OPTIMUM ILLUMINATION FOR NIGHTTIME FLAGGER OPERATIONS

Final Report

SPR 617

RESEARCH

Oregon Department of Transportation

OPTIMUM ILLUMINATION FOR NIGHTTIME FLAGGER OPERATIONS

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SPR 617

by

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16. Abstract

Highway maintenance and construction undertaken by the Oregon Department of Transportation (ODOT) can involve the use of flaggers to control the work zone. When the work is undertaken at night, illumination of flaggers is needed to ensure the safety of the motorists, flaggers, and workers.

A number of recent developments have taken place that improve the ability for motorists to see flaggers. These include highly reflective apparel and illuminated "STOP/SLOW" paddles. In addition to using such personal protective and directional equipment, consideration should be given to other factors associated with lighting of the flagger station:

- What amount of light should be used, where should the light source be located, and how should the light be directed, to effectively and efficiently illuminate the flagger?
- What light level and quality are necessary and economically practical, which avoid creating blinding glare for the motorists approaching a flagger station?
- How mobile is the lighting equipment and can it be moved without creating additional risk exposure to the flagger?

This study developed guidelines for the optimal illumination of flaggers during nighttime maintenance and construction operations on highway projects. The guidelines address minimum and optimum lighting levels, optimal methods of delivering the light, and maneuverability of the lighting equipment.

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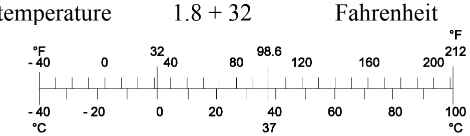
SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celsius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8 + 32	Fahrenheit	°F



* SI is the symbol for the International System of Measurement (4-7-94 jbp)

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OPTIMUM ILLUMINATION FOR NIGHTTIME FLAGGER OPERATIONS

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1.0 INTRODUCTION

Highway maintenance and construction undertaken by the Oregon Department of Transportation (ODOT) can involve the use of flaggers to control traffic in the work zone. When the work is undertaken at night, illumination of flaggers is needed to ensure the safety of the motorists, flaggers, and workers. ODOT entered into a contract with the Department of Civil, Construction and Environmental Engineering at Oregon State University (OSU) to study the illumination of flaggers during nighttime work and develop guidelines for its optimal implementation in practice.

This document is the final report for the study. It describes the work undertaken in the research, the results recorded, and conclusions established from the study. Recommended flagger illumination guidelines and suggestions for future research are also provided. The report is intended to provide ODOT with a comprehensive account of the performance and results of the study in order for ODOT to implement the results and recommendations in practice and identify needs for future research.

1.1 BACKGROUND

Prior to conducting highway maintenance and construction operations, careful consideration and planning are required to ensure safe work zones. Traffic control plans can incorporate a variety of means for providing motorists safe passage through the work zone and for furnishing workers with a safe work environment. One traffic control measure that may be employed is the use of flaggers. Flaggers are commonly utilized when site conditions exist that prohibit the creation of a sufficient buffer between the work and adjacent traffic. Flaggers provide the ability to shift traffic away from workers and equipment, and enable control of the frequency and speed of traffic through the work zone. When planning and implementing flagger operations, consideration should be given to the safety of the motorists, the workers, and the flaggers. Cost efficiency and ease of mobility of the flagging operation are additional factors commonly considered.

Performing highway maintenance and construction at night is becoming more prevalent. Increased traffic volumes on roadway networks have resulted in a greater need for maintaining and upgrading existing facilities. This increased demand has prompted maintenance and construction work to be conducted at a greater frequency. With high daytime traffic demands, much of the needed maintenance and construction work has been shifted from the daytime to nighttime. Lower traffic volumes at night allow greater opportunity to occupy work areas without significantly impacting traffic flow. Maintenance and construction operations can then be undertaken without severe adverse impacts to daily traffic flow, the community, maintainability, and constructability.

Nighttime work, however, adds to the risk exposure of motorists, workers, and flaggers. Reduced visibility, a higher incidence of impaired drivers, drivers and workers who are less alert, and higher traffic speeds are significant safety concerns. To mitigate the affects of these factors, enhanced safety controls are typically required during nighttime operations.

The demand to complete maintenance and construction work in a short period of time in order to minimize impact to the public has prompted a greater use of flaggers to control traffic through the work zone. The increased amount of work conducted at night and the associated risk exposure have increased awareness and concern for flagger safety. Over the past several years, Oregon has seen many flaggers injured and some killed by inattentive drivers. While it may be the case that the motorist fails to follow the directions of the flagger and thus places the flagger and workers at risk, difficulty in seeing the flagger can contribute to the cause of the incident as well. It is critical that the motorist not only follows the instructions of the flagger, but also be able to see the flagger.

Ensuring the safety of the flagger, motorists, and workers is an important consideration when planning and implementing flagger operations. A number of recent developments improve the ability for motorists to see flaggers. These include highly reflective apparel and illuminated "STOP/SLOW" paddles. In addition to using such personal protective and directional equipment, consideration should be given to other factors associated with lighting of the flagger station. The following are some of the questions that should be asked when planning a nighttime flagger operation:

1. What amount of light should be used, where should the light source be located, and how should the light be directed, to effectively and efficiently illuminate the flagger?

   Flagger illumination is often provided by trailer mounted generator light plants (light towers). This is the same type of lighting and light source used for illuminating construction work activities, and is often far more light than is necessary.

2. What light level and quality are necessary and economically practical that avoid creating blinding glare for the motorists approaching a flagger station?

   It is often the case that the location of a flagger station makes it difficult to avoid bright light shining into oncoming vehicles. This problem is exacerbated by the use of large light towers meant for providing coverage over a large area. It is often necessary to raise the lights high above the roadway to direct the light toward the flagger and not at the motorist.

3. How mobile is the lighting equipment and can it be moved without creating additional risk exposure to the flagger?

   Large, trailer mounted light plants that contain a generator are re-located using a tow vehicle. This operation can place the flagger at a disadvantage while the light is being re-located, and require them to move into non-lighted areas to perform their tasks.

Guidance is needed to assist maintenance and construction workers in planning and implementing effective and safe flagger operations at night. Current literature, however, provides minimal assistance with this important task. Expanded guidelines on optimal illumination of nighttime flagger operations are needed.

