toward the job site and away from unwanted areas such as traffic and residential areas. Although visors distort the light distribution of a luminaire, they can in some instances provide as much as 13% increase in the fixture's usable light in the work area. Most manufactures offer visors as optional equipment (Greenquist, 2001).

Glare screens are another hardware measure that can be used to control glare. They are utilized on site in the form of a series of steel paddles that are cemented on the top of temporary traffic barriers, which separate motor vehicle traffic from the work area (MUTCD 2000). Screens are often spaced eight feet apart, facing traffic, to allow police to see past them to respond to emergencies. Glare screens and barriers are used by several states when other glare avoidance measures fail. Table 6.4 shows the use of glare screens and barriers in several states (Amos 1994). Louver is a grid type of optical assembly used to control light distribution from a fixture, it usually consists of a series of baffles used to shield a source from view at certain angles or to absorb unwanted light. The baffles are arranged in a geometric pattern (Kaufman and Haynes 1981). External glare shields may also be used as shown in Figure 6.4 to control glare.

Table 6.4. Glare Screening Methods Used in Various States (Amos 1994)

State	Screens or Barriers Utilized to Avoid Glare to Motorists.
California	2 ft high plywood “GAWK” screens mounted on concrete. barrier walls K-rail used by the contractors for maintenance work.
Georgia	Plywood paddles on concrete barrier walls for apparent glare problem.
Illinois	Screens used usually at crossovers and curves.
Iowa	Glare screens to help separate lanes.
Kansas	Sometimes Jersey barriers are utilized.
Kentucky	Concrete barrier walls.
Maine	Concrete barriers on bridge decks.
Maryland	Modular units consisting of vertical blades mounted on a continuous horizontal base rail.
Missouri	Concrete barrier walls.
Nevada	Vertical panels generally used at curves.
New York	Fabric screens are utilized based on contractor’s discretion.
Oklahoma	Median barrier with blade-type portable modular glare screen
Rhode Island	24 inches high Modular Guidance System on top of Jersey barrier

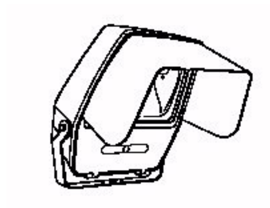


Figure 6.4. A Shielded Floodlight (International Dark-Sky Association Information Sheet 106 1996)

6.3 Lighting Equipment

Lighting equipment includes: (1) luminaires; (2) lamps; (3) power sources; and (4) supporting equipment (i.e. poles, mast arms, wiring and other hardware necessary for installation). Lighting equipment for nighttime construction operations should be selected and arranged so as to provide the required visibility for construction activities and to ensure safety in the construction zone in a cost effective manner. Several types of light sources are currently available in the market and can be used for lighting nighttime construction operations. The following sections provide a summary of available lighting equipment and their basic characteristics.

6.3.1 Type of Luminaires

A luminaire is a complete lighting unit that consists of one or more lamps together with the parts designed to distribute the light, position and protect the lamp, and connect the lamp to the power supply (Kaufman and Haynes 1981).

6.3.1.1 Operational Characteristics

The operational characteristics of a luminaire determine its performance and should be considered in the selection process of light sources. The operational characteristics include: (1) lamp lumen output; (2) efficacy; (3) rated life; (4) lamp lumen depreciation; (5) color; and (6) starting time (IESNA, 1998).

Lamp lumen output:

Lamp lumen output represents the visual effect created by the energy emitted from the lamp (Lewin 2001). Lumen output can be obtained by summing up all the results of multiplying the radiation of the lamp at each wavelength in the visible spectrum by the visual response or sensitivity of the human eye at that wavelength (Taylor 2000).

Efficacy:

Efficacy of a lamp is a primary criterion in comparing and selecting light sources. Efficacy is the measure of light produced by the lamp relative to its energy consumption and is expressed as lumens per watt (IESNA, 1998). It should be noted that the operation of certain types of lamps (e.g. high discharge lamps) requires ballasts, which has an impact on luminaire efficacy. For these lamps, efficacy can be measured for the lamp or for the combined system of lamp and ballast. The system efficacy is less than the lamp efficacy due to the additional power losses in the ballast (IESNA, 1998). Ballast losses vary according to ballast type, design, and line voltage, and may range from 5% to 20% of lamp electrical power (IESNA, 1998). For lamps that do not require ballast (i.e. incandescent, tungsten, and halogen lamps), the lamp efficacy is the same as system efficacy (IESNA, 1998). Figure 6.5 shows the efficacy ranges for different lamps. It should be noted that published efficacy values for every lamp are based on the performance of the lamp at high lighting levels (He et al 1996).

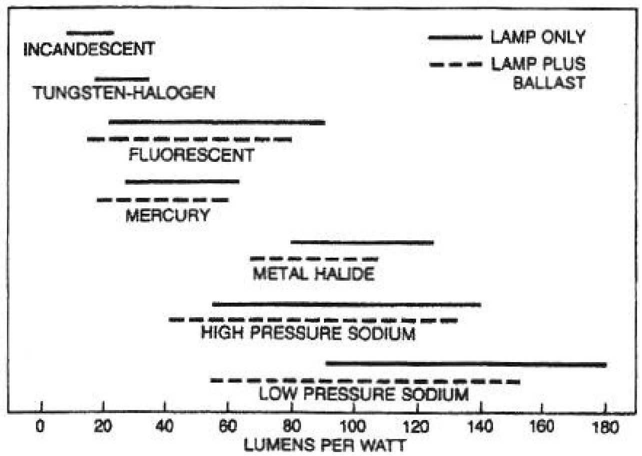


Figure 6.5. Efficacy Ranges of Various Lamps (IESNA, 1998)

Rated life:

Lamps differ in their rated life which can be estimated as the time at which at least 50% of lamps used in a lighting system are still operating (IESNA, 1998). The cost of the lamp and its replacement should be taken into account in the selection of lamps with different rated lives (IESNA, 1998). Figure 6.6 shows the ranges of rated life for different light sources.

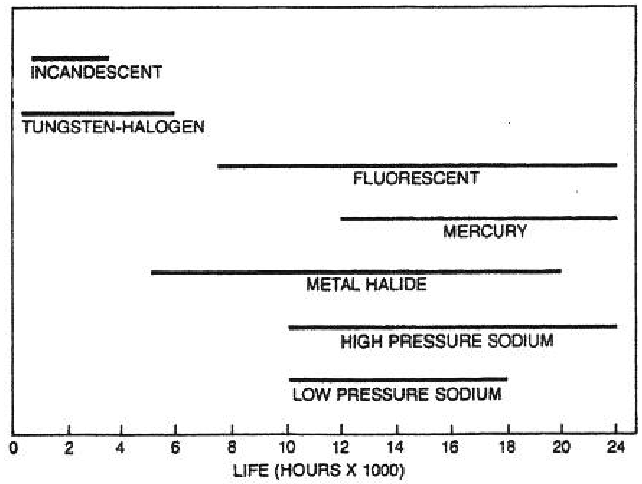


Figure 6.6 Ranges of Rated Life for Various Lamps (IESNA, 1998).

Lamp lumen depreciation:

This represents the loss in the ability of lamps to produce light over time. Lamp lumen depreciation varies from one light source to another, and ranges from only 5% in tungsten and halogen lamps up to 20% in incandescent filament lamps over the life of the lamp (IESNA, 1998). The actual lamp lumen depreciation of a discharge light source depends on the type of ballast, tolerance in line voltage, and number of times the lamp is turned on and off (IESNA, 1998).

Color:

The color characteristics of lamps include color temperature and color rendering. First, color temperature is the color appearance of lamps during operation. Color temperature is measured in Kelvin, and ranges from 2000K (Warm yellowish) to 5000K (Cold bluish) (IESNA 1998). Second, color rendering represents the degree of how the original colors of objects appear under a light source, and is measured by color rendering index (CRI). (IESNA 1998). Table 6.5 shows color characteristics for different light sources.

<u>Starting Time:</u>

Lamp starting time is one of the factors that should be considered in the selection process, and includes: (1) starting time; (2) warm-up time; and (3) hot restrike time which is the restart time after an interruption in the current flow (IESNA, 1998). Table 6.6 illustrates common ranges for these three times for different types of lamps.

Table 6.5. Color Characteristics for Different Light Sources (IESNA, 1998).

Lamp Type	Color Temperature	Color Rendering
Standard incandescent filaments	2800K	Excellent (CRI at or close to 100)
Tungsten –Halogen	3000K	Excellent (CRI at or close to 100)
Fluorescent	Depends on the phosphor coating inside the gas tube	Depends on the phosphor coating inside the gas tube
Mercury (Clear)	6000K	Very low (CRI of 15-25)
Mercury (Phosphor-coated)	4000K	(Up to a CRI of 50)
Metal halide (Clear)	3000K to 6000K depending on lamp design	(CRI of 65-90 depending on lamp design
Metal halide (Phosphor-coated	Slightly lower than clear metal halide	Moderately improved CRI relative to clear metal halide
High-pressure sodium	2100K	CRI in the low 20’s
Low-pressure sodium	1800K (Monochromatic yellow light)	Very poor

Table 6.6 Lamps Starting Time (IESNA, 1998).

Lamp Type	Starting Time	Warm-up Time	Hot Restrike Time
Standard incandescent filament and Tungsten-Halogen	Instantaneous	Fraction of a second	Instantaneous
Fluorescent	Starting process consists of changing a gas from the nonconducting to the conducting state. (For rapid start lamps: 1 second)	Affected by ambient temperature. Under normal temperatures, there is no significant warm up time associated with fluorescent lamps.	Same as starting time
High-Intensity Discharge Lamps	Start as low pressure/low-intensity devices and require time until the arc tube temperature and the vapor pressure reach an equilibrium to reach full brightness	Depends on ballast, luminaire characteristics, and ambient temperature. Few minutes to reach 80% of normal light output	One minute for high pressure sodium, and several minutes for other high intensity discharge lamp types
Low-Pressure Sodium	Same as high intensity discharge lamps	Full light output is achieved only after 7 to 15 minutes of operation	Re-start immediately upon reconnection of the power

A summary of all the above-described operational characteristics (i.e. lumen output, efficacy, rated life, lumen depreciation, color, and starting time) for different lamps is shown in Table 6.7. It should be noted that the values listed in this table are for comparison purposes, and specific manufacturers catalogs should be consulted for exact values (IESNA, 1998).

Table 6.7. Characteristics of Commonly Used Light Sources (IESNA, 1998)

Lamp Type and Color Temperature	Lamp Watts	Lumen Output	Efficacy (LPW)[1]	Lumen Depreciation[2] (%)	Life (Hours)	CRI	Warm up Time[3] (Minutes)
Standard Incandescent Filament, 2700K	100	1690	17	85	750	100	0
Tungsten Halogen (Linear), 2950K	300	5950	20	95	2000	100	0
Tungsten Halogen (Reflector), 2850K	90	1300	14	95	2500	100	0
Tungsten Halogen (Low Voltage, Reflector), 3000K-3200K	50	900	18	95	4000	100	0
Fluorescent T-5 4ft. 3000K-4100K	28	2900	104	95	16,000	82	0
High Output Fluorescent T-5 4ft.6, 3000K-4000K	54	5000	93	95	16,000	82	0
Fluorescent-T-8 4ft., 3000K-4100K	32	2850	89	85	20,000	75	0
Fluorescent-Reduced Wattage T-12 4ft., 3500K	34	2800	82	85	20,000	73	0
Fluorescent Slimline Reduced Wattage 8ft., 3000K-5000K	60	5900	98	80	12,000	82	0
Fluorescent-High Output Reduced Wattage 8ft., 4100K	95	8000	84	75	12,000	62	0
Compact Fluorescent (Long Twin), 3000K-4100K	39	3150	81	85	20,000	82	1
Compact Fluorescent (Double), 2700K-6500K	26	1800	70	85	10,000	82	1
Mercury Vapor, 700K	175	7950	45	60	24,000	15	< 10
Metal Halide, Low Wattage, 3200K	100	9000	90	85	15,000	70	< 5
Metal Halide, High Wattage, 4000K	400	36,000	90	80	20,000	65	< 10
High Pressure Sodium, Low Wattage, 1900k	70	6400	91	90	24,000	22	< 5
High Pressure Sodium, High Wattage(Diffuse), 2100K	250	26,000	104	90	24,000	22	< 5

[1] Efficacy for lamp is shown in lumens per watt. Ballasting is required for high intensity discharge and fluorescent lamps.
[2] As defined in the IESNA Lighting Handbook for each light source.
[3] Time intervals to reach usable light output.

6.3.1.2 Type of Lamps

Light produced by different types of lamps is defined by IESNA as "radiant energy that is capable of exciting the retina and producing a visual sensation" (Kaufman and

Haynes 1981). Light is a very small part of the electromagnetic spectrum between ultraviolet and infrared radiation and extends from about 380 to about 780 nanometers (nm). This part of the electromagnetic spectrum is visible because radiation in this segment can be absorbed by the photoreceptors of the human visual system and in that way initiates the process of seeing (Taylor 2000). The photoreceptors in the eye convert radiation within the visible region into signals to the brain. The photoreceptors in the eye translate light into color according to the light's wavelength. Six basic colors are generally associated with the visible region of the electromagnetic spectrum. Starting from "Violet" at the shorter wavelengths (around 390 to 455 nm) to "blue" to "green" to "yellow" to "orange", and ending with "red" at the longest wavelengths (around 622 to 780 nm). Each type of lamp produces a unique amount of radiant energy in the different ranges of this visible color spectrum.

The major types of lamps that can be used in lighting include: (1) incandescent filament lamps; (2) tungsten-halogen lamps; (3) fluorescent lamps; (4) low-pressure sodium lamps; (5) mercury lamps; (6) metal-halide lamps; and (7) high-pressure sodium lamps (IESNA, 1998). The following paragraphs provide a brief description of these different types of lamps.

Incandescent Filament Lamps:

Incandescent filament lamps consist of tungsten wire filament enclosed in a glass bulb containing an inert gas or vacuum. Electric current flows through the high resistance filament wire and produces heat that causes the filament to be incandescent (IESNA, 1998). Voltage fluctuations affect incandescent lamp life, efficacy, and lamp output (IESNA, 1998). The spectral output of an incandescent lamp is continuous, as shown in Figure 6.7. The incandescent lamp has a low power output in the blue part of the visible spectrum, moderate yellow output, and very high red output.

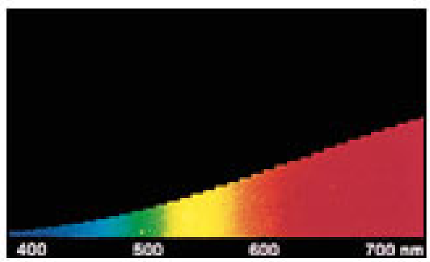


Figure 6.7. The spectral output of an Incandescent Lamp (Lewin 2000)

Tungsten-Halogen Lamps:

Tungsten-halogen lamps are a special type of incandescent lamps that use a halogen regenerative cycle to provide better lumen maintenance, higher efficacy, and/or longer life than standard incandescent lamps (IESNA, 1998). In halogen lamps, the evaporated tungsten particles from the hot filament combine chemically with the small amount of halogen in the lamp and form a gaseous compound that decomposes and redeposits the tungsten when it contacts the filament. This process helps prevent bulb blackening (IESNA, 1998).

Fluorescent Lamps:

Fluorescent lamps produce light by activating fluorescent phosphors that coat the inside surface of the lamp's tube by ultraviolet energy generated by ionized mercury vapor (IESNA, 1998). Electric voltage produces an arc between electrodes that generates ultraviolet radiation, which excites the phosphors to emit light (IESNA, 1998). Fluorescent lamps contain a small amount of argon gas to aid the starting process. They are affected by ambient temperature; low temperature and high winds affect starting and warm-up time. Low and high temperatures also affect lumen output adversely (IESNA, 1998).

Low-Pressure Sodium (LPS) Lamps:

Low-pressure sodium lamps consist of a U-shaped resistant arc tube sealed into an outer bulb. As shown in Figure 6.8, the light output of low-pressure sodium lamps is monochromatic and consists of radiation in the yellow region of the visible spectrum (IESNA, 1998).

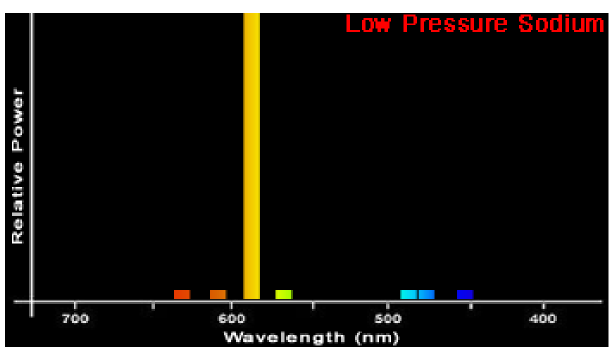


Figure 6.8. The spectral output of a Low-Pressure Sodium Lamp (www.neon-lighting.com)

Mercury Lamps:

Mercury lamps are manufactured with quartz arc tubes containing pure mercury that vaporizes during lamp operation; they also contain a small amount of argon gas to aid the starting process (IESNA, 1998). The mercury arc tube generates a blue-green visible light and a significant amount of ultraviolet radiation that is absorbed by the outer bulb (IESNA, 1998). Mercury lamps can be provided with or without phosphors coating. This coating can be used to convert much of the ultraviolet energy to visible light and to improve color rendering by balancing the blue-green radiation of the arc tube with the emitted red-orange wave lengths of the phosphors (IESNA, 1998). Mercury lamps without coating are suitable where focused lighting is required because the effective size of the light source is only the size of the arc tube within the outer clear bulb (i.e. smaller size). On the other hand, using mercury lamps with phosphors coating is suitable for area lighting because the effective source size is the size of the outer bulb (i.e. larger size) (IESNA, 1998).

Metal Halide Lamps:

Metal halide lamps are mercury lamps with additional metal halides in the arc tube to increase lamp lumen and improve color-rendering characteristics of the light (IESNA, 1998). Metal halide lamps can be divided into two categories: low wattage (32-150 watts), and high wattage (172-2000 watts) (IESNA, 1998). Metal halide lamps are available with clear outer bulbs or with a diffuse coating such as phosphors to reduce brightness of a source, and change color-rendering characteristics (IESNA, 1998). The spectral energy output of a typical metal halide lamp is shown in Figure

6.9. There are strong peaks in the blue, green and yellow regions and there is a 'continuum' of energy output at all wavelengths in addition to the peaks (Lewin 2002).

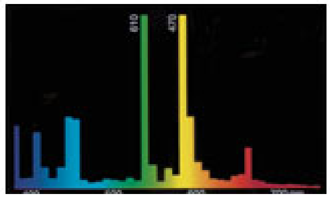


Figure 6.9. The spectral output of a Metal Halide Lamp (Lewin 2000)

<u>High-Pressure Sodium Lamps (HPS):</u>

HPS lamps are manufactured with aluminum oxide arc tubes containing sodium-mercury amalgam that partially vaporizes during lamp operation (IESNA, 1998). HPS lamps have high efficacy and low color rendering. HPS lamps with improved color rendering are available but with lower efficacy and life (IESNA, 1998). The spectral distribution of energy output of a typical HPS lamp is shown in Figure 6.10

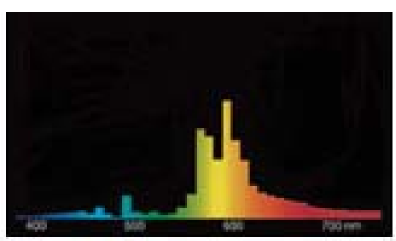


Figure 6.10. The spectral output of a High-Pressure Sodium Lamp (Lewin 2000)

6.3.1.3 Visibility

The primary purpose of lighting nighttime construction operations is to provide better visibility conditions for both workers and road users. This can be achieved by selecting proper light sources that provide better visibility for the same illuminance level. The type of lamps (i.e. spectral distribution of lamps) affects visibility under varying outdoor conditions (Lewin 2002). Visibility depends on the sensitivity of the photoreceptors in the eye to the radiation, which varies quanitively and qualitatively depending on the wave length and lighting levels (Pritchard 1999; Lewin 2002). Visual response of the human eye depends on the prevailing lighting level. High lighting levels with luminances greater than 3 candelas per square meter (cd/sq.m) are called “photopic” levels, low lighting levels with luminance below 0.001 cd/sq.m are called “scotopic”, and lighting levels between these are called “mesopic", as shown in Figure 6.11 (Lewin 2001). The International Commission on Illumination (CIE) has established two curves that relate visual response of the human eye to the wavelengths of the light source, as shown in Figure 6.12 and 6.13. Figure 6.12 shows the response curve at high (photopic) lighting levels, while Figure 6.13 shows the response curve at very low (scotopic) lighting levels. These figures illustrate that the lumen output of a lamp (i.e. visual effect) is not only dependent on the type of lamp and its emitted energy, but on the prevailing lighting level as well.

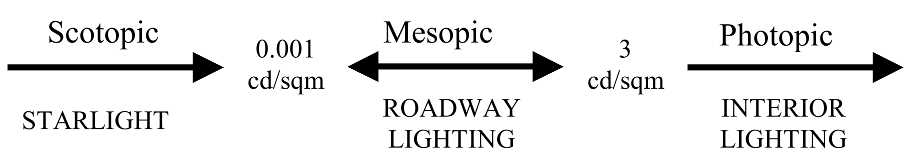


Figure 6.11. The Range of Photopic, Mesopic and Scotopic Light Levels (Lewin 2001).

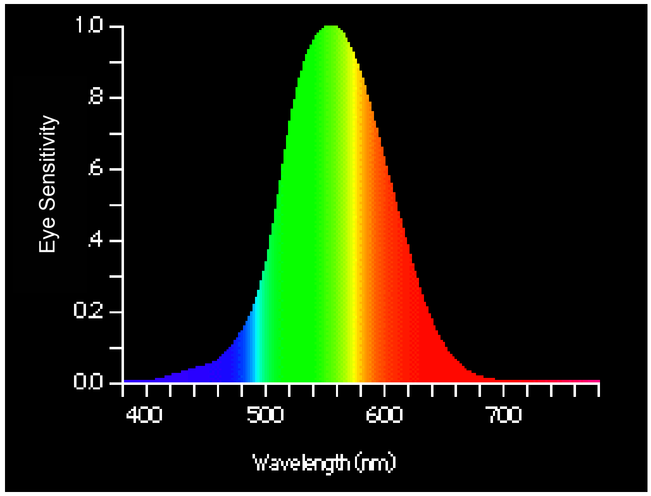


Figure 6.12. Spectral Sensitivity of the Human Eye at Photopic Lighting Levels (FLATNET Technical Glossary 2003)

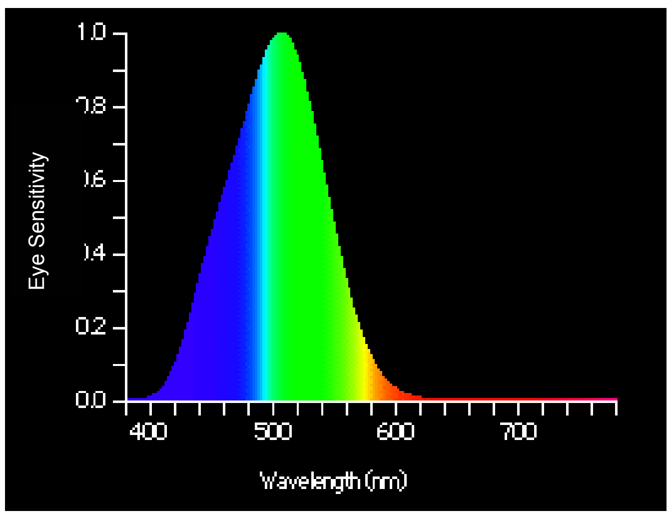


Figure 6.13. Spectral Sensitivity of the Human Eye at Scotopic Lighting Levels (FLATNET Technical Glossary 2003).

There are two types of photoreceptors in the retina: cones and rods. Cones are active at high light levels and are most densely situated in the central part of the field of view. Cones are responsible for photopic vision and their spectral response corresponds to the photopic sensitivity curve (see Figure 6.12). Rods, on the other hand, are active at low lighting levels and are prevalent in the peripheral field of view. Rods are responsible for scotopic vision and their spectral response corresponds to the scotopic sensitivity curve shown in Figure 6.13. Cones are responsible for central vision (less than 2 degrees) while rods are responsible for peripheral vision. Peripheral vision has a significant impact on safety and detection of hazards due to the fact that it is primarily responsible for detecting changing road conditions and movements of objects. In order to improve peripheral vision and detection of road hazards, light sources should be carefully selected to maximize emitted energy in the ranges of high sensitivity for the rods in the human eye as shown in Figure 6.13. This indicates that light sources with high emitted energy in the blue and green ranges of the light spectrum are expected to provide improved peripheral vision. Visibility improvements by the use of blue/green sources are important for peripheral detection (Lewin 2002).

Different luminaires provide varying degrees of visibility, which depends on the lighting levels and spectral distribution of the lamp color and the prevailing lighting conditions on site. Practical vision experiments were conducted using human subjects to study the effect of luminaire type on visibility under different lighting levels. The tested luminaire types include: (1) mercury; (2) metal halide; (3) high and low-pressure sodium; and (4) incandescent light sources (Lewin 2002). In the first experiment, contrast threshold was used to measure visibility (i.e. a lower contrast threshold indicates that the eye is able to distinguish smaller contrasts due to improved visibility). As shown in Figure 6.14, the results indicated that for luminance of 3 cd/m² and less, visibility under the metal halide source was substantially better than under sodium sources (Lewin 2002).

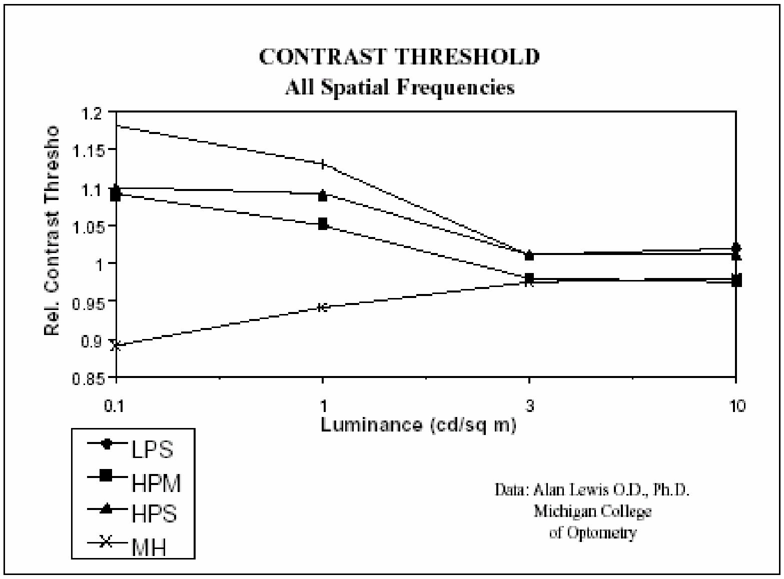


Figure 6.14. Contrast Thresholds Under Different Light Sources (Lewin 2002)

In another experiment, the reaction time of subjects to detect an object in the visual field was used to measure visibility. As shown in Figure 6.15, the results also demonstrated that for luminance of 3 cd/m² and less, the reaction time for metal halide luminaires is less than other light sources. At luminance of 0.1 cd/m², the reaction time for high pressure sodium is about 50% longer than for metal halide (Lewin 2002).

Research sponsored by the US Army Corps of Engineers found that metal halide lamps are superior to high-pressure sodium in supporting peripheral vision on an equal lumen basis. Furthermore, the study found that metal halide lamps provide better color identification (i.e. better color rendering) than high-pressure sodium lamps of equal luminance (Jenicek 2002). Improvements in peripheral vision can reduce nighttime traffic accidents. Metal halide was also found to be a more efficient source of light in the mesopic range (0.034 to 3.4 cd/m^2), which includes the range of roadway illuminances recommended by IESNA (0.3 to 1.2 cd /m^2). The study also concluded that an energy reduction of nearly 40 percent can be achieved by switching to metal halide, with no reduction in visibility (Jenicek 2002). Another study was conducted at Lawrence Berkeley Laboratory, and indicated that the blue rich light sources (e.g. metal halide lamps) reduce focusing problems that are common in visual tasks at multiple distances and also achieve the greatest visual sensitivity (Amos 1994).