1.2 STUDY GOAL AND OBJECTIVES

The objective of this study was to develop guidelines for the optimal illumination of flaggers during nighttime maintenance and construction operations on highway projects. It was intended that the guidelines address minimum and optimum lighting levels, optimal methods of delivering the light, and maneuverability of the lighting equipment. The guidelines are to be included in ODOT maintenance manuals, ODOT's *2002 Standard Specifications* (*ODOT 2002*), and/or ODOT's *Traffic Control on State Highways for Short Term Work Zones* manual (*ODOT 1998*).

The ultimate goal to be realized by meeting this objective is enhanced flagger, motorist, and worker safety during maintenance and construction operations on highway projects. Improved ability to deliver light and maneuver lighting equipment and greater consistency and effectiveness of flagger operations throughout the State are also aims of the study. Some of the benefits expected from the study include the following:

- Improved visibility of traffic flaggers at nighttime;
- Reduced incidents where motorists endanger flaggers, maintenance workers, or construction workers in work zones;
- Enhanced flagger station illumination of mobile flagging activities; and
- Reduced glare to motorists.

In addition, it was intended that the study focus on commercially available lighting systems and technologies and evaluate the associated lighting effectiveness, ease of use, and cost competitiveness.

1.3 RESEARCH SCOPE

To meet the stated objective, five primary research activities were planned and undertaken for the study: 1) a review of current literature and documentation of current industry practice; 2) documentation and review of lighting equipment that is currently commercially available; 3) laboratory testing of light equipment for illuminating flaggers; 4) field testing of lighting equipment for illuminating flaggers; and 5) the development of flagger illumination guidelines and recommendations. The first four research tasks provide the basis for the guidelines and recommendations for flagger illumination. Each of the activities, and the specific tasks associated with each activity, is described in further detail below:

1.3.1 Task 1 – Literature and current practice review

Task 1 consisted of conducting an in-depth review of literature, reports, and procedure manuals used as guidance for flagger illumination. Special consideration was given to current practices of State Agencies and contractors with significant nighttime flagger operations. The research was designed to build upon previous research efforts and not duplicate recent work published by the Transportation Research Board (TRB) and FHWA. Some of these recent publications include NCHRP Reports 475 and 476 published by TRB, and the *Traffic Control Handbook for Mobile Operations at Night* published by FHWA (*Bryden and Mace 2002a; Bryden and Mace 2002b; FHWA 2003*).

The second part of this task included surveying construction firms in the Portland and Western Oregon areas to determine the types of lighting equipment commonly used and the practices currently employed to illuminate flaggers during nighttime construction operations. This effort also involved soliciting suggestions from the construction personnel for ways to better illuminate flagger operations.

1.3.2 Task 2 – Survey of commercially available lighting equipment

Task 2 consisted of conducting a comprehensive survey of available lighting technologies and intensities that are commercially available with a particular focus on diffused lighting systems and systems suitable for outside foul weather environments. The equipment must be designed for mobile construction and highway maintenance environments with an emphasis on mobility and ease of use.

In addition, this task involved developing a protocol for laboratory and field testing of the equipment that describes the types and number of pieces of equipment to be tested and the types and number of tests to be conducted. The information collected in Tasks 1 and 2, and the objectives of the study, were used as a guide to determine the types of equipment and tests selected. Additionally, the protocol was developed to fit within the funding and time constraints of the study.

1.3.3 Task 3 – Laboratory testing of lighting equipment

Task 3 consisted of conducting laboratory testing of light levels and quality of equipment identified in Tasks 1 and 2 according to the established testing protocol. Equipment was tested to determine if it meets minimum acceptable guidelines for lighting levels, ease of use, and mobility. The testing was to be conducted on a site (e.g., roadway or parking lot) on or near the OSU campus. When possible, large, expensive pieces of equipment used in the testing (e.g., light towers) were to be rented and/or borrowed from construction companies.

1.3.4 Task 4 – Field testing of lighting equipment

Task 4 consisted of field testing of one or more commercially available lighting systems with ODOT or contractor personnel in a mobile nighttime operation requiring the use of flaggers. Equipment was evaluated in the field for mobility, lighting levels, ease of transport to the work zone, cost, and reduced glare to the motorist. Jobsites used for field testing were selected with input from the ODOT Technical Advisory Committee. For the purposes of estimating the budget and time for this task, it was initially estimated that three different types of equipment would be tested on three different projects, with one piece of equipment tested per night (total of three nights of testing per jobsite).

1.3.5 Task 5 – Develop lighting equipment guidelines and recommendations

Task 5 comprised the preparation of documentation of the research along with recommendations of minimum illumination performance expectations and lighting system guidelines for highway work zone flaggers. This task also included presentation of the findings to ODOT staff and committees including, but not limited to, the Standing Committee on Construction and the Maintenance Leadership Team.

1.4 IMPLEMENTATION

The study results are expected to be incorporated into existing ODOT documents for reference and implementation in practice. The ODOT *2002 Standard Specifications* and ODOT's *Traffic Control on State Highways for Short Term Work Zones* manual are suggested documents in which the study results could be incorporated. The guidelines are expected to be implemented in practice by maintenance and construction personnel when planning and implementing nighttime flagger operations.

2.0 CURRENT KNOWLEDGE, TECHNOLOGIES, AND IMPLEMENTATION

An extensive search was conducted to uncover literature on illumination of flaggers during nighttime highway maintenance and construction. Keyword searches of article databases (TRIS Online and Compendex) and the World Wide Web (using Google as a search engine) were used to locate research articles, reports, industry standards, and other documents that address issues related to flagger illumination and construction work zone lighting. The literature collected from this activity was reviewed for its relevance and application to the study. This section of the report describes previous research on the topic published in documents such as journal articles, research reports, and conference proceedings. Applicable State and Federal standards were also examined as part of the literature review. Regulatory requirements in place for flagger illumination are provided in Section 2.2 of this report.