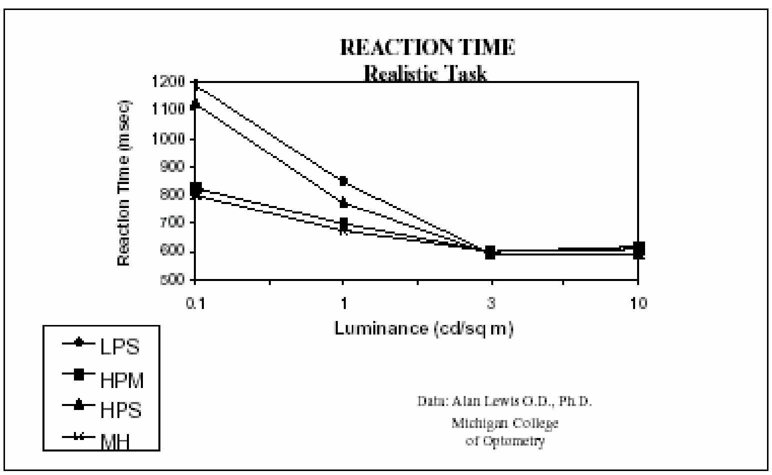


Figure 6.15. Reaction Time Under Different Light Sources (Lewin 2002)

A study conducted by the Road Research Laboratory in the United Kingdom to study drivers' preference for blue rich (e.g. metal halide) or halogen headlamps of equal intensity revealed that drivers overwhelmingly preferred to drive with blue rich light headlamps, supporting the idea that these sources produce better visibility (Bullough et. al. 2002).

6.3.2 Portable Light Towers

Portable light towers are the most widely used lighting equipment in nighttime construction. These lighting towers usually encompass generators to provide power to the luminaires. Several types of lighting towers are available in the market. In selecting portable light towers for nighttime construction lighting, a variety of factors need to be considered:

- Type of luminaires: The majority of available portable lighting systems use high-pressure sodium, metal halide, and tungsten halogen luminaires (Trotti 2001).
- Machine size: compact light towers are preferred as they provide better maneuverability and save space on site and in storage (Trotti 2001).
- Generator capacity: This capacity can also be used to provide power for small units on the jobsite (Greenquist 1999).
- Noise consideration: towers with reduced noise are preferred, especially when quiet operation is an important factor (Greenquist 1999).
- Fuel tank capacity: portable towers with a bigger fuel tank provide more hours of continuous operation (Bryden and Mace 2002). Fuel tank capacity and the availability of fuel on site must be sufficient to permit uninterrupted operation of all portable generators used to generate power to operate all required lighting equipment throughout the entire night shift.
- Electrical considerations: All power sources must be grounded to prevent electrical shock. All wiring must be weatherproof and installed according to OSHA requirements (Trotti 2001).

6.3.3 Equipment Mounted Luminaires

Providing adequate lighting levels for mobile construction activities that extend for long distances (e.g. paving or milling bituminous surfaces) is more challenging than stationary operations. Lighting in such activities is often provided by luminaires that are attached to the construction equipment in order to supplement the available headlights of the equipment. The provision of mobile lighting does not eliminate the need for area lighting provided by portable light towers since work zone lighting is needed not only for task lighting but also to promote safety and security. Required illuminance levels for a particular construction activity should be satisfied by the collective effect of all light sources utilized in the work zone. The same principles used in arranging portable light towers are also applicable for equipment mounted lighting. Equipment mounted lighting design should determine the luminaires' mounting height above the ground, aiming angle of luminaires, and type of lumninaires. This process is less challenging than that of portable light towers since it needs to be done only once during the process of retrofitting construction equipment for nighttime construction.

6.3.4 Operation and Maintenance

A properly designed, operated and maintained lighting system for nighttime construction operations is a crucial factor to ensure that the intended lighting levels and quality can be achieved on site. Consequently, this will enable the performance of construction tasks safely and promote construction quality. Performing regular maintenance ensures proper operation of the lighting system, and minimizes interruption to the nighttime work that may result from failures in the lighting system.

Planned lighting maintenance was proven to be the most effective method for maintaining lighting levels and lighting quality at the lowest operation and maintenance cost (Amos 1994). Routine maintenance should be scheduled and may include: (1) cleaning of lamps and luminaires; (2) checking critical components in both power systems and lighting equipment and replacing defective components; and (3) group lamp replacement (Bryden and Mace 2002). Sufficient fuel and spare parts, such as lamps and fuses, should be available on site (Amos 1994). Maintaining a suitable voltage is also necessary for proper performance since operating at a lower voltage will reduce light output and light efficacy while operating at a higher voltage will reduce lamps life significantly (IESNA 1993).

Reliability and safety of lighting systems is another important factor. Faulty lighting systems could lead to safety hazards and significant economic losses, especially when dealing with construction materials that should be placed timely such as concrete and asphalt (Amos 1994). Requiring contractors to provide backup systems is recommended. However, the amount of backup equipment depends on the type of lighting system utilized in the work zone. For example, a portable lighting system that utilizes a single generator is more likely in need of a backup generator than a portable lighting system with multiple generators (Amos 1994). If any failure occurs to the lighting system, nighttime operations should be stopped until the system is fixed and the required design criteria are restored.

6.4 Administrative Issues

Proper lighting of nighttime construction operations plays a significant role in promoting safety and minimizing hazards associated with reduced visibility at night. The responsibilities for providing lighting arrangements and for judging their suitability should be clearly defined in advance. Requiring a lighting plan before starting nighttime construction and establishing a systematic inspection procedure are essential for properly designed and installed lighting arrangements.

6.4.1 Lighting Plan

Every nighttime project should have a lighting plan that is submitted by the contractor and approved by the resident engineer before nighttime operation starts. Lighting plans should contain detailed information on: (1) positions of all lighting equipment for all intended nighttime construction activities; (2) luminaires details including type of lamps and model number; (3) power sources for all lighting equipment; (4) values of the design parameters (i.e. mounting height, aiming angle, rotation angle) for all luminaires used in the design; (5) photometric charts and power ratings for all luminaires; (6) type and specification of hardware glare control measures to be used (louvers, shields, screens) if needed; and (7) lighting calculations to verify that the required design criteria can be met with the proposed plan (Bryden and Mace 2002). All types of lighting equipment should be installed according to the lighting plan prior to the beginning of nighttime work. This includes both portable lighting towers and equipment-mounted luminaires.

6.4.2 Lighting Inspection

Inspection of lighting conditions on site is essential to determine whether the installed lighting system meets the lighting design requirements to ensure that the construction work can be completed safely and within acceptable quality. Lighting inspection should include: (1) photometric measurements of illuminance levels to determine average illuminance and uniformity ratio; (2) comparison between the provided lighting arrangement and the values presented in the contractor's lighting plan; (3) observation of the lighting arrangement to evaluate glare potential for road users and construction workers (Bryden and Mace 2002); and (4) light trespass must be kept within permissible levels.

A resident engineer should inspect the installed lighting arrangement before the beginning of the work. A photometer should be provided to measure illuminance levels in lux or fc. Photometric measurements should be taken uniformly every 3 m (10 ft) in both directions throughout the inspected area. Average horizontal illuminance can be obtained by averaging all the readings in the test area while uniformity ratio can be obtained by dividing the average of the readings over the lowest reading obtained. The contractor must make the necessary adjustments to the lighting arrangement if the obtained illuminance or uniformity ratio violates the design criteria requirements (Bryden and Mace 2002). Illuminance readings should be recorded and compared, and they should be investigated wherever they do not conform to the design specifications. Significant differences between illuminance measurements and lighting design may be an indication of the need for lamp replacement, problems in the power supply, or movement of the lighting equipment, which affects the values of the design parameters (i.e. mounting height, aiming angle, rotation angle) (Bryden and Mace 2002).

Evaluation of the lighting from the standpoint of the worker and the driver should also be performed at night to identify the potential for glare problems as well as any areas that are poorly illuminated. Driving through the work zone to inspect and evaluate glare experienced by road users is recommended and can be performed along with the visual inspection of all traffic control devices (MUTCD 2000). If objectionable levels of glare or light trespass exist, luminaires must be reoriented and/or glare control hardware must be added (Bryden and Mace 2002), and the overall lighting design rechecked.

6.4.3 Sample Lighting Specification

Adapted from existing IDOT lighting design criteria, a sample lighting specification for nighttime construction was developed to provide technical requirements to help contractors better understand the lighting design criteria. This sample nighttime lighting specification can be found in Appendix A.

6.5 Summary of Recommendations for Lighting Arrangements

A properly selected, designed, arranged, and maintained lighting system is vital to the safety and quality of nighttime highway construction operations. In order to achieve this, a number of practical recommendations were provided in this chapter for nighttime lighting arrangements, including:

1. Temporary lighting arrangements can be supplied on site in the form of fixed lighting arrangements, and/or mobile lighting systems. The factors that should be considered in the selection process of lighting arrangements include: work zone size and layout, required mobility, duration of work, required illuminance level and the ability to satisfy minimum requirements, existing lighting, cost, power requirements, glare control, and light trespass.

2. Mobile lighting systems should be designed to provide the required lighting levels in adequate areas in front of and behind construction equipment to ensure their safe and effective utilization. The minimum distance to be illuminated should be 9 m (30 ft) in front and behind slow moving equipment such as pavers and milling machines, and 30 m (100 ft) in front and behind faster moving equipment such as backhoes and wheel loaders, scrapers, rollers, and motor graders.

3. The utilization of a mobile lighting system to provide lighting in localized work areas for various construction tasks does not eliminate the need for portable light towers which are often required to provide lighting in wider areas in and around the construction zone for safety and security purposes. Required

illuminance levels for a particular construction task should be satisfied by the collective effect of all utilized lighting systems (i.e. fixed and/or mobile) in the work zone.

4. Three measures can be utilized to control glare during nighttime construction operations including: selection of lighting sources that minimize glare on site (e.g. cutoff luminaires), proper design and arrangement of lighting equipment (e.g. aiming angle, fixtures rotation, and mounting height), and utilizing glare control hardware (e.g. visors, louvers, shields, screens and barriers), if needed.

5. High-pressure sodium and metal-halide lamps are the most widely used types of lamps in nighttime construction operations. Metal halide lamps provide better visibility in an outdoor environment as well as improved peripheral vision, which has a significant impact on safety since it facilitates detection of changing road conditions and movements of objects.

6. Planning and performing regular maintenance of the lighting system is vital to ensure proper operation and minimize interruptions to the nighttime work resulting from failures in the lighting system. Routine maintenance may include: cleaning of lamps and luminaries, checking critical components in both power systems and lighting equipment and replacing defective components, and group lamp replacement.

7. Backup lighting systems are recommended to ensure reliability of lighting systems. Faulty lighting systems can lead to safety hazards and significant delays and economic losses.

8. Every nighttime project should have a lighting plan that is submitted by the contractor and approved by the resident engineer before nighttime operation starts. The location of all types of lighting equipment on site should be consistent with that approved in the submitted lighting plan. This covers both fixed and mobile lighting systems.

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CHAPTER 7
CONCLUSIONS AND FUTURE RESEARCH

7.1 Introduction

In recent years, there has been a significant increase in the number of highway construction and rehabilitation projects that are being performed during off-peak, nighttime hours. This can be attributed to the many reported advantages of nighttime work practice, including reduced traffic congestions, improved work zone conditions and reduced project duration. Despite these advantages, nighttime construction still faces various challenges, including safety issues due to inadequate lighting conditions and glare from construction lighting, reduced construction quality and productivity due to insufficient lighting conditions, and adverse impact on neighboring environments due to light trespass.

7.2 Research Tasks and Findings

In order to overcome many of the above challenges, proper and adequate lighting conditions needs to be provided on nighttime construction sites. To achieve this goal, the following three major research objectives were identified: (1) to survey the types of work zone lighting practices currently being used in Illinois and other states; (2) to evaluate and recommend design criteria for an acceptable level of lighting for nighttime construction operations; and (3) to evaluate the impact of selected lighting arrangements to ensure that the recommended design criteria is practical and can be implemented on nighttime construction sites. Administered by Illinois Transportation Research Center (ITRC) and IDOT personnel, a joint research team from the University of Illinois at Urbana-Champaign and Bradley University conducted the research project with five major phases: (1) performing an extensive literature review; (2) conducting surveys of contractors, resident engineers and other state DOTs; (3) evaluating and recommending a practical lighting design criteria; (4) conducting field studies to evaluate selected lighting arrangements; and (5) providing practical recommendations for lighting nighttime construction.

In the first phase of this study, literature review was conducted to gather and review the latest research and developments in lighting practices for nighttime construction operations. Sources of information included textbooks, publications from professional societies, such as IESNA (Illuminating Engineering Society of North America), journal articles, on-line databases, and contacts from DOT's and government agencies. This review focused on the latest developments in roadway lighting, work zone lighting, governmental organizations' guidelines for lighting design, and light trespass and pollution. Key findings of the literature review include:

- Identifying design parameters in lighting design including luminaire selection, luminaire mounting height, luminaire spacing, light termination, and lighting system depreciation.
- Technical information regarding lighting design criteria including illuminance, luminance, glare, visibility, uniformity, and quality.

- Collecting relevant lighting standards used by state DOTs (e.g. New York DOT) and professional organizations (e.g. OSHA and ANSI) as reported in Chapter 2.

The second phase of this project focused on conducting surveys targeting resident engineers, contractors with experience in nighttime operations, and state departments of transportation. The survey questions covered nighttime work experiences, advantages and challenges of nighttime construction, lighting design criteria/parameters/procedures, and methods for nighttime lighting inspections. The survey results were processed statistically and were reported in Chapter 4, using various charts and graphs. Key findings of the survey include:

- Nighttime construction is gaining acceptance and popularity as it was reported by participating DOTs that an average of 17% of their construction projects in 2001 involved work during nighttime hours.
- DOTs responding to the survey viewed reduced traffic congestion and increased freedom in planning lane closures as the most important advantages of nighttime construction operations. Other reported advantages include: reduced project duration, reduced impact on surrounding businesses, enhanced work conditions at night, minimal air pollution from gases emitted by idling vehicles in traffic congestions, and faster delivery of materials at night.
- Reduced visibility and unsatisfactory lighting conditions were among the main reported challenges in nighttime operations. Other challenges include

accidents involving road users and/or workers, lower quality, reduced productivity, complaints from neighboring properties, difficulty in quality inspection, complexity of inspecting lighting conditions, and difficulty in personnel coordination.