The literature search uncovered only a limited number of documents discussing flagger illumination. The majority of the literature on illumination of nighttime maintenance and construction operations relates to the conduct of the work itself. Illumination of maintenance and construction work activities has been studied to identify its impact on worker performance, determine appropriate lighting strategies, and evaluate types of lighting equipment. While the needs and characteristics of illumination of the work activities are different than those for flagger operations, some of the research findings are of interest to this study. Therefore, findings from studies on illumination of the work activities that relate to the illumination of flaggers were also recorded and are included in this report.

2.1 PREVIOUS RESEARCH

2.1.1 Factors impacting illumination and flagger operations

Research has been undertaken to identify the factors associated with effective illumination of work zones. A handful of previous studies have investigated nighttime work as compared with work performed in the daytime. While the studies essentially focus on the work activities undertaken by construction workers, some of the findings are relevant to flagger illumination activities as well.

Several studies have identified factors to consider in the decision to conduct nighttime construction (e.g., *Shepard and Cottrell 1985; Price 1985; Hinze and Carlisle 1990*). NCHRP Report 475, titled "A Procedure for Assessing and Planning Nighttime Highway Construction and Maintenance," includes lighting and safety as factors in the decision-making process (*Bryden and Mace 2002a*). It is suggested that consideration be given to the safety of not only the public and workers, but also to those providing traffic control. Consideration should be given to safety while setting up and taking down the work zone and to the visibility of the workers. Other factors identified for consideration are the impacts on the surrounding community (both neighborhoods and businesses) and noise and light impacts.

Models and procedures for determining whether to schedule maintenance and construction work at night have also been created (e.g., *Douglas and Park 2003; Bryden and Mace 2002a; El-Rayes and Hyari 2002*). The results of these studies aid transportation agencies in determining whether maintenance and construction work should be conducted during the day or at night. In their study to develop a decision support system for lighting design in highway nighttime construction projects, El-Rayes and Hyari (*2002*) note the following disadvantages of conducting work at night rather than during the day:

- Decreased visibility;
- Problems in implementing quality control procedures;
- More drivers on the road that are tired;
- Increased noise during late hours;
- Finding personnel willing to work late hours;
- Difficulties with material delivery; and
- Increased costs.

In addition to their impact on the actual work activities, each of these disadvantages can impact flagging operations and the ability and effectiveness of flaggers in controlling traffic through the work zone.

El-Rayes and Hyari (*2002*) also identify seven decision variables to be considered in the development of a lighting plan: 1) lighting equipment selection; 2) type of luminaire; 3) lamp lumen output; 4) luminaire height; 5) light tower positioning; 6) aiming angle of luminaires; and 7) light tower rotation around a vertical axis. The authors suggest that design objectives should consider the optimization of illuminance, glare, uniformity ratio, and lighting cost. Glare is measured using the veiling luminance ratio.

Similar illumination factors are also presented by Douglas and Park (*2003*). In the development of their lighting decision model, Douglas and Park incorporate the following factors: geometric relationships, orientation, power of lamps, gradient uniformity, and glare. Luminance plays a significant part in the lighting of work tasks. The visual task is largely influenced by the luminance of the object, luminance of the background, contrast, size, and duration (*Hanna 1996*).

A survey of nighttime construction practitioners, resident engineers, and state departments of transportation revealed that many in the industry feel there is an increased amount of risk by working at night and that safety is a common concern (*Hancher and Taylor 2001*). Several of the state departments of transportation responding to the survey reported that some nighttime construction sites have a problem with glare and that glare is the biggest concern with lighting on jobsites. All three of the survey groups showed a concern for safety on nighttime projects, but none of them saw any effects on safety from working at night. It was thought that this could be due to increased awareness from workers. One out of twenty contractors surveyed provided advanced training for workers involved in nighttime operations, but most just required additional reflective clothing to be worn.

With respect to a contractor's project work plan, Hancher and Taylor (*2001*) describe two parts: a lighting plan and special safety considerations. The lighting plan includes the layout for the light towers, a description of the equipment used, and an electrical power source detail. The special safety considerations look at equipment warning devices, personal protective clothing, and whether there are overhead power lines present nearby.

2.1.2 Flagger illumination practices

NCHRP Report 476, titled "Guidelines for Design and Operation of Nighttime Traffic Control for Highway Maintenance and Construction", provides assistance with illumination of both the work activities and flaggers (*Bryden and Mace 2002b*). The report cites loss of visibility as a significant factor during nighttime work. Nighttime maintenance and construction projects require additional lighting that will satisfy the visibility requirements of the workers. However, workers are not the only people affected. The driver's ability to detect objects, the flaggers, and the details of the road also decreases at night. This often results in a longer response time. Therefore, the report recommends that flagging operation on nighttime maintenance and construction projects should be avoided whenever possible.

NCHRP Report 476 recommends that, when flaggers are used for traffic control, lighting should make the flagger as visible as possible. The only exception to this may be when the project is a very short term or emergency operation. The report provides the following additional recommendations regarding illumination of flaggers:

- In addition to providing temporary illumination for flaggers at locations that do not have existing light, illumination should also be provided at locations that do have existing light. When additional illumination is provided at locations with existing light, the additional illumination will help the flagger stand out against the surroundings.
- Illumination should be provided directly overhead rather than from the front or back. This helps eliminate glare to the driver and flagger.
- On normal operations, the flagger should be located in a way that isolates him/her from the remaining work zone. The flagger should also be located on the shoulder or in the closed lane.
- In the case of an emergency or very short term operation when no temporary lighting is provided, the flagger should be positioned in a way that best takes advantage of existing worksite illumination.
- Flaggers should be equipped with paddles or flags that have reflectorized tape. Yellow flashers on the handles are suggested.
- The vests worn by flaggers should have reflective markings on the front and back.
- Bright colored garments and coveralls may also be worn to help make the flagger more visible.
- The flagger must be able to be seen from a distance of 1,000 feet under headlight illumination and the reflective tape must be visible from all motions.

2.1.3 Minimum lighting levels

The amount of light in an area is measured in terms of illuminance. Illuminance is the amount of light falling on a surface and is usually measured in foot-candles (S.I. units) or lux (metric units). A foot-candle is defined as the illuminance on a uniform surface 1 foot away from the light of one candle. One foot-candle equals 1 lumen/ft^2, and one lux is equal to 1 lumen/m^2. The illuminance of an object can be increased by increasing the intensity of the light source (i.e., increasing the number of lumens), increasing the number of sources, or by decreasing the distance between the source and the surface area. The horizontal illumination is the measurement with the photocell of the light meter parallel to the road surface.

Three different levels or categories of illuminance are recommended for work operations (*Bryden and Mace 2002b; Hanna 1996; Ellis and Amos 1996*). Level I is recommended for general illumination in the work zone and for areas where crew movement takes place. Level II is recommended for illumination on and around maintenance and construction equipment. Level III is recommended for tasks that require increased attention. Table 2.1 provides the categories and minimum illuminance levels recommended for different types of nighttime highway work. General construction requires 10 foot-candles of illuminance.

Table 2.1: Illuminance levels and categories for nighttime highway work (*Hanna 1996*)

Category	Minimum Illuminance Level	Area of Illumination	Application	Example of Areas and Activities to be Illuminated
I	54 lux (5 fc)	General illumination throughout spaces	Large size visual task Low accuracy General safety requirement	Excavation Sweeping and cleanup Movement areas in the work zone Movement between two tasks
II	108 lux (10 fc)	General illumination of tasks and around equipment	Medium size visual task Low to medium contrast Medium accuracy Safety on and around equipment	Paving Milling Concrete work Around paver, miller, and other construction equipment
III	216 lux (20 fc)	Illumination on task	Small size visual task Low contrast High accuracy and fine finish	Crack filling Pot filling Signalization or similar work requiring extreme caution and attention

Another value that is commonly calculated to assess the quality of illumination is the uniformity of illuminance. Uniformity is the ratio of the average illuminance to the minimum illuminance over the work area. The uniformity ratio should not exceed 10:1, with 5:1 being more reasonable (*Bryden and Mace 2002b*).

Two types of glare are defined: discomfort and disabling (*Bryden and Mace 2002b*). Discomfort glare is measured subjectively and has no direct effect on the driver's vision. Disabling glare reduces the contrast, and therefore the visibility, of the object. Disabling glare is measured in terms of veiling luminance, in units of candela per square meter. The Illuminating Engineering Society of North America (IESNA) recommends that veiling luminance be no greater than a third of average pavement luminance (IESNA, 1993). Therefore, in well-lit areas where the level of pavement luminance is high, a higher level of glare becomes intolerable.

Glare can be controlled by having the axis of maximum candle power located away from the most critical line of sight of motorists. Ellis and Amos (*1996*) suggest that reducing glare can be accomplished through consideration of four factors that relate to beam spread, mounting height, location, and aiming (see Table 2.2).

Table 2.2: Glare control checklist (*Ellis and Amos 1996*)

Factor	Control Measures
Beam Spread	Select vertical and horizontal beam spreads to minimize light spillage. Consider using cutoff luminaires.
Mounting Height	Coordinate minimum mounting height with source lumens.
Location	Luminaire beam axis crosses normal lines of sight between 45° and 90°.
Aiming	Angle between main beam axis and nadir less than 60°. Intensity at angles greater than 72° from the vertical less than 20,000 candela.
Supplemental Hardware	Visors, louvers, shields, screens, barriers.

2.1.4 Lighting systems and equipment

Several different types of lighting systems are available that can be provided on a project site: temporary, portable, and equipment mounted (*Bryden and Mace 2002b; Hanna 1996*). Temporary lighting systems can provide light over the entire work zone and have high mounting heights. These systems are immobile and, therefore, are typically used for projects where the work occurs at just one location.

Portable systems, such as light plants, can incorporate all of the components – the luminaires, power supply, and pole – into one system. Light plants commonly provide more light than needed. In addition, they are often a non-uniform source of light, positioned at a low height, and can produce very high glare. This type of equipment is the predominant system used on construction sites because of the large amount of light it produces, its relatively low cost to rent, high availability, and ease of operation and maintenance. Light stands are another type of portable system. These are much smaller in size, cannot extend to as great a height, produce less light, and do not contain the power supply unit.

Mobile lighting may be mounted directly on maintenance and construction equipment. Mobile lighting will often require additional lighting surrounding the work area on the jobsite. Isofootcandle diagrams provided by the manufacturer can be used for determining height and aiming angles.

Two basic types of light sources are commonly used for construction work zone lighting: incandescent and electric discharge (*Hanna 1996*). General service and tungsten halogen lamps are examples of incandescent lamps. Electric discharge lamps include: metal halide, mercury, high pressure sodium, low pressure sodium, and fluorescent lamps. The general features of several light sources and the recommended application for each are shown in Table 2.3.

Table 2.3: Lamp characteristics and applications (*Hanna 1996*)

Light Source	Lumen Output Per Lamp	Efficacy (Lumens Per Watt)	Life (Hrs)	Color Adaptability	Degree of Light Control	Maint. of Lumen Output	Recommended Applications
Incandescent tungsten halogen	Fair	Low (24)	Low (2,000)	High (Daylight white)	High	Fair	Task oriented lighting Equipment mounted lights Small areas Low mounting heights
Mercury vapor	Good	Fair (63)	High (24,000)	Fair to Good (Medium white)	Fair	Fair	Not recommended
Metal Halide	High	Good (110)	Good (10,000)	Good (Bright white)	Good	Good	Medium sized areas Good color rendition required Varied mounting heights
High pressure sodium	High	High (140)	High (24,000)	Fair (Soft, orange)	Good	High	Large areas Color rendition not important Varied mounting heights
Fluorescent	Low	Fair to good (85)	Fair (7,500)	Fair to High (Daylight white)	Fair	High	Not recommended

2.2 REGULATORY REQUIREMENTS, SPECIFICATIONS, AND STANDARDS

State and Federal agencies provide standards that must be followed during highway maintenance and construction operations to ensure the safety of motorists, workers, and flaggers. As part of the literature review, standards published by State of Oregon and national agencies were examined for content applicable to nighttime flagger operations. This section describes the regulatory requirements contained in those standards.