- The main lighting challenges of nighttime construction were reported to be insufficient lighting, non-uniformity of lighting, and glare to road users.
- There are limited available standards/guidelines to regulate lighting design for nighttime operations despite the increased utilization of nighttime construction in various states in recent years. Only 8 out of 20 responses received from state DOTs indicated that they have standards/guidelines for nighttime construction lighting. One surveyed contractor stated that "*the burden of approving a contractor's night lighting plan is often placed on the CM/CE without guidelines for evaluating the quality of a plan or without specifications and specific light levels that the contractor needs to develop a plan to meet; 'as needed' or 'as determined by the engineer' are too open to judgment to be enforceable.*"

The primary purpose of the third phase of this research project was to evaluate and recommend lighting design criteria for nighttime construction operations. The recommended criteria were developed by analyzing available standards acquired from a number of sources including: (1) professional organizations such as OSHA, ANSI, NCHRP, IESNA, CIE, and FAA; (2) state DOTs such as New York, California, Florida, Maryland, Michigan, Mississippi, North Carolina, and Oregon; and (3) surveyed resident engineers and contractors. The recommended design criteria include requirements for (1) illuminance; (2) uniformity; (3) glare; and (4) light trespass during nighttime construction operations. These lighting criteria are presented in details in Chapter 4, and can be summarized in the following four major recommendations:

(1) Recommended illuminance levels: The recommended illuminance levels for different construction activities were divided into three categories:

- Low category with a recommended illuminance level of 54 lux (5 fc). This level is recommended for the following eight major construction activities: (1) earthwork (excavation/embankment/backfill); (2) landscaping (seeding/mulch/sodding/ planting); (3) erosion control (riprap/ditch lining); (4) subgrade; (5) subbase/base courses; (6) shoulders (earth and aggregate); (7) work zone access and materials handling; and (8) work zone setup, take down and revision.

- Medium category with a recommended illuminance level of 108 lux (10 fc) This level is recommended for the majority of construction activities as follows: (1) paving bituminous surfaces; (2) rolling bituminous surfaces and pavements; (3) milling and removal; (4) pavement resurfacing; (5) shoulders (bituminous and PCC); (6) paving PCC surfaces; (7) finishing PCC pavements; (8) concrete sawing; (9) bridge construction and maintenance; (10) culverts and sewers; (11) drainage structures; (12)

guardrail and fences; (13) highway signing; (14) pavement marking (stripping and markers); and (15) work zone flagger station.

- High category with a recommended illuminance level of 216 lux (20 fc). This level is recommended for the following activities: (1) electrical wiring and cables; (2) electrical poles and posts (lighting and traffic signals); (3) pavement patching; and (4) crack and joint sealing.

(2) Recommended uniformity ratio: The uniformity of lighting, defined as the ratio of average to minimum illuminance levels, shall not exceed 6:1 in the work areas.

(3) Recommended glare control measure: The ratio of maximum veiling luminance to the average pavement luminance is recommended as a control measure of glare.

(4) Recommended light trespass control: The use of vertical illuminance at the level of observer's eye at possible viewing locations of the light sources is recommended to control light trespass. Measurement of vertical illuminance should be taken at the edge of the property line and should satisfy the maximum allowable limits recommended by IESNA (IESNA TM-2000).

The objective of the fourth phase of this project was to evaluate the performance of selected lighting arrangements for a variety of typical nighttime construction operations. A set of field experiments was conducted to examine the performance of selected lighting arrangements, that utilize commonly used lighting equipment, in satisfying the earlier recommended lighting design criteria. The field experiments were conducted to evaluate the performance of four major types of lighting arrangements, namely: (1) fixed lighting arrangements; (2) mobile lighting arrangements; (3) flagger station arrangements; and (4) transition zone arrangements. More details on the setup of these field experiments and their measured performance are provided in Chapter 5. Key findings of this phase include:

- Example lighting arrangements are provided based on typical work zone configurations provided by IDOT operation engineers. This includes work zones on two-lane, two-way highways and four-lane, two-way highways.
- The field experiments verified the lighting criteria as outlined in Chapter 4, and confirm the adequacy of recommended level of lighting for typical construction operations.
- The conducted field tests illustrate that the recommended design criteria are attainable using commonly available lighting equipment which ensures practicality of the developed design criteria.

In the fifth and final phase of this project, a set of practical recommendations was developed for lighting arrangement in nighttime construction operations. These recommendations were developed to help nighttime construction personnel in complying with the requirements of the recommended lighting design criteria. These practical recommendations were provided for: (1) fixed lighting arrangements; (2) mobile lighting arrangements; (3) glare control measures; and (4) selection of lighting equipment. The key findings of this phase include:

- High-pressure sodium and metal-halide lamps are the most widely used types of lamps in nighttime construction operation but, metal halide lamps provide better outdoor visibility and improved peripheral vision, which has a significant impact on safety since it is primarily responsible for detecting changing road conditions and movements of objects.

- Temporary lighting arrangements can be provided in the form of fixed lighting arrangements, and/or mobile lighting systems. The factors that should be considered in the selection process of lighting arrangements include: work zone size and layout, required mobility, duration of work, required illuminance level and the ability to satisfy minimum requirements, existing lighting, cost, power requirements, glare control; and light trespass.

- Three measures can be utilized to control glare during nighttime construction operations including: selection of lighting sources that minimize glare on site, proper design and arrangement of lighting equipment (e.g. aiming angle, mounting height) in order to reduce high glare levels, and utilizing glare control hardware, if needed.

These research findings are in fact a collaborative effort of researchers from the University of Illinois at Urbana-Champaign and Bradley University, Illnois

Transportation Research Center (ITRC) and IDOT technical personnel who served on the technical review panel (TRP). The recommended guidelines and sample specifications should aid contractors and resident engineers in planning and managing nighttime construction lighting.

7.3 Future Research

During the course of this study, the research team also identified a number of significant research areas that require further in-depth analysis and investigation in the future. These areas include: (1) developing practical tools for evaluating glare on nighttime construction sites; and (2) developing objective lighting design criteria for nighttime construction operations.

7.3.1 Practical and Objective Evaluation of Glare

Improper lighting of nighttime work zones produces harmful levels of glare, leading to increased levels of hazards and accidents on and around nighttime construction sites. In this project, glare from work zone lighting was reported to be one of the most serious challenges confronting nighttime construction operations. The major challenge in minimizing glare on nighttime construction sites is caused by the lack of a practical and objective tool that can be used to measure and quantify glare on nighttime construction sites. The lack of such a tool often causes: (1) the inability to quantify reductions in glare that can be achieved on site by properly adjusting the utilized lighting equipment; and (2) disputes among resident engineers and contractors on what constitutes acceptable or objectionable levels of glare. Unlike illuminance levels and uniformity ratios that can be easily measured on nighttime construction sites using simple light meters, there is no available tool that can be used to measure glare. This was clearly evident after analyzing all the available standards and guidelines for nighttime construction (Chapter 4) that recommend subjective measures to determine the acceptable levels of glare on site.

The research conducted in this project revealed that it is feasible to develop a practical, inexpensive and objective tool to measure glare on nighttime construction sites. Such a tool can be developed as a practical computational model that runs on inexpensive handheld computers and/or laptops and can be used by resident engineers and contractors on site. This proposed model can be designed to integrate (1) vertical illuminance readings that can be easily measured using simple light meters; and (2) available computational models (IESNA 2000) that calculates glare as described earlier in Section 4.2.3 in this report. The application of this proposed tool can lead to significant improvements in safety for both motorists and workers and can significantly minimize the type of disputes that are often caused by the currently employed subjective methods for evaluating glare on nighttime construction sites.

7.3.2 Objective Lighting Design Criteria

This research project evaluated and recommended lighting design criteria for nighttime construction operations. The recommended criteria were developed by analyzing available standards acquired from a number of sources including: professional organizations, state DOTs and surveyed resident engineers and contractors. This analysis revealed that there was a wide range of recommended illuminance levels for different highway construction activities. Further research is needed to develop an objective and systematic approach for determining the required illuminance levels for various highway construction activities. An objective approach can be developed using a similar concept utilized in the small target visibility procedure for roadway lighting design (see section 2.2.3.4 in Chapter 2). This proposed approach can be developed to determine the required illuminance level that ensures adequate visibility of an array of targets that need to be visible for each construction task.

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Appendix A: SAMPLE SPECIFICATION
LIGHTING FOR NIGHTTIME HIGHWAY CONSTRUCTION

SAMPLE SPECIFICATION
LIGHTING FOR NIGHTTIME HIGHWAY CONSTRUCTION

DESCRIPTION

This work shall consist of furnishing, installing, operating, maintaining, moving and removing all necessary lighting equipment and materials for the duration of nighttime operations on the contract. Nighttime operations consist of work specifically scheduled during the hours of darkness, which occur shortly before sunset until shortly after sunrise.

MATERIALS

Furnished lighting equipment may include fixed and/or mobile lighting systems. Fixed lighting systems utilize portable lighting towers, while mobile lighting systems use luminaires attached to mobile construction equipment. At times fixed lighting may take the form of roadway luminaires on temporary poles. All lighting equipment shall be in good operating condition and in compliance with applicable safety and design codes to the satisfaction of the Engineer.

GENERAL REQUIREMENTS

Whenever the Contractor's operations are being conducted at night, the Contractor shall provide such artificial lighting as may be necessary to ensure safety on and around the worksite, quality of construction, and adequate conditions for inspection of the work by the Engineer. Lighting requirements in this specification are not intended to substitute other required safety measures, including: reflective clothing, traffic control devices, warning lights, barricades, cones, and signs. Existing street and highway lights shall not eliminate the need for the Contractor to provide adequate lighting to satisfy the requirements of this specification. The amount of illumination provided by existing street lights can be considered in the Contractor's lighting plan in determining the quantity of additional lights to be provided on site. The quantity and wattage of provided lighting equipment shall satisfy all the required specifications for (1) lighting levels; (2) lighting uniformity; (3) glare control; and (4) light trespass, which are highlighted in the following sections.

LIGHTING LEVELS

Lighting levels should be provided according to the lighting requirements of the construction activities being performed. Average maintained horizontal illuminance shall be provided at no less than 54 lux (5 fc) for category I work, 108 lux (10 fc) for category II work, and 216 lux (20 fc) for category III work, as shown in Table 1 below, which classifies different highway construction activities into one of these three categories. For other types of work, the Engineer should be consulted to determine the appropriate category and its lighting requirements. The minimum average maintained horizontal illuminance throughout the work zone and areas where crew movements take place shall be 54 lux (5 fc). Lighting levels in excess of the category I, II, and III requirements shall be implemented, as deemed necessary by the Contractor and approved by the Engineer, to ensure project safety.

All Illuminance levels shall be measured using a photometer in a horizontal plane at the level of the work being performed with the exception of flagger stations. Illuminance requirements for flagger stations shall be measured in a vertical plane facing traffic on the closest lane open to traffic to ensure that all flaggers are clearly visible to traffic and that their positions are safe and effectively lighted.

Table 1 Required Lighting Levels

Category	Highway Construction Activity	Average Illuminance Level
I (Low)	Earthwork (excavation/embankment/backfill), landscaping (seeding/mulch/sodding/planting), erosion control (riprap/ditch lining), subgrade, subbase/base courses, shoulders (earth and aggregate), work zone setup, take down and revision, work zone access and material handling.	54 lux (5 fc)
II (Medium)	Paving bituminous surfaces, rolling bituminous surfaces and pavements, paving PCC surfaces, finishing PCC pavements, milling and removal, pavement resurfacing, concrete sawing, shoulders (bituminous and PCC), bridge construction and maintenance, culverts and sewers, drainage structures, guardrail and fences, highway signing, pavement marking (striping and markers), work zone flagger station.	108 lux (10 fc)
III (High)	Pavement patching, crack and joint sealing, electrical wiring and cables, electrical poles and posts (lighting/ traffic signals).	216 lux (20 fc)

Required lighting levels shall be maintained throughout the specific work area. The work area shall extend: (1) a minimum of 9 m (30 ft) in front of and behind slow moving equipment such as pavers and milling machines; (2) a minimum of 20 m (65 ft) in front of and behind faster moving equipment such as backhoe and wheel loaders, scrapers, rollers, and motor graders; and/or (3) to the satisfaction of the Engineer to ensure the safety and quality of construction and proper inspection of the work. Construction operations shall be deemed to include all work operations by the Contractor, including layout and measurement ahead of the actual work.

LIGHTING UNIFORMITY

The lighting over the entire work area shall be uniformly distributed to prevent dark areas on nighttime construction sites. The uniformity of lighting, defined as the ratio of average to minimum illuminance levels, shall not exceed 6:1 in the work areas and, to the extent possible, throughout the work zone.

GLARE CONTROL

All provided lighting shall be designed, installed and operated so as to avoid glare that interferes with traffic on the roadway. The Contractor shall locate, aim, and adjust lighting equipment and/or add glare control hardware as necessary to eliminate objectionable glare to the satisfaction of the Engineer while still providing the required lighting levels and uniformity within the work area. Glare control hardware that can be provided by the Contractor to reduce objectionable levels of glare include, but is not limited to, shields, visors, or louvers on luminaries or glare screens.

All lighting fixtures shall be mounted and aimed in a manner precluding any disability glare to approaching traffic. In no case should the main beam of the light be aimed higher than 60° above the vertical. The horizontal location and vertical height of lights should be set as far from traffic as practical. Luminaires should be positioned so that the axis of maximum candlepower of the luminaires is directed away from the motorists' line of sight. The Contractor shall carefully select light sources that produce low glare levels such as cutoff luminaires that shield the emitted light above a specified vertical angle in order to direct a greater proportion of candlepower to the work area, and away from oncoming traffic.

LIGHT TRESPASS

Lighting shall be provided and maintained so as not to cause annoyance for residences adjoining the worksite. If any complaints are received by the Engineer and/or the Contractor from residences adjoining the worksite, the Contractor shall respond immediately and modify lighting arrangement or add any necessary hardware to shield light trespass to adjoining properties. These modifications should not affect the Contractor's compliance with other requirements in this specification.

LIGHTING EQUIPMENT

All lighting equipment shall be furnished as required and retained by the Contractor after the work is completed. Material and/or equipment shall be in good operating condition. Before nighttime operations may begin all required lighting equipment and/or materials must be ready for operation to the satisfaction of the Engineer. Lighting shall be provided and maintained in conformity with the requirements of both the National Electrical Code (NEC) and the National Electrical Safety Code (NESC), and any applicable safety and design codes.

In a fixed lighting system, light towers utilized on site shall be fully extended to their maximum mounting height to minimize glare to traffic and workers on site. In a mobile lighting system, additional light fixtures shall be professionally mounted on construction equipment in a way that does not obstruct the sight of the equipment operator and ensures secure connection to the equipment with minimum vibration. When the construction equipment is outside the work zone or behind traffic control devices, the Contractor shall not operate the additional mobile lights and will only utilize standard headlights.