2.2.1 Traffic control on state highways for short term work zones

ODOT's *Traffic Control on State Highways for Short Term Work Zones* manual provides a quick reference for controlling traffic through short term work zones on state highways (*ODOT 1998*). The manual is based on the principles set forth in Section 6 of the *Manual on Uniform Traffic Control Devices*, published by the Federal Highway Administration (FHWA), and the *1996 Short Term Traffic Control Handbook*. The ODOT guidelines are intended to be used for emergency or incident traffic control if practical. For illumination of flaggers during nighttime operations, the manual provides the following guidelines:

- Flagger stations should be illuminated with a floodlight.
- The light should not create a glare for motorists.
- Flaggers shall use a minimum 18-inch by 18-inch octagon shaped STOP/SLOW paddle.
- Flaggers shall wear an orange or strong yellow-green, retroreflectorized vest, shirt or jacket, at all times.
- An approved hat must be worn.

No guidelines are provided in the manual that describe the best means to illuminate the flagger or reduce glare.

2.2.2 ODOT 2002 standard specifications

"Section 00225 – Work Zone Traffic Control" of the ODOT *2002 Standard Specifications* provides direction on flagger operations and illumination as well (*ODOT 2002*). The following are excerpts taken from Section 00225 that cover nighttime flagger operations:

> **Materials:**
>
> **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 luminaire.
> - Provide shielding to prevent the illumination from adversely affecting traffic.
>
> **Equipment:**
>
> **00225.27 Flaggers** – Equip flaggers as follows:
> - Clothing to cover the complete body except head, neck, and arms below the point of the shoulders.
> - An orange, yellow, strong yellow-green, or fluorescent versions of these colors, retroreflective vest. The retroreflective material shall be orange, yellow, white, silver, strong yellow-green, or a fluorescent version of one of these colors, and shall be visible at a minimum distance of 300 m (1,000 feet). The vest shall be designed to identify the wearer as a person and be visible through the full range of body motions.
> - A fluorescent yellow-green, orange, yellow, or bright white hardhat or baseball-style cap. Wear hardhats when there is danger of falling or flying objects or electrical shock or burns.
> - Highly visible "STOP/SLOW" sign paddles conforming to the MUTCD and fabricated using encapsulated lens reflective sheet or brighter.

- For flaggers farthest from the work site, as indicated in 00225.47, a minimum 610 mm (24 inch) square red flag made of tightly woven fabric or plastic attached to a 914 mm (36 inch) long staff or highly visible “STOP/SLOW” sign paddles. The free edge shall be weighted.
- Portable, self-contained two-way radio with a range suitable for the Project.
- Illuminated stand area of high visibility at night.

Construction:

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

00225.47 Flaggers – Locate flaggers far enough in advance of the work area to permit adequate time for the motorist to respond to the flagger’s instructions. When two flaggers are used for one direction of traffic in advance of a worksite, the flagger farthest from the site may use either a red flag or “STOP/SLOW” sign paddle. The flagger nearest the worksite shall use only the “STOP/SLOW” sign paddle.

When one flagger is used in advance of a worksite, that flagger shall use only the “STOP/SLOW” sign paddle.

Position flaggers, as directed, at locations where traffic can enter the highway within the limits of the work zone. Direct vehicles entering the highway to follow the pilot car line.

Flagging stations shall be staffed continuously or until the Engineer determines flagging is no longer required.

Provide continuous illumination as required for nighttime flagging or until the Engineer determines the illumination is no longer required.

Maintenance:

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 luminaire system.
- Repair equipment and parts recommended by the manufacturer or have an acceptable backup temporary luminaire.

Further specifications are provided by ODOT for the vests worn by flaggers (*Brown 2002*). These additional vest specifications are provided in Appendix A to this report.

2.2.3 Manual on Uniform Traffic Control Devices (MUTCD)

Chapter 6 of the *Manual on Uniform Traffic Control Devices* (MUTCD), published by FHWA, discusses the use of temporary traffic control (*FHWA 2000*). These guidelines address all types of traffic control including flagger operations during nighttime maintenance and construction. Information related to flagger operations is provided in Chapter 6E. The following are excerpts from Chapter 6E of the MUTCD that relate to nighttime flagging operations:

> **Section 6E.02 – High-Visibility Clothing**
>
> For daytime work, the flagger's vest, shirt, or jacket shall be either orange, yellow, yellow-green, or a fluorescent version of these colors. For nighttime work, similar outside garments shall be retroreflective. The retroreflective material shall be either orange, yellow, white, silver, yellow-green, or a fluorescent version of these colors, and shall be visible at a minimum distance of 300 m (1,000 ft). The retroreflective clothing shall be designed to clearly identify the wearer as a person.
>
> **Section 6E.03 – Hand-Signaling Devices**
>
> The STOP/SLOW paddle shall have an octagonal shape on a rigid handle. STOP/SLOW paddles shall be at least 450 mm (18 in) wide with letters at least 150 mm (6 in) high and should be fabricated from light semi-rigid material. The background of the STOP face shall be red with white letters and border. The background of the SLOW face shall be orange with black letters and border. When used at night, the STOP/SLOW paddle shall be retroreflectorized.
>
> Option: The STOP/SLOW paddle may be modified to improve conspicuity by incorporating white flashing lights. Two lights may be installed and centered vertically above and below the STOP legend, or centered horizontally on either side of the STOP legend. Instead of the above two-light arrangement, one light may be centered below the STOP legend.
>
> When used at nighttime, flags shall be retroreflectorized red.
>
> **Section 6E.05 – Flagger Stations**
>
> Flagger stations shall be located far enough in advance of the work space so that approaching road users will have sufficient distance to stop before entering the work space.
>
> Flagger stations should be preceded by proper advance warning signs. At night, flagger stations should be illuminated.
>
> The flagger should stand either on the shoulder adjacent to the road user being controlled or in the closed lane prior to stopping road users. A flagger should only stand in the lane being used by moving road users after road users have stopped. The flagger should be

> clearly visible to the first approaching road user at all times. The flagger also should be visible to other road users. The flagger should be stationed sufficiently in advance of the workers to warn them (for example, with audible warning devices such as horns, whistles, etc.) of approaching danger by out-of-control vehicles. The flagger should stand alone, never permitting a group of workers to congregate around the flagger station.

The requirements for flagger illumination have remained basically the same for the past 15 years. The 1988 and 2000 editions of the MUTCD state "At night, flagger stations should be illuminated", as noted above. An upcoming revision to the 2000 MUTCD will change "should" to "shall" in this sentence.

2.2.4 OR-OSHA construction safety and health standards

The Oregon Occupational Safety and Health Division (OR-OSHA) publishes safety and health standards for employees. Division 3 of the standards applies specifically to the safety of workers on construction sites (*OR-OSHA 2002*). Within Division 3, illumination on construction sites is covered in Section 1926.56 of Subdivision D – Occupational Health and Environmental Controls, which states the following:

> (a) General. Construction areas, ramps, runways, corridors, offices, shops, and storage areas shall be lighted to not less than the minimum illumination intensities listed in Table D-3 while any work is in progress.

Table 2.4 provides the minimum illumination intensities listed in Table D-3 of the OR-OSHA construction safety and health standards.

Table 2.4: Minimum illumination intensities in foot-candles (Table D-3 in *OR-OSHA 2002*)

Foot-Candles	Area or Operation
5	General construction area lighting.
3	General construction areas, concrete placement, excavation and waste areas, accessways, active storage areas, loading platforms, refueling, and field maintenance areas.
5	Indoors: warehouses, corridors, hallways, and exitways.
5	Tunnels, shafts, and general underground work areas: (Exception: minimum of 10 foot-candles is required at tunnel and shaft heading during drilling, mucking, and scaling. Bureau of Mines approved cap lights shall be acceptable for use in the tunnel heading.)
10	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 work rooms).
30	First aid stations, infirmaries, and offices.

The above standards apply to all work conducted on construction sites and are derived from the specifications provided in the American National Standards Institute (ANSI) standard ANSI A11.1-1965, R1970. The OR-OSHA standards for construction do not specify worksite conditions or processes specific to the illumination of flaggers during nighttime operations.

2.2.5 American National Standards for Practice for Industrial Lighting

The *American National Standards for Practice for Industrial Lighting*, published by the Illuminating Engineering Society of North America (IESNA), and approved by the American National Standards Institute (ANSI), provides recommendations for consideration when designing and implementing lighting in work environments (*IESNA 1991*). The following recommendations apply to the illumination of flaggers:

- Design the lighting for the expected activity.
- Use more effective and efficient luminaires.
- Use light sources of the highest practicable efficacy (high lumens-per-watt output).
- Consider the accessibility of luminaries for maintenance.
- Keep the equipment clean and in good operating condition.

The ANSI standard defines luminance as frequently the one controllable factor in task visibility. This standard recommends an illuminance of 10 foot-candles for general construction. Glare is the "sensation produced by luminance within the visual field that is sufficiently greater than that to which the eyes are adapted." Two types of glare are described: discomfort and disability. Discomfort glare does not affect a person's ability to see. Disability glare reduces both visibility and visual performance. Reflected glare is frequently more annoying than direct glare because it is close to the line of vision and the eye cannot avoid it. It is suggested that direct glare may be reduced by:

1. Decreasing the luminance of light sources or lighting equipment, or both;
2. Reducing the area of high luminance causing the glare condition;
3. Increasing the angle between the glare source and the line of vision; and
4. Increasing the luminance of the area surrounding the glare source and its background.

2.3 CURRENT INDUSTRY PRACTICE

An understanding of current practice for illuminating flaggers during nighttime maintenance and construction operations in Oregon was developed through a survey of maintenance and construction industry personnel. The purpose of the survey was to gather information on current flagger illumination practice, the range of lighting equipment typically used, and the types of personal protective equipment used by flaggers. Barriers to effective illumination and recommendations for enhanced illumination were also sought.

The survey consisted of telephone interviews of construction personnel who work for firms located in the Portland and Western Oregon areas. Personnel in construction firms that specialize in highway work were targeted for an interview. A representative from ODOT Maintenance was also targeted to obtain a viewpoint from those who maintain roadways.

A total of seven interviews were conducted. Five of those interviewed work for firms that perform heavy civil/highway construction work. The types of paving projects performed by the contractors ranged from driveways to interstates and freeways. The ODOT Maintenance person interviewed performs maintenance and striping of state highways. The positions held by the respondents include project manager, district engineer, vice president, and president.

Structured interviews were conducted using a list of eight questions aimed at flagger illumination in practice. Provided below are summaries of the responses to each survey question. The actual responses to the questions from each person interviewed are provided in Appendix B to this report.

Question #1: Do you perform nighttime construction operations?

Six of the seven interviewees stated that they perform construction or maintenance operations at night. Most also noted that they try to avoid the use of flaggers whenever possible in favor of other traffic control methods, but do use flaggers when necessary.

Question #2: How are flaggers illuminated during these operations?

Of the six interviewees who stated that they perform nighttime work, all said that they use a portable light plant for illuminating the flagger. One contractor noted that on well-illuminated intersections in urban areas, sufficient light may exist and eliminate the need for additional lighting of flaggers. When lighting is needed and a light plant is not used, a small generator with one or two lights is used.

One construction firm has employed an alternative system that consisted of a hand truck with a small generator attached to its base. The generator was used to power a single light aimed at the flagger and a yellow light, similar to those found on trucks, mounted on the top of the hand truck. The use of this type of lighting was discontinued as the requirements for lighting increased.

On paving operations where a flagger is not required to stop traffic but is used to slow traffic down, such as on freeways, the flagger is placed near the pavers. Illumination of the flagger is provided using balloon lighting mounted on the pavers. The flagger moves down the roadway along with the pavers.

Question #3: How are flaggers moved from one location to another during nighttime operations?

Several of the companies try to avoid having to move the flagger stations whenever possible, but when they do have to move them, there appeared to be two basic approaches. The first is to lower the tower and slowly move the plant down the road using a tow vehicle. Of the companies that do this, some turn off the lights during the relocation, while others leave them on. ODOT maintenance crews that move down the roadway will typically shut off the lights when moving the light plant. The lights will be allowed to warm up while the subsequent work zone is being set up. The time required for the maintenance crew to set up a work zone is approximately 20 minutes, which is sufficient time for the lights to warm up.

The other method employed for relocating flagger stations is to use two light plants and alternate their use as the operation moves down the road. While work is being conducted at one location, the second light plant is set up and the lights warmed up at the next location. This eliminates delays associated with the cool down and warm up times for the light plants, and helps keep the operation moving down the road quickly.