The Contractor shall provide sufficient fuel, spare lamps, generators, and personnel qualified to operate the lights to assure that they will be maintained in operation during night work. The Contractor shall provide backup lighting to replace failed lights and equipment during night work. The backup equipment shall be on the project and available for use at all times during night work. Maintaining a proper voltage is also necessary for proper performance since operating at a lower voltage will reduce light output and light efficacy while operating at a higher voltage will significantly reduce lamps life.

APPROVED LIGHTING PLAN

The Contractor shall submit a lighting plan for review and approval prior to the start of night work. The lighting plan shall include the following:

- Lighting layout for each work area and the entire work zone that clearly shows the number, location and spacing of all fixed lighting and/or mobile light fixtures. The layout shall include distances to various elements within and adjoining the work zone and all work areas within the work zone.
- Description and technical details on all provided lights, including photometric data and power ratings.
- Mounting details for luminaries in all light towers, including mounting height, rotation and aiming angles.
- Mounting details for mobile lights attached to construction equipment.
- Any hardware measures to be used to control glare, such as, louvers, shields, and screens.
- Lighting design showing calculated illuminance, uniformity and glare avoidance verification throughout the work zone as well as at adjoining property lines and active traffic lanes.
- Description of electrical power source.

The lighting plan shall be submitted with all supporting calculations, catalog cut sheets, and supporting documentation to verify compliance with this specification. The Contractor shall allow 30 days for the Engineer to review and approve the submitted lighting plan. Nighttime work shall not begin without the Engineer's approval of a lighting plan and the indicated lighting equipment being in good operating condition.

INSPECTION

The Engineer and the Contractor should have an on-site, after dark, meeting to inspect the conformity of provided lighting conditions on site to this specification. No work shall be permitted until all requirements are met. The Engineer shall suspend all night work except for traffic control if lighting is inadequate on any nighttime work operation. At any time during the course of nighttime work should the lighting be deemed inadequate by the Engineer, the work shall be halted and adequate lighting provided at no additional cost.

MEASUREMENT

The Contractor must furnish a photometer, for the use of the Engineer, and must monitor all lighting levels to the satisfaction of the Engineer. The photometer shall be a rugged unit capable of English or metric readout on a large LCD display. The light sensor head shall be spectral and cosine corrected. Calibration must be performed annually and the Contractor shall make available the latest certified test report. Illuminance and lighting uniformity shall be checked by taking a uniform pattern of photometric readings spaced on a 3 m (10 ft) grid within the work area (see example). Light trespass shall be measured in vertical illuminance at the edge of the property adjoining construction. Also check for glare that may impair the vision of drivers passing through the project or cause annoyance for workers within the worksite. Glare inspection shall be performed by driving past the work zone from both directions of traffic and walking through the work zone.

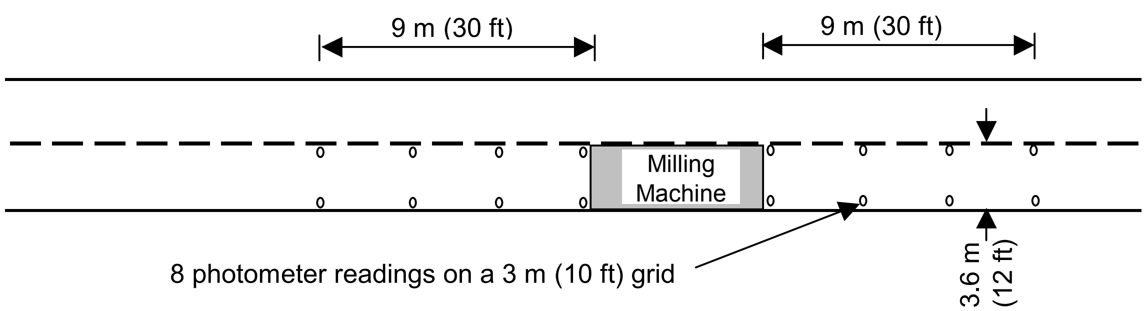
BASIS OF PAYMENT

Payment for lighting provided to comply with the requirement of this specification will be made only when a significant amount of nighttime work is explicitly required and a pay item for LIGHTING FOR NIGHTTIME WORK has been included in the contract. Otherwise, full compensation for complying with the provisions of these specifications shall be considered as included in the contract prices paid for the various items of work involved and no separate payment will be made. When nighttime operations are done at the Contractor’s request and convenience, these requirements apply but no separate payment shall be made.

Payment for the lighting provided to comply with the requirement of these specifications will be made at the contract lump sum price for LIGHTING FOR NIGHTTIME WORK. Such price and payment will be full compensation for all work of furnishing, operating, and maintaining everything necessary to provide lighting. There will be no adjustment in the lump sum price regardless of the number or type of lighting systems required to complete all night work on the project as required in this specification and as directed by the Engineer.

Example

Milling operation:
Required light level = 108 lux (10 fc) = E_{avg}
Maximum allowed ratio for lighting uniformity = 6 (average to minimum)
Required distance = 9 m (30 ft) in front of and behind milling machine



$$E_{avg} = \text{Average Maintained Horizointal Illuminance} = \frac{\text{Sum of 8 readings}}{8}$$

$$\text{Average to Minimum Uniformity Ratio} = \frac{E_{avg}}{\text{Lowest of the 8 readings}}$$

Drawing not to scale

Appendix B. Resident Engineer Survey

ILLINOIS

University of Illinois at Urbana-Champaign
Department of Civil and Environmental Engineering
Construction Management Research Group

ITRC PROJECT VD-H1, FY 00/01
NIGHTTIME CONSTRUCTION: EVALUATION OF LIGHTING FOR HIGHWAY CONSTRUCTION OPERATIONS IN ILLINOIS

Nighttime Lighting
Resident Engineer Survey

(We expect that this questionnaire will take about 10 minutes to be completed)

This survey is intended for the evaluation of lighting arrangements in nighttime construction. The objectives of this survey are to collect data regarding the required lighting levels and to identify the problems associated with lighting configurations in nighttime construction.

Name: ______________________________

Position: ______________________________

Experience With Construction: ____________________**Years**

District: ______________________________

Date: ______________________________

1- In your past projects, which of the following **problems** did you encounter during nighttime construction operations due to improper/insufficient lighting?

No.	Nighttime construction problem/difficulty	Check all applicable boxes
1	Accidents to road users	❑
2	Accidents to workers	❑
3	Lower quality	❑
4	Reduced Productivity	❑
5	Complaints from neighboring properties	❑
6	Difficulty in quality inspection	❑
7	Difficulty in inspecting lighting conditions	❑
8	Difficulty in personnel coordination	❑
List other problems that you commonly encounter		
9		❑
10		❑

2- What are the main **lighting problems** that you often face during nighttime construction projects?

No.	Lighting problem	Check all applicable boxes
1	Insufficient lighting levels	❑
2	Glare to workers	❑
3	Glare to road users	❑
4	Non uniformity of lighting levels throughout the work area	❑
5	Light trespass to adjacent properties	❑
List other problems that you know of		
6		❑
7		❑

3- From your past experience, which of the following **measures** were used by contractors to **control glare** during nighttime construction?

No.	Glare control measure	Check all applicable boxes
1	Reducing lighting levels	❑
2	Cutoff luminaries	❑
3	Glare screens	❑
4	Louvers	❑
5	Visors	❑
6	Repositioning lighting equipment	❑
List other measures that you know of		
7		❑

4- From your experience, what is the **lighting level requirement** for performing each of following nighttime highway **construction activities?**

No	Highway construction activity	Lighting level requirement: High	Medium	Low	No Experience
1	Earthwork: excavation/embankment/backfill	☐	☐	☐	☐
2	Landscaping: seeding/mulch/sodding/planting	☐	☐	☐	☐
3	Erosion control: riprap/ditch lining	☐	☐	☐	☐
4	Subgrade	☐	☐	☐	☐
5	Subbase / Base courses	☐	☐	☐	☐
6	Paving bituminous surfaces	☐	☐	☐	☐
7	Rolling bituminous surfaces and pavements	☐	☐	☐	☐
8	Paving Portland cement concrete surfaces	☐	☐	☐	☐
9	Finishing Portland cement concrete pavements.	☐	☐	☐	☐
10	Milling and removal	☐	☐	☐	☐
11	Pavement resurfacing	☐	☐	☐	☐
12	Pavement patching	☐	☐	☐	☐
13	Crack and joint sealing	☐	☐	☐	☐
14	Concrete sawing	☐	☐	☐	☐
15	Shoulders: earth and aggregate	☐	☐	☐	☐
16	Shoulders: bituminous and Portland Cement	☐	☐	☐	☐
17	Bridge construction and maintenance	☐	☐	☐	☐
18	Culverts and sewers	☐	☐	☐	☐
19	Drainage structures	☐	☐	☐	☐
20	Guardrail and fences	☐	☐	☐	☐
21	Work zone setup, take down, and revision	☐	☐	☐	☐
22	Work zone flagger station	☐	☐	☐	☐
23	Work zone access and material handling	☐	☐	☐	☐
24	Highway signing	☐	☐	☐	☐
25	Pavement marking: striping and markers	☐	☐	☐	☐
26	Electrical wiring and cables	☐	☐	☐	☐
27	Electrical poles and posts: lighting/ traffic signals	☐	☐	☐	☐
List additional nighttime construction activities that you know of					
28		☐	☐	☐	☐
29		☐	☐	☐	☐
30		☐	☐	☐	☐

5- What are the measures that you usually use to ensure the conformity of the provided lighting arrangements on site to the lighting requirements of IDOT?

No.	Measure	Check all applicable boxes
1	A lighting plan and calculations need to be submitted by contractors before construction	❑
2	Field inspection of lighting levels	❑
3	Field inspection of glare	❑
4	Field inspection of light trespass	❑
5	No measure in place	❑
List additional measures that you use		
6		❑

6- If a lighting plan is required for nighttime construction, who should prepare the lighting plan?

❑ Contractors ❑ Consultant ❑ IDOT engineers ❑ Others(please specify)__________

7- If you inspect lighting levels on site, which inspection method do you currently use?

❑ Engineering judgment ❑ Lighting meter ❑ Others(please specify) __________

8- If you inspect glare levels on site, which inspection method do you currently use?

❑ Engineering judgment ❑ Lighting meter ❑ Others(please specify) __________

9- If you inspect light trespass on site, which inspection method do you currently use?

❑ Engineering judgment ❑ Lighting meter ❑ Others(please specify) __________

10- Do you think a guideline for the design and inspection of lighting during nighttime construction will help you in performing your work?

❑ Yes ❑ No

11- Which of the following tools will be most useful for resident engineers in designing and inspecting lighting arrangements for nighttime construction?

❑ Light measuring equipment

❑ Paper-based design and inspection manual

❑ Design and inspection Software that runs on

❑ Desktop PCs ❑ Notebooks ❑ Handheld PCs ❑ Web-based systems

❑ Others (please specify) ____

12-During the past five years, please indicate:

12.1 - The total number of nighttime construction projects that you worked on: (_____).

12.2 - The total number of all the projects that you worked on: (_____)

13- Feel free to use this space to provide additional comments:

We wish to express our gratitude for your valuable time and effort in responding to this questionnaire

Please complete this questionnaire and return to:
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Appendix C. Contractor Survey

ILLINOIS

University of Illinois at Urbana-Champaign
Department of Civil and Environmental Engineering
Construction Management Research Group

ITRC PROJECT VD-H1, FY 00/01
NIGHTTIME CONSTRUCTION: EVALUATION OF LIGHTING FOR HIGHWAY CONSTRUCTION OPERATIONS IN ILLINOIS

Nighttime Lighting
Contractor Survey

(We expect that this questionnaire will take about 10 minutes to be completed)

This survey is intended for the evaluation of lighting arrangements in nighttime construction. The objectives of this survey are to collect data regarding the required lighting levels and to identify the problems associated with lighting configurations in nighttime construction.

Name: ______________________________ **(Optional)**

Position: ______________________________

Company ______________________________

Date: ______________________________

1- In your past projects, which of the following **problems/difficulties** did you encounter during nighttime construction operations?

No.	Nighttime construction problem/difficulty	Check all applicable boxes
1	Accidents to road users	☐
2	Accidents to workers	☐
3	Lower quality	☐
4	Reduced Productivity	☐
5	Complaints from neighboring properties	☐
6	Difficulty in quality inspection	☐
7	Difficulty in inspecting lighting conditions	☐
8	Difficulty in personnel coordination	☐
List other problems that you commonly encounter		
9		☐
10		☐

2- What are the main **lighting problems** that you often face during nighttime construction projects?

No.	Lighting problem	Check all applicable boxes
1	Insufficient lighting levels	☐
2	Glare to workers	☐
3	Glare to road users	☐
4	Non uniformity of lighting levels	☐
5	Light trespass to adjacent properties	☐
6	Availability of suitable lighting equipment	☐
7	Lighting equipment reliability	☐
8	Difficulty to retrofit construction equipment with additional lighting	☐
9	Placement of lighting equipment	☐
10	Mobility of lighting equipment	☐
11	Lack of experience in lighting design	☐
12	Lack of a lighting design/guidelines tool	☐
13	Cost of lighting arrangements	☐
List other problems that you know of		
14		☐
15		☐

3- From your past experience, which of the following **measures** do you usually use to **control glare** during nighttime construction?

No.	Glare control measure	Check all applicable boxes
1	Reducing lighting levels	☐
2	Cutoff luminaries	☐
3	Glare screens	☐
4	Louvers	☐
5	Visors	☐
6	Repositioning lighting equipment	☐
List other measures that you know of		
7		☐
8		☐

4- Using a scale of 1 to 5, rate the following factors that are usually considered in **positioning lighting towers** on site. (1: not important, 5: very important)

No.	Factor	1	2	3	4	5
1	Movement of construction equipment	☐	☐	☐	☐	☐
2	Road users movement	☐	☐	☐	☐	☐
3	Mobility of lighting towers	☐	☐	☐	☐	☐
4	Light trespass to the neighboring	☐	☐	☐	☐	☐
List other factors that you know of						
5		☐	☐	☐	☐	☐
6		☐	☐	☐	☐	☐

5- Which of the following **types of lamps** do you use in your nighttime construction lighting equipment?