Question #4: What types of lighting equipment do you use? (If tower lighting is used, at what height are the lights raised to?)

Most of the contractors use portable lighting towers consisting of a generator, an extendable mast, and 4 lights. The height of the tower used varies from company to company. Some contractors raise them to their full height (approximately 30 feet), unless an obstruction prevents that height from being reached. Others may only raise them 10 to 20 feet. The manufacturer of the portable light tower is not of concern to the construction companies and typically depends on the rental company from which the towers are rented. Smaller generators with floodlights were also mentioned as an alternative to light towers.

Question #5: Are your flaggers required to have any additional reflective clothing besides a vest?

The majority of contractors just require the standard high reflective vests. Some also require that a hard hat be worn. Flaggers can choose to wear additional reflective clothing, such as reflective pants or jackets, but are not required to. One contractor reported that some of their flaggers will place a small flashing light on their hard hat similar to those seen on runners or bicycle riders. This helps them stand out a little more from their surroundings. It was also noted that the vests and paddles should be clean and bright. Failure to have a clean vest could reduce the reflectivity and the contrast of the tape and vest material.

Question #6: What do you consider (e.g., project location, size of operation, flagger safety, glare, etc.) when determining how flaggers will be illuminated, and how are these considered (e.g., by what process and by whom)?

The general response to this question was that either a Traffic Control Supervisor (TCS) or the Project Foreman will determine the location and lighting to be used. The Superintendent will overrule their decision if it is felt the location is unsafe or not the best placement for the flagger. The size and location of the project affects the illumination used and the illumination should be located to give drivers as much visual warning as possible.

Question #7: What types of operations, site conditions, etc. make illuminating flaggers difficult?

All of the respondents stated that moving operations are the most difficult to flag. The difficulty is mostly due to flaggers not being at one location long enough to increase driver expectation or for drivers to know where the flaggers will be. Narrow lanes and shoulders can also make it difficult to illuminate flaggers. With narrow lanes and shoulders there is not enough room to place the light plant on the shoulder.

Some also noted that curves with short tangent sections where the sight distance is short and does not give drivers enough time to slow down can also be difficult to illuminate. Short tangents are not the only problem that can reduce visibility. Heavy rain, snow and fog can reduce visibility and reduce the effects of illumination on the flagger.

Question #8: Do you have any suggestions for ways to better illuminate flaggers during nighttime operations?

The contractors generally did not have suggestions or recommendations for improving the illumination of flaggers. One contractor stated that making sure vests and signs are clean will help with their reflectivity. Another stated that placing the illumination right over the flagger would be of benefit as well. One contractor did not necessarily feel that illumination was the answer. He felt that a yellow flashing light similar to those found on trucks was better and more effective at grabbing the driver's attention.

2.4 LIGHTING EQUIPMENT

A wide range of equipment is available that can be used at flagging stations during nighttime operations. There is lighting equipment and reflective equipment. Lighting equipment can be portable lighting plants, balloon lights, or light stands with generators. The reflective equipment used by flaggers is also very important to help drivers see them. The following sections describe the different types of portable light towers, flagger equipment, and other types of equipment that are commercially available. All of the equipment discussed below can be used to help illuminate flaggers during nighttime operations. Some of the equipment may physically shine light on the flagger, while others will help draw attention to the flagger.

2.4.1 Light towers

A search of the World Wide Web was performed to locate types of lighting equipment that could be used on highway maintenance and construction operations. The search identified 13 different manufacturers of portable light towers, each offering several different models. Even though a large number of different light towers are available, they are all very similar. A list of the different tower manufacturers and models along with various technical specifications is provided in Appendix C to this report.

Portable light towers (also referred to as portable light plants) consist of a generator, a mast, and two to six light fixtures, all of which are mounted on a trailer to be towed behind a vehicle. The light fixtures are typically outfitted with 1,000- or 1,500-watt metal halide bulbs. The bulbs are not limited to metal halide, and some of them have the option of using high pressure sodium or tungsten halogen lights. Bulbs differ with respect to the color of the light which they emit and the time they take to warm up. Tungsten halogen lights are natural daylight white and are instant on. High pressure sodium lights are a soft orange and produce less glare. Metal halide lights are a bright white.

The mast on portable light towers can be raised as high as 30 feet and most of the light towers have the ability to rotate 360 degrees. These capabilities allow the lighting to be adjusted as needed and can lead to larger amounts of area illuminated. Most light towers have an illumination range of 5 to 7 acres for towers containing four 1,000-watt lights. If the number of watts is increased, the area illuminated also increases. The tower model that is used on projects will vary from company to company and will depend on whether the user owns or rents the equipment.

2.4.2 Light stands, balloon lights, and flashers

Several other types of lighting equipment exist that are not classified as lighting tower units. Balloon lights, light stands, and flashers are common examples of other types of equipment available. Each of these types of equipment is described below. A list of the different manufacturers and models along with various technical specifications for the equipment is provided in Appendix C.

Balloon lights, developed by Airstar Space Lighting, are lights inflated with air or helium and can be mounted on portable stands or a vehicle. The light is either a halogen bulb or a Hydrargyrum Medium-arc Iodide (HMI) system. Balloon lights have an illumination range of 108,000 to 432,000 square feet and are glare free. Light is distributed over 360 degrees, and some balloons can be elevated as high as 164 feet.

Light stands are another type of light equipment that can be used during flagging operations. The survey of lighting equipment found 8 different manufacturers of light stands. Most of these do not have a generator attached to them and would require one for operation. Light stands generally have one to two lights on them that range from 500 to 1,500 watts each. The stands can be extended to a height of 6 to 12 feet.

Also used to supplement illuminating lights are yellow flashing/rotating lights similar to those found on trucks and paving equipment. These lights can either be mounted on the vehicle or to a stationary stand. Barricade lights are also a yellow light and typically contain a photocell detector to conserve battery power during daylight hours. These lights may also have a reflective border that will increase their visibility. A newer type of warning device is a flare light that is produced by Stinson Equipment.[1] This light is highly visible and is being used by many emergency responders to replace the use of a flare. It uses a triple flash with over 500 hours of battery life.