No.	Lamp type	Check all applicable boxes
1	Incandescent	☐
2	Fluorescent	☐
3	Mercury Vapor	☐
4	High Pressure Sodium	☐
5	Low Pressure Sodium	☐
6	Metal Halide	☐
7	Halogen	☐
8	Not sure of lamp type	☐
List other types that you know of		
9		☐

6- From your experience, what is the **lighting level requirement** for performing each of following nighttime **highway construction activities?**

No	Highway construction activity	Lighting level requirement			
		High	Medium	Low	No Experience
1	Earthwork: excavation/embankment/backfill	☐	☐	☐	☐
2	Landscaping: seeding/mulch/sodding/planting	☐	☐	☐	☐
3	Erosion control: Riprap/ditch lining	☐	☐	☐	☐
4	Subgrade	☐	☐	☐	☐
5	Subbase / Base courses	☐	☐	☐	☐
6	Paving bituminous surfaces	☐	☐	☐	☐
7	Rolling bituminous surfaces	☐	☐	☐	☐
8	Paving Portland cement concrete surfaces	☐	☐	☐	☐
9	Finishing Portland cement concrete pavements.	☐	☐	☐	☐
10	Milling and removal	☐	☐	☐	☐
11	Pavement resurfacing	☐	☐	☐	☐
12	Pavement patching	☐	☐	☐	☐
13	Crack and joint sealing	☐	☐	☐	☐
14	Concrete sawing	☐	☐	☐	☐
15	Shoulders: earth and aggregate	☐	☐	☐	☐
16	Shoulders: bituminous and Portland Cement	☐	☐	☐	☐
17	Bridge construction and maintenance	☐	☐	☐	☐
18	Culverts and sewers	☐	☐	☐	☐
19	Drainage structures	☐	☐	☐	☐
20	Guardrail and fences	☐	☐	☐	☐
21	Work zone setup, take down, and revision	☐	☐	☐	☐
22	Work zone flagger station	☐	☐	☐	☐
23	Work zone access and material handling	☐	☐	☐	☐
24	Highway signing	☐	☐	☐	☐
25	Pavement marking: striping and markers	☐	☐	☐	☐
26	Electrical wiring and cables	☐	☐	☐	☐
27	Electrical poles and posts: lighting/ traffic signals	☐	☐	☐	☐
	List additional nighttime construction activities that you know of				
28		☐	☐	☐	☐
29		☐	☐	☐	☐
30		☐	☐	☐	☐

6- Which of the following **measures** do you usually use to **adjust lighting levels** on site to satisfy lighting requirements?

No.	Measure	Check all applicable boxes
1	Adjusting the mounting **height** of lighting fixtures	❑
2	Changing the **spacing** between lighting towers	❑
3	Modifying the **aiming** of the lighting fixtures	❑
4	Turning some **lights off**	❑
5	Others (please specify)	❑

7- If a **lighting plan** is required for nighttime construction, who should prepare the lighting plan?

❑ Contractors ❑ Consultant ❑ IDOT engineers ❑ Others(please pecify)________

8- If you **inspect lighting levels** on site, which **inspection method** do you currently use?

❑ Engineering judgment ❑ Light meter ❑ Others (please specify) ____________________

9- If you **inspect glare levels** on site, which **inspection method** do you currently use?

❑ Engineering judgment ❑ Light meter ❑ Others (please specify) ____________________

10- If you inspect **light trespass** on site, which **inspection method** do you currently use?

❑ Engineering judgment ❑ Light meter ❑ Others(please specify) ____________________

11- In a typical nighttime project, how many portable lighting towers do you usually provide on site? ______________Towers

12- In your past projects, what was the main source of electricity for lighting equipment?

No.	Electrical Power Source	Check all applicable boxes
1	Portable generators	❑
2	Fixed electrical power sources	❑
3	Others (please specify)	❑

13- Do you own or lease lighting equipment?

❑ Own ❑ Lease ❑ Rent ❑ Others (please specify)
____

14- Do you follow a specific **standard** in providing lighting arrangements on site?

❑ Yes ❑ No If Yes, please specify_______________________________

15- Do you think a **guideline** for the design and inspection of lighting during nighttime construction will help you in performing your work?

❑ Yes ❑ No

16- Which of the following **tools** will be most useful for contractors in **designing and inspecting** lighting arrangements for nighttime construction?

❑ Light measuring equipment
❑ Paper-based design and inspection manual
❑ Design and inspection Software that runs on

❑ Desktop PCs ❑ Notebooks ❑ Handheld PCs ❑ Web-based systems

❑ Others (please specify) ___________________________________

17- During the past five years, please indicate:

18.1- The total number of nighttime construction projects that you worked on: (______).
18.2- The total number of all the projects that you worked on: (______)

18- Feel free to use this space to provide additional comments:

We wish to express our gratitude for your valuable time and effort in responding to this questionnaire

Please complete this questionnaire and return to:
Prof. Khaled El-Rayes,
Department of Civil and Environmental Engineering
University of Illinois at Urbana-Champaign
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Appendix D. DOT Survey

University of Illinois at Urbana-Champaign
Department of Civil and Environmental Engineering
Construction Management Research Group

ITRC PROJECT VD-H1, FY 00/01
NIGHTTIME CONSTRUCTION: EVALUATION OF LIGHTING FOR HIGHWAY CONSTRUCTION OPERATIONS IN ILLINOIS

Nighttime Lighting
Survey of State Departments of Transportation

(We expect that this questionnaire will take about 10 minutes to be completed)

This survey is intended for the evaluation of lighting arrangements in nighttime construction. The objectives of this survey are to collect data regarding the required lighting levels and to identify the problems associated with lighting configurations in nighttime construction.

Name: ______________________________

Position: ______________________________

Department: ______________________________

Date: ______________________________

1- What is the total value of construction projects undertaken by your department in your last fiscal year 2001?

Type of Project	Number of projects	Total cost of projects ($)
Annual volume of **all construction projects**		
Annual volume of **all nighttime construction** projects (including the ones that are partly daytime and partly nighttime)		

2- Based on your experience, rate the following advantages of utilizing nighttime construction operations in highway projects using a scale of 1 to 5. (1: not important, 5: very important)

No.	Nighttime construction advantage	1 2 3 4 5
1	Reduced traffic congestion	
2	Reduced project duration	
3	Reduced impact on surrounding businesses	
4	Minimized economic effect of delay	
5	Minimized air pollution	
6	Increased freedom to plan lane closures	
7	Enhanced work conditions at night	
8	Faster delivery of material at night	
List other advantages that you know of		
9		

3- Which of the following **problems/difficulties** are faced by your agency during nighttime construction operations due to improper lighting design?

No.	Nighttime construction problem	Check all applicable boxes
1	Accidents to road users	☐
2	Accidents to workers	☐
3	Lower quality	☐
4	Reduced Productivity	☐
5	Difficulty in quality inspection	☐
6	Difficulty in inspecting lighting conditions	☐
7	Difficulty in providing adequate lighting	☐
8	Complaints from neighboring properties	☐
9	Complaints from motorists	☐
10	Difficulty in personnel coordination	☐
List other problems that you know of		
11		☐
12		☐

4- What are the main lighting problems that are faced by your department during nighttime construction projects?

No.	Lighting problem	Check all applicable boxes
1	Insufficient lighting levels	❑
2	Glare to workers	❑
3	Glare to road users	❑
4	Non uniformity of lighting levels	❑
5	Light trespass to adjacent properties	❑
List other problems that you know of		
6		❑
7		❑

5- Does your department have a set of Standards, Specifications, or Guidelines to specify lighting requirements in nighttime construction operations?

❑ Yes ❑ No

If yes, please attach these requirements to this survey form if possible, and/or please provide us with contact information in your department to obtain them:

Contact Information

Name: ____

Position: ____

Phone: ____

Email address: _______________________________________

Address: ____

We wish to express our gratitude for your valuable time and effort in responding to this questionnaire

Please complete this questionnaire and return to:

Prof. Khaled El-Rayes,
Department of Civil and Environmental Engineering
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Appendix E. Additional Comments in the Responses

E-1 Resident Engineer Survey

Nighttime Construction Problems:

- Drainage problems.
- Loose tools.
- Trouble repairing equipment on site.
- Accidents to construction vehicles and equipment.
- Difficulty in locating layout stakes and paint.
- Poor flagger visibility.
- Driver confusion / which is the closed lane?
- Near miss accidents for road users and workers.

Lighting Problems:

- Invisible workers.
- Dawn and dusk visibility problems.

Measures to ensure conformity of provided lighting to the requirements:

- Contractor with IDOT approval.
- Provide our own lighting--Amida lgt.
- Check on coming traffic for glare and visibility.

General Comments:

- The 2 projects used for this questionnaire, completed in the late 80's, are a grading section and a paving section. The grading section was in a rural setting where the contractor worked 2-10 hr. shifts/days to haul approx. 700,000. C.Y. of sand for a large fill area on I-255. The second section involved the sawing of joints on a concrete paving section in a mostly rural setting. Neither road was opened to traffic.

- Many of the questions in this survey are better answered by the resident engineer of our projects. My position is with [IDOT.] Although a majority of our work on expressways is done at night, I'm looking at traffic control devices and delineation of motorist versus work zones. I try to drive around the projects and closures as a motorist. I look for glare of lighting that may distract the motorist's sight. One of the main problems that I have noticed is the poor visibility of flaggers to motorists. They [the flaggers] think they are visible, but at speed > 70 mph in the area at night they do not realize how little people see them as a person not just another sign.
- My only nighttime construction project was in a commercial area where light trespassing was no issue.
- The projects I was involved in were milling, placing level, binder and surface. It was important to have a light with paver at all times to identify any segregation. Also it was important to have a light near the finish roller to remove any marks and bumps left by the break down and pneumatic rollers. The light level near the breakdown rollers was not good. It was necessary to have a flashlight handy to check for tearing of the mat.
- Anything that can be decided on by the R.E. would be helpful to the quality of the painting job. Many of the suggestions that I have given to painting contractors were ignored due to the expense. Light units was the biggest one and both painters agreed that not being able to see past shadows caused problems.

- As more nighttime construction is required, contractors will invest in better lighting to increase their productivity.
- My comments and answers are based on driving through and inspecting traffic control for nighttime closure on the Chicago area expressway system. We have had one or two nighttime resurfacing projects every year for approximately the last 15 years. The only problems we had were: 1) glare to the motorists; and 2) poorly lit flagger stations.
    - Glare to road users can only be inspected by someone driving through the project.
    - Lighting requirements for flagger stations are needed ; however these requirements should be easy to measure, such as minimum Wattage for lights.
- Most complaints came from residents that excessive glare and bright lights disturbed their sleeping habits.
- In general engineering judgment and input from the contractors are big factors in determining the lighting levels on construction projects. Currently specification in the uniform manual for traffic control [flaggers station] and general wording related to artificial lighting on nighttime resurfacing projects are the only work efforts indicating that some type of artificial lighting will be needed during night operations. Specify wording that would be part of the contract documents on the actual amount of light (lumens) required for a given work task would be helpful.
- Set-up of traffic control devices at dawn and dusk is very dangerous. Either set-up at night or during the day when visibility is better. The special

provisions should state how the contractor is to light each work area. The nighttime pay items should be bid separately to prevent contractors from complaining about prices.

- Nighttime construction is highly appreciated for interstate work exclusively. It is not appreciated for two lane state highway construction except where temporary traffic signals and New Jersey barriers with glare screens are in place. Light plants need to be – and are mandated to be–field examined and positioned nightly based on visual on site judgment. The only exception is for flaggers where light plants need to be utilized always with strategic positioning. This is sometimes tedious and inefficient for contractors but the benefits in visibility for protection warrant the hassle. Enforcement to maintain light plants, at least to date, is highly necessary. Comments seldom comply unless they are required by contract and field enforcement is employed. As traffic volumes have increased on interstates so has the need for night construction.
- One of the problems in setting up your lighting needs is that the lighting provided by the controlling entity varies--e.g., expressway lighting in I-90/94 versus lighting on I-80 in Will County. Some contractors are required to furnish floodlights but definitions are vague and do not cover every situation.

E-2 Contractor Survey

Nighttime Construction Problems:

- Added cost (premium)
- Suppliers--no nighttime deliveries
- Higher costs
- Difficulty in suppliers access
- Equipment repair if equipment breaks down

Lighting Problems:

- Road users distracted by over-lighting
- Lighting too harsh for eyes

Factors Affecting Lighting Equipment Positioning:

- Work zone space availability
- Distraction areas for road users
- Location of construction activities

Lighting Levels Adjustment Measures:

- Additional towers

General Comments:

- Our preference is not exclusive night-only projects, but with night operations required during portions of a larger project. There are benefits to night work: reduced traffic volumes and cooler temperatures. But there are definitely disadvantages to night work: slow production, higher costs, safety liability, coordination and equipment.

- The question of whether or not to utilize night construction should be highly scrutinized to determine the risk/reward value received. In most cases, we believe night work is not the most appropriate, or best, option.
- Each job has it own different needs and problems to consider. A lighting design would have to be flexible.
- Most nighttime work is or has been on fairly well lit expressways. We have utilized portable light plants--mostly for patching
- The burden of approving a contractor's night lighting plan is often placed on the CM/CE, without guidelines for evaluating the quality of a plan or without specifications and specific light levels that the contractor needs to develop a plan to meet. "As needed" or "As determined by the engineer" are too open to judgment to be enforceable.

E-3 DOT Survey

Lighting Problems:

- Mobile operations (paving, guardrail, etc.)
- Costly over long, rural projects (> 5 miles)
- Keeping up light with mobile operations

Advantages of Nighttime Construction:

- Many of the "Advantages" you listed above can also be a disadvantage if work is done at night versus daytime. For example, working at night may not reduce the project duration. On the contrary, in urban areas, the hours you may be allowed to work are limited due to the volumes of traffic that remain on the highways well past the "normal peak hours." The reduced hours may mean a longer completion schedule.
- In addition, the work conditions may not be enhanced due to the reasons I mentioned in the first paragraph. Because of many of the issues having to do with work at night, ODOT is looking at multi-day full closures (weekday and weekend) of the facility to get the work done. The philosophy is to get in, get the work done as quickly as possible, and then open the highway back up to traffic.

General Comments

- One item that is overlooked in this survey is that much of the work zone is not lighted and that we rely on the reflectivity of the Traffic Control Devices (TCD) to show traffic where it needs to be or to go. The beginnings of lane closures or shifting tapers are our most critical areas and work lights do not often light these areas. Night work is inherently more dangerous because of the need for the traveling public to rely on the quality of the reflectivity of signs, channelization devices, pavement markings and protective clothing worn by construction workers and flaggers.

Appendix F. DOT Nighttime Lighting Standards

F-1 Florida DOT

Night Work Specifications

8-4.1 Night Work: During active nighttime operations, furnish, place and maintain lighting specifications to permit proper workmanship and inspection. Use lighting with 5 ft.cd [54 lx] minimum intensity. Arrange the lighting to prevent interference with traffic or produce undue glare to property owners. Operate such lighting only during active nighttime construction activities. Provide a light meter to demonstrate that the minimum light intensity is being maintained.

Lighting may be accomplished by the use of portable floodlights, standard equipment lights, existing street lights, temporary street lights, or other lighting methods approved by the Engineer.

Submit a lighting plan at the Preconstruction Conference for review and approval by the Engineer. Submit the plan on standard size plan sheets (not larger than 24 by 36 inch [610 by 915 mm] and on a scale of either 100 or 50 ft to 1 inch [30 or 15 m to 25 mm]. Do not start night work prior to the Engineer approval of the lighting plan.

During active nighttime operations, furnish, place and maintain variable message signs to alert approaching motorists of lighted construction zones and operate the variable message signs only during active construction activities.

Equip all pickups and automobiles used on the project with either a flashing lights or flashing white lights. Equip all other equipment with a minimum of 4 ft2 [0.37 m2] of reflective sheeting, or flashing lights. To avoid distraction to motorists, do not operate the lights on the vehicles or equipment when the vehicles are outside the clear zone or behind traffic control devices.

Ensure that all personnel shall wear reflective vests at all times while in the work area.

Comply with all applicable regulations governing noise abatement.

Have an ATSSA Certified Worksite Supervisor on site during all nighttime operations to ensure proper Maintenance of Traffic.

Include compensation for lighting for night work in the Contract price of the various items of the Contract. Take ownership of all lighting equipment for work.

8-4.2 Sequence of Operations: Do not open up work to the prejudice of already started. The Engineer may require the Contractor to finish a section which work in progress before starting work on any additional section.

8-4.3 Interference with Traffic: At all times conduct the work in such ma and in such sequence as to ensure the least practicable interference with traffic. Operate all vehicles and other equipment safely and without hindrance with traffic. Park all private vehicles outside the clear zone. Place material stored along the roadway so as to cause no obstruction to the traveling public as possible.

Where existing pavement is to be widened and stabilizing is not required, prevent any open trench from remaining after working hours by scheduling operations to place the full thickness of widened base by the end of each day. Do not construct widening strips simultaneously on both sides of the road, except while separated by a distance of at least ¼ mile [0.5 km] along the road and where either the work of excavation has not been started or the base has been completed.

8-4.4 Coordination with other Contactors: Sequence the work and displacement of materials so as to not to interfere with the operations of other contractors engineers upon adjacent work; join the work to that of others in a proper manner in accordance with the spirit of the Contract Documents; and perform the work in proper sequence in relation to that of other contractors; all as may be directed by Engineer.

Each contractor is responsible for any damage done by him or his agent and not the work performed by another contactor.

F-2 Missouri DOT

1. **Description.** Because of the traffic congestion within the project limits during daylight hours, the contractor is encouraged and will be allowed to perform some or all of the construction operations during nighttime hours. Nighttime hours shall be considered to be 9:00 p.m. to 5:30 a.m. for this project.

2. **Construction Requirements.** If work is performed during nighttime hours, the contractor shall provide the necessary lighting and take the necessary precautions to protect the workers and work from harm.

    2.1 Care should be taken when working near residential areas. Nighttime work should be limited to operations that do not produce excessive amounts of noise and disturbance to residential areas.
    2.2 The engineer will monitor nighttime operations conducted on this project. The engineer may modify or limit contractor operations during nighttime hours.
    2.3 Working hours for nighttime operations shall be approved by the engineer.

3. **Method of Measurement.** No measurement of nighttime working hours will be made.

4. **Basis of Payment.** Payment for any work performed during nighttime hours will be fully covered under contract pay items for such work. No payment will be made for any additional cost resulting from construction operations which are performed during nighttime hours.

F-3 Oregon DOT

00225.17 Temporary Illumination for Nighttime Flaggers - Use temporary illumination equipment
conforming to the following:

- Provide an illuminated area of at least 12 m (40 feet) diameter at ground level
- Provide portable illumination equivalent to a 200 W to 250 W high-pressure sodium luminaries
- Provide shielding to prevent the illumination from adversely affecting traffic

00225.44 Temporary Illumination - Construct and remove temporary illumination according to the plans, Sections 00950, 00960, 00970, 02920, and this subsection of the Special Provisions.

00225.60 Temporary TCD - Evaluate the condition of TCD and maintain them using the criteria shown in the current American Traffic Safety Services Association (ATSSA) publication titled "Quality Standards For Work Zone Traffic Control Devices". The ATSSA publication is available for review at the Project Manager's office. Using the above criteria, the Engineer will make regular documented inspections during the Contract and when changing stages or restarting work after extended shutdown periods. Except for electrical devices, replace all TCD that are in "marginal" or "unacceptable" condition with equal devices, in new or like-new condition, within a time period agreed upon by the

Engineer.

Electrical devices that are in "marginal" or "unacceptable" condition may be repaired instead of being replaced, as long as the repairs are satisfactorily completed within a time period agreed upon by the Engineer.

The replacement or repair of TCD, found to be in "marginal" or "unacceptable" condition, shall be made at the Contractor's expense except as in 00225.90(a).

The above inspections and subsequent replacement of devices does not relieve the Contractor of the responsibility to evaluate, maintain and repair or replace TCD, or to perform other duties including the following:

Keep the devices in proper position, clean, and legible at all times

Keep lights, reflectors, and flashers clean, visible, and operable during both daylight and darkness

Trim or remove vegetative growth or other materials so the devices can be seen.

- Verify the effectiveness of the installations at frequent intervals, both in daylight and darkness, by actual travel and inspection
- Repair, replace, or restore damaged or destroyed devices to maintain continuity and effectiveness.

Maintain temporary TCD during suspensions of work the same as if work were in progress.

00225.61 Existing TCD - Maintain existing TCD as follows:

(a) Signs and Other Existing TCD - Maintain existing guide signs, warning signs, regulatory signs, and other existing TCD, the same as temporary signs and devices are maintained.

(b) Signals, Illumination, and Sign Illumination - Maintain existing signals, illumination, and sign illumination after adjusting or working on them until accepted. Routine maintenance of electrical items will be performed by the Agency at the Agency's expense before the Contractor works on them and after work on them is completed and accepted.

00225.67 Temporary Illumination for Nighttime Flaggers - Maintain and use the required temporary illumination equipment according to the manufacturer's recommendation and as required.

When the temporary illumination equipment is in use, have on the Project site, the following:

- Two extra lamps for the temporary luminaries system
- Repair equipment and parts recommended by the manufacturer or have an acceptable backup temporary luminaries

00225.84 Temporary Illumination - No measurement of quantities will be made for this work.

00225.94 Temporary Illumination - The item "Temporary Illumination", will be made at the Contract lump sum amount, and will be payment in full for all required materials called for by the plans and Specifications and for minor adjustments not requiring disassembly.

F-4 Washington DOT

Temporary Illumination System

The temporary illumination system shall be operational prior to opening any temporary connection or detour to traffic. Where required, the Contractor shall perform necessary excavation and embankment around pole shafts without disturbing them.

Electrical services for the temporary illumination system shall be the Contractor's responsibility. The Contractor shall contact the servicing utility and make all necessary arrangements for service. The Contractor shall furnish and install temporary services sized to operate the temporary illumination system at 480 volts, 60 HZ. A meter base and disconnect cabinet shall be installed independent of the service cabinet. The contractor shall also install a current potential transformer (furnished by the utility) and 60 amp DPDT disconnect breaker. Service locations shall be determined by the Contractor in coordination with the utility and approved the Engineer.

The Contractor shall be responsible for the hookup, monthly power and all other utility charges incurred during the Contract.

The Contractor shall be responsible for the installation, operation, and maintenance of the temporary illumination system. In the event of lamp burnout’s, the Contractor is advised for planning purposes that with respects to relamping, he may except relamp instructions consistent with the following;

High mast luminaries: If one lamp is out on a light standard, it shall be relamped within three working days following notification of outage by the Engineer. If more than one lamp is out on a light standard, relamp shall be completed on the first working day following the notification by the Engineer.

All cost for general maintenance shall be included in the lump sum contract price for “Temporary Illumination System.”

The temporary illumination system when no longer required as determined by the Engineer shall be removed and will become the property of the Contractor. Removal shall include all timber light standard, luminaries, cables, and service equipment. When poles are removed, they shall be either pulled out entirely or that shall be cut off a minimum of 18 inches below the finished ground line. The holes shall be backfilled to the level of the surrounding surface with like materials and thoroughly compacted.

F-5 New York DOT

LIGHTING FOR NIGHTTIME OPERATIONS

DESCRIPTION

This work shall consist of furnishing, installing, operating, maintaining, moving and removing portable light towers and equipment-mounted lighting fixtures for nighttime construction operations, for the duration of nighttime work on the contract. Nighttime operations consist of work specifically scheduled to occur after sunset and before sunrise.

MATERIALS

None specified.

CONSTRUCTION DETAILS

General - Before nighttime operations may begin; (1) an acceptable lighting plan must be submitted and (2) all required lighting equipment and/or materials must be ready for operation.

Lighting Plan - Thirty days prior to the start of night work, the Contractor shall submit a lighting plan to the Engineer. The lighting plan shall include the following:

- Layout plan showing location of light towers, including both typical spacing and lateral placement.
- Description of light towers to be used.
- Description of electrical power source.
- Attachment and mounting details for lights to be attached to equipment.
- Specific technical details on all lighting fixtures to be provided, including power rating and photometric charts.
- Details on any hoods, louvers, shields, or other means to be used to control glare.
- Lighting calculations confirming that the illumination requirements will be met by the layout plan.

The layout plan shall be on U.S. standard D size sheets (22 x 34 inch) at an appropriate scale to adequately describe the work. It shall clearly show the location of all lights necessary for every aspect of work to be done at night.

In addition to the plan sheets, the Contractor shall submit catalog cuts giving the specific brand names, model numbers and ratings of the lighting equipment. The submittal shall include power ratings and photometric data.

Light Levels - Tower-mounted luminaries, whether portable, trailer-mounted, or equipment-mounted, shall be of sufficient wattage and/or quantity to provide an average maintained horizontal illuminance equal to or greater than the following over the work area:

Level I - 50 lx

Level II - 100 lx

Level III - 200 lx

The uniformity of illuminance, defined as the ratio of the average illuminance to the minimum illuminance over the work area, shall not exceed 5:1.

Illuminance Requirements - Lighting shall be adequate to meet the required level of illuminance and uniformity over the entire area of operation as follows:

Level I - All areas of general construction operations including excavation; cleaning and sweeping; landscaping; planting and seeding. Level I shall also be provided at the area of lane and/or road closures continuously throughout the period of closure, including the setup and removal of the closures.

Level II - Asphalt paving, milling, and concrete placement and/or removal.

Level III- Pavement or structural crack filling, joint repair, pavement patching and repairs, installation of signal equipment or other electrical/mechanical equipment, and other tasks involving fine details or intricate parts and equipment.

For paving and milling operations, including bridge decks, Level II illuminance shall be provided 15 m ahead of and 30 m behind the paving or milling machine. In addition, Level I illuminance shall be provided a minimum of 120 m ahead and 240 m behind the paving or milling machine, or for the entire area of concrete placement or pavement work if less than this distance. This area shall be extended as necessary to incorporate all vehicle and equipment operations associated with the paving operation. The only exception to the requirement for Level I illumination throughout the area of construction operations is that finish rollers can work beyond the area of Level I illumination using floodlights mounted on the roller.

Construction operations shall be deemed to include all work operations by contractor's personnel, including layout and measurements ahead of the actual work.

Equipment - All lighting equipment will be furnished as required and retained by the Contractor after the work is completed. Material and/or equipment shall be in good operating condition and in compliance with applicable safety and design codes.

Lighting Fixtures - Lighting fixtures shall consist of portable ground-mounted or trailer-mounted light towers; light towers affixed to paving machines, finishing machines, and milling machines; and floodlights mounted on construction equipment.

Flood lights mounted on construction equipment shall consist of a minimum of two 500 W floodlights facing in each direction to provide a minimum of 10 lx of horizontal illuminance measured 20 m in front of and behind the equipment. Construction equipment that is operating solely in areas illuminated by tower lighting shall not require floodlights.

Portable Generators - The contractor shall provide portable generators to furnish adequate AC power to operate all required lighting equipment. Fuel tank capacity and availability of fuel on site shall be sufficient to permit uninterrupted operation throughout the planned shift. Adequate switches shall be provided to control the various lights. All wiring shall be weatherproof and installed according to local, State, Federal and OSHA requirements. All power sources shall be equipped with a Ground-Fault Circuit Interrupter to prevent electrical shock.

Light Meter - The Contractor shall furnish, for the use of the Engineer, a photometer capable of measuring the level of illuminance. This photometer shall be available to the Engineer for use as necessary to check the adequacy of illumination throughout the nighttime operations.

Equipment Mounting - The Contractor shall provide suitable brackets and hardware to mount lighting fixtures and generators on machines and equipment. Mountings shall be designed so that light fixtures can be aimed and positioned as necessary to reduce glare and to provide the required illuminance. Mounting brackets and fixtures shall not interfere with the equipment operator or any overhead structures, and shall provide for secure connection of the fixtures with minimum vibration.

Portable and Trailer-Mounted Light Towers - Light towers shall be provided as the primary means of illumination, and shall provide Level I illuminance throughout the work area. They shall be supplemented to the extent necessary by lighting fixtures mounted on construction equipment to provide Level II or Level III illuminance where required. Towers shall be sturdy and free-standing without the aid of guy wires or bracings. Towers shall be capable of being moved as necessary to keep pace with the construction operation. Portable towers and trailers shall be positioned to minimize the risk of being impacted by traffic on the roadway or by construction traffic or equipment.

Light Towers on Paving, Milling, and Finishing Machines - If needed to supplement portable and/or trailer-mounted light towers, towers shall be affixed to paving, milling, and finishing machines to provide the required level of illuminance for the specified distance in front of and behind the machine. Machine mounted light towers shall not exceed a height of 4 m above ground. Luminaries shall be aimed and adjusted to provide uniform illumination with a maximum uniformity ratio of 5:1. The hopper, auger, and screed areas of pavers shall be uniformly illuminated. The operator's controls on all machines shall be uniformly illuminated.