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[1] Stinson Equipment Ltd., Concord, Ontario, L4K 1P2, CANADA

2.4.3 Flagger equipment

Flagger equipment is used to control traffic as well as help make the flaggers as visible as possible. There are basically two primary types of equipment used. The first is the clothing worn by the flagger and the second is the paddle or flags used by the flagger for traffic control. Both of these will be discussed below with respect to the minimum requirements and additional items that could help identify the flagger. These descriptions provide a summary of the standards presented previously in Section 2.2 of this report.

Flaggers are required to wear a high visibility shirt, jacket, or vest with retroreflective material. The MUTCD states that the retroreflective material may be orange, yellow, silver, white, yellow-green, or a fluorescent version of these colors. Flaggers should be able to be seen at a distance of 1,000 feet. Some flaggers will also wear pants that have reflective material or white coveralls with a vest or jacket over them. The contrast of white coveralls was found to help make flaggers more visible. In addition to their reflective clothing, some flaggers will also wear a hat (soft or hard) that has reflective material on it. Using a small flasher similar to those used by bicyclists and runners can also help draw attention to the flagger.

Traffic control equipment such as STOP/SLOW paddles and flags should also be reflectorized. The paddles shall be at a minimum 18 inches wide with 6-inch tall letters. NCHRP Report 476 notes that the use of a small yellow flasher on the handle could be of benefit as well. Keeping this equipment clean also helps to make the flagger visible as soon as possible and clearly identifies him/her as a person. All of these tools will help make flaggers visible at a distance of 1,000 feet and give drivers enough time to react.

2.5 SUMMARY

As daytime traffic demands increase, more and more maintenance and construction work is being conducted at night. The use of flaggers is growing in popularity as well. Effective and efficient illumination of flaggers is a significant concern when planning and implementing flagging operations for nighttime highway maintenance and construction work. Insufficient light levels, disabling glare, poor quality personnel protective equipment, and a lack of mobility can increase the risk exposure of the flaggers, motorists, and workers on the jobsite. To eliminate hazards associated with flagging operations at night, guidelines are needed that provide specific direction and recommendations for optimal illumination of flaggers on highway projects.

Current literature contains limited guidance on how to design and implement illumination for flagging operations given specific project characteristics. With ensuring safety of the flagger, motorists, and workers as the specific goal, previous research has identified the optimization of illuminance, glare, uniformity ratio, and cost as design objectives for nighttime flagger operations. When designing the lighting systems used for illumination, the following design variables have been identified:

- Lighting equipment selection;
- Type of luminaire;

- Lamp lumen output;
- Luminaire height;
- Luminaire location;
- Aiming angle of luminaire; and
- Luminaire rotation (around a vertical axis).

Applicable regulatory requirements and standard specifications provide minimum requirements for flagger illumination. ODOT and FHWA documents specify the design of paddles and vests, the location of flaggers, and the minimum size of the illuminated area and amount of light. It is also recommended that flagger stations should be illuminated with a floodlight, and that the light should not create a glare for motorists. The standards, however, lack practical guidance on how to not only meet these requirements, but also implement effective and efficient illumination in practice.

Beyond these minimum requirements, previous studies have generated some additional practical suggestions for illuminating flaggers. It is recommended that lighting be designed to make the flagger as visible as possible. This should be the case when existing light does and does not exist. It is also suggested that illumination be located directly overhead of the flagger and that the uniformity ratio not exceed 10:1.

Current industry practice reflects the lack of guidance available. Light towers are the predominant light source used in practice for illuminating flaggers. While light towers are highly available, easy to set up and use, and meet the minimum regulatory requirements, the amount of light emitted from the towers is commonly much more than is needed and often creates disabling glare for motorists passing through the work zone. Alternative lighting systems and configurations are available, but are not generally used.

While the literature review, survey of maintenance and construction industry personnel, and review of commercially available equipment provide insight regarding flagger illumination, additional information is needed to effectively illuminate flaggers in practice. Currently, maintenance and construction workers typically apply one lighting design for all situations, while alternative designs may be more effective and efficient. Guidelines are needed to assist the workers with selecting and locating lighting systems that meet regulatory requirements and are optimal for the work at hand. Guidance for ad-hoc flagging for short-term maintenance operations is also needed. In addition, factors such as ease of use, mobility, and cost should be incorporated into the design process.

2.6 RECOMMENDATIONS FOR RESEARCH STUDY

Further research is needed to establish practical guidelines and recommendations for the illumination of flaggers during nighttime highway maintenance and construction operations. The goal of the research should be to determine the layout and design of lighting for flagger stations that optimizes illumination of the flaggers and meets minimum regulatory requirements. Guidelines and recommendations for flagger illumination in practice should then be developed based on the research results.

2.6.1 Outcome measures and design variables

The research should focus on six outcome measures: illuminance, glare, uniformity, ease of use, mobility, and cost. These measures reflect the level and quality of illumination provided and the applicability and efficiency of the lighting equipment and layout to implementation in the field. Selection of the appropriate means to illuminate flaggers would then be made based on the optimization of all of the outcome measures considered together.

The following design variables are recommended as inputs to assess the outcome measures for a particular lighting system and arrangement:

- Lighting equipment selection;
- Type of luminaire;
- Lamp lumen output;
- Luminaire height;
- Luminaire location;
- Aiming angle of luminaire;
- Luminaire rotation (around a vertical axis);
- Operability and maintainability of lighting equipment; and
- Time and resources required for, and complexity of, setting up, breaking down, and relocating the lighting equipment.

Each of the outcome measures is impacted by one or more of the design variables. Table 2.5 indicates which design variables would be used to assess each outcome measure.

Table 2.5: Design variables used to assess each outcome measure

Design Variable	Outcome Measure					
	Illuminance	Glare	Uniformity	Ease of Use	Mobility	Cost
Lighting equipment selection	X	X	X	X	X	X
Type of luminaire	X	X	X			X
Lamp lumen output	X	X	X			X
Luminaire height	X	X	X			
Luminaire location	X	X	X			
Aiming angle of luminaire	X	X	X			
Luminaire rotation	X	X	X			
Operability and maintainability				X		X
Set-up, break down, & relocation