Equipment Lights - All construction equipment, including rollers, backhoes, loaders, and other equipment operating in work areas not illuminated to a minimum of Level I illuminance shall be equipped with floodlights as described above. Whether or not floodlights are provided, all construction equipment shall be equipped with conventional vehicle headlights to permit safe movement in non-illuminated areas. Headlights shall not be permitted as the sole means of illumination while working.

Glare Control - All lighting provided under this item shall be designed, installed, and operated to avoid glare that interferes with traffic on the roadway or that causes annoyance or discomfort for residences adjoining the roadway. The contractor shall locate, aim, and adjust the lighting fixtures to provide the required level of illuminance and uniformity in the work area without the creation of objectionable glare. The Engineer shall be the sole judge of when glare exceeds acceptable levels, either for traffic or for adjoining residences.

The contractor shall provide shields, visors or louvers on luminaries as necessary to reduce objectionable levels of glare. As a minimum, the following requirements shall be met to avoid objectionable glare on roadways open to traffic in either direction:

- Tower-mounted luminaries shall be aimed either generally parallel or perpendicular to the roadway.

- All luminaries shall be aimed such that the center of the beam axis is no greater than 60E above the vertical

- No luminaries shall be permitted that provide a luminous intensity greater than 20 000 cd at an angle of 72E above the vertical.

Existing Roadway Lights - Existing street and highway lighting shall not eliminate the need for the contractor to provide lighting. Consideration may be given to the amount of illumination provided by existing lights in determining the wattage and/or quantity of lights to be provided. Such consideration shall be discussed in the Contractor's lighting plan.

Continuous Operation - The Contractor shall provide sufficient fuel, spare lamps, generators, and qualified personnel to ensure that all required lights will operate continuously during nighttime operation. In the event of any failure of the lighting system, the operation shall be discontinued until the required level of illumination is restored.

Traffic Control Areas - Level I illuminance shall be provided during the setup of lane closures or road closures installed in conjunction with nighttime construction operation and shall be maintained until the closure is removed. Such lighting shall be required at the actual points of closure, including the lane closure tapers. Lighting shall not be required throughout the entire lane closure, except as required at work areas.

METHOD OF MEASUREMENT

Payment for lighting for nighttime operations will be made on a lump sum basis.

BASIS OF PAYMENT

The lump sum price bid for portable lighting shall include all equipment, materials, and labor necessary to provide, install, operate, and maintain illumination of the nighttime work areas and associated traffic control operations.

Payment will be made at the lump sum price bid as follows:

- Ten percent when the lighting plan has been accepted and satisfactory lighting of nighttime operations has begun.

- The remaining ninety percent will be paid in progress payments per calendar day of nighttime operations completed. The amount of such calendar day payment will be determined by dividing ninety percent of the lump sum amount bid by the total number of days of nighttime operations included in the contractor's current schedule of operations.

F-6 Michigan DOT

SPECIAL PROVISION
LIGHTING FOR NIGHT WORK AND NIGHT PAVING

a- Description.- In addition to the requirements of the 1996 Standard Specifications for Construction, this work shall consist of furnishing, installing and maintaining lighting to allow workers to clearly see and perform all nighttime operations. The lighting shall allow inspector to clearly see and inspect all work operations, including repairs to existing pavements, cleaning, resurfacing, and all other night work.

b- Materials.- Lighting systems may be fixed, portable, or equipment mounted. A power source shall be supplied with sufficient capacity to operate the lighting system.

c- Operation and Requirement.- All lighting fixtures shall conform to the Michigan Manual on Uniform Traffic Control Devices (MMUTCD), 1994 Edition, Part VI, revised March 1988, Section 6F-7B for floodlights, which states: “In no case shall floodlighting be permitted to glare, shine, or be directed into the eyes of oncoming drivers. The adequacy of flood light placement and elimination of potential glare can best be determined by driving through and observing the floodlight area from each direction on the main roadway after initial floodlight setup.”

d- Bituminous Paving Operations.-

1- Pavers- Shall be equipped with lighting that provides a minimum illuminance of 108 lux to allow the operator and paving crew to clearly see the material going into the hopper, the auger area, and for alignment. In addition to this, an auxiliary generator will be required on the paver to supply power for a light tower mounted paver. When used, a light tower should be minimum of 2 meters above the paver, and adjustable up down, and rotatable horizontally. One light on the tower shall be facing forward and four lights facing toward the new mat being laid. The area behind the paver shall be lighted 30 to 60 meters, or to satisfaction of the Engineer, so the work and operations can be seen clearly and inspected properly.

2- Rollers – Each roller shall be equipped with four headlights, two facing each direction of travel. In addition to this, an auxiliary generator will be required on each roller with a light tower, a minimum of 1.2 m higher than the roller, which shall be equipped with flour floodlights, two facing each direction of travel, which will light the area 15 to 30 meters, in front and back if the roller, or to the satisfaction of the Engineer.

3- Sufficient auxiliary lighting shall be provided for all bituminous paving operations from pavement preparation through finish rolling to light the area as required by the Engineer. There shall be provided sufficient lighting at each work area where night work is occurring for the removal and replacement of pavement repairs and cleaning and sealing existing joints and cracks.

4- The Contractors shall provide backup lighting to replace failed lights and equipment during paving operations and night work. The backup equipment shall be on the project and available for use at all times during paving and night work. The backup system shall meet the criteria described above.

5- The Engineer shall suspend all night work except for traffic control if lighting is inadequate on any nighttime work operations.

e- Measurement and Payment.- The Contractor shall be paid for furnishing, installing and maintaining lighting for entire project, as described above and this work shall be paid for as a lump sum unit.

Contract Item (Pay Item)	**Pay Unit**
Lighting for Night Work and Night Paving……………………....	LS

There will be no adjustment in the lump sum unit price regardless of the number or type of lighting system required to complete all night work on the project as outlined above and directed by the Engineer.

F-7 Mississippi DOT

SPECIAL PROVISION NO. 907-680-1

DATE: 12/18/2000

8.1.1.1.1 SUBJECT: Portable Construction Lighting

Section 907-680, Portable Construction lighting, is hereby added to and made a part of the 1990 Edition of the Mississippi Standard Specification for Road and Bridge Construction as follows:

SECTION 907-680 – PORTABLE CONSTRUCTION LIGHTING

907-680.01—Description. Whenever the Contractor's operations are being conducted at night, the Contractor shall provide artificial lighting as may be necessary to provide for safe and proper construction and inspection of the work.

907-680.02—Materials. All lighting equipment will be furnished as required and retained by the Contractor after the work is completed. Materials and/or equipment is not required to be new but shall be in good condition and in compliance with applicable safety and design codes.

The Contractor shall submit, for the Engineer's review and approval, a lighting plan showing the type and location of lights proposed for use during night work. The lighting shall be presented on standard size roadway plan sheets (22"*36") and on a scale of either 50 feet or 100 feet to the inch. It shall clearly show the location of all lights necessary for every aspect of work to be done at night. In addition to the plan sheets, the Contractor shall submit catalog cuts giving the specific brand names, model numbers and ratings of the lighting equipment. The submittals shall include power ratings and photometric data. The Contractor shall allow 14 days for the Engineer to review the submittals. Night work shall not begin without the Engineer's approval of a lighting plan and the indicated lighting equipment and/or materials being in operation.

The Contractor may be required to take lighting level measurements in the presence of the Engineer at location designated by the Engineer to verify compliance with the approved lighting layout submittals. Field light level measurements shall be equal to or exceed light levels on the submittal.

907-680.02.1—Tower Lights. A tower light shall consist of mercury vapor, metal halide, high-pressure sodium or low-pressure sodium fixture mounted on a tower approximately 30' in height. The tower light fixtures shall be heavy-duty flood, area, or roadway style with wide beam spread. The tower shall be sturdy and free-standing without the aid of guy wires or bracing. The power supply shall be sufficient capacity to operate the light(s) and shall be located for the shortest safe routing of cables to the fixtures.

Tower lights shall be of sufficient wattage and/or quantity to provide and average maintained horizontal illuminance greater than 20 foot-candles over the work area.

In no case should the main beam of the light be aimed higher than 60 degrees above straight down. The lights should be set as far from traffic as practical and aimed in the direction of, or normal to, the traffic flow.

907-680.02.2—Machine Lights: All moving equipment used during nighttime operations shall have a mounted lighting system and flashing amber light on the equipment. In lieu of a flashing amber light, the Contractor may install four square feet of approved reflective material on the equipment in a location that will be seen by the traveling public. This lighting system shall illuminate the work area in each direction of travel of the equipment. Machine lights shall be mercury vapor, metal halide, high-pressure sodium or low-pressure sodium conventional roadway enclosed fixtures mounted on supports attached to the construction machine at a height of approximately thirteen feet (13’). The power supply shall be of sufficient capacity to operate the light(s) and shall be securely mounted on the machine. Electrical grounding of generators to frames of machines on which they are mounted shall be done in conformance with the National Electrical Code (NEC).

The machine light fixtures shall be of sufficient wattage and/or quantity to provide an average maintained horizontal illuminance greater than 10 foot-candles on the machine and the surrounding work area. Machine lights are in addition to conventional type headlights, which are necessary for maneuverability.

To avoid distraction to motorists, do not operate the flashing lights on the equipment working outside the clear zone or behind traffic control devices.

907-680.03—Construction Requirements. Tower lights may be used when the night work is confined to fairly small area and is essentially a stationary operation.

Machine lights may be used when the night work is not confined to a small area and is essentially a continuous moving construction operation.

The Engineer may provide tower lights in lieu of machine lights upon approval. Use of tower lights in lieu of machine lights will be considered when the number of machines, type of work, or need for inspection justify their use as decided by the Engineer.

The work area where traffic control devices are being set up or repositioned at night shall be illuminated.

The illuminated work area shall be large enough so that the movements of all personnel and equipment engaged in the work will be contained in the area.

The Contractor shall provide sufficient fuel, spare lamps, generators, and personnel qualified to operate the lights to assure that they will be maintained I operation during night work.

Existing roadway lights shall not eliminate the requirement for the Contractor to provide lighting. Consideration may be given to the amount of illumination provided by existing lights in determining the wattage and/or quantity of lights to be provided, if noted in the Contractor's submitted lighting plan.

907-680-.04—Method of Measurement. Payment for Portable Construction Lighting, by tower and/or machine lighting systems, will be made only when a pay item for portable construction lighting is included in the contract. Otherwise, portable lighting will be considered incidental to other contract items and no direct payment will be made.

Payment for the portable construction lighting will be made at the contract lump sum price. Partial payments for this pay item will be made as follows:

1. 50% of the lump sum price on the first monthly estimate after using the lighting system.
2. 25% of the lump sum price on the first monthly estimate made after the project is 50% complete.
3. 25% of the lump sum price on the first monthly estimate after the completion of all scheduled night work.

907-680.05—Basis of Payment. Portable Construction Lighting, as measured above, shall be paid for at the contract lump sum price, which price shall be full compensation for furnishing, operating and maintaining everything necessary to provide a portable construction lighting system.

Payment will be made under:

907-680-A: Portable Construction Lighting -per lump sum

Grade control for bridge deck slab replacements shall conform to 405.03.02.

(2) Superstructure Placement Restrictions. The superstructure shall not be erected until the substructure forms have been sufficiently stripped to determine the character of the concrete in the entire substructure, unless otherwise permitted by the Engineer. In all spans, the concrete bridge deck slabs outside of the stringers shall be cast using plywood forms.

Unless otherwise specified in the Contract Documents, concrete for deck slabs shall be pumped whenever the volume of concrete in the pour exceeds 50 yd^3.

The Contractor shall place all superstructure concrete in conformance with the following schedule:

SUPERSTRUCTURE CONCRETE PLACEMENT SCHEDULE		
DATES	BEGIN CONCRETE PLACEMENT AFTER	FINISH BURLAP PLACEMENT BEFORE
May 15 - June 15	7:00 PM	11:00 AM
June 16 - Aug. 14	9:00 PM	7:00 AM
Aug. 15 - Sept. 15	7:00 PM	11:00 AM
Sept. 16 - May 14	No time restrictions	

Superstructure concrete shall not be placed or worked in any manner when the temperature in an unshaded location at the placement site is above 80 F. Floodlighting shall be used when existing light is less than 20 average horizontal ft-c over the construction area.

The Contractor shall submit a Situation Plan to the Engineer showing the locations and aiming of floodlights. After reviewing this plan, the Engineer will witness a test of the floodlighting system at the proposed construction area. The Contractor shall run the floodlighting test. The floodlighting system shall be capable of maintaining 20 ft-c without producing a glare on traffic. Floodlighting systems will be approved by the Engineer. When portable generators are used, an emergency backup system shall be available at all times on the job site.

104.06.02 MATERIALS
Tubular Markers Reflectorization: As approved by the Office of Traffic and Safety 950.03

104.06.03 CONSTRUCTION. Tubular markers shall be installed as recommended by the manufacturer and approved by the Engineer

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104.06.04 MEASUREMENT AND PAYMENT. Tubular Markers will be measured and paid for at the Contract unit price per each. The payment will be full compensation for the removal of and for all material, labor, equipment, tools, and incidentals necessary to complete the work.

Tubular markers that are damaged as a result of traffic operations shall be replaced and will be measured and paid for at the Contract unit price per each for Replacement of Tubular Marker Mast. If the base detaches from the pavement, the entire tubular marker assembly shall be replaced by the Contractor at no additional cost to the Administration, unless damaged by Administration snow removal operation.

104.07 ARROW PANEL (AP)

104.07.01 DESCRIPTION. This work shall consist of furnishing and placing APs for temporary use. APs shall supplement but not replace, standard signing as specified in the Contract Documents.

APs shall be self-contained, vehicle mounted or portable and shall be approved by the Engineer. Self-contained trailer units shall be used unless otherwise specified in the Contract Documents.

APs shall have both manual and automatic dimmer devices. These devices shall be capable of reducing the light intensity by 50 percent. Photocells for the automatic dimmers shall be periodically cleaned to prevent malfunctioning of the brightness control. The use of dimmer device shall be mandatory during the night operation of any APs. Manual and automatic dimmer devices shall be designed to include a fail safe system which shall ensure that maximum brightness is displayed during sunlight and 50 percent brightness is displayed during darkness, regardless of which dimmer device is operational.

104.07.02 MATERIALS. Not applicable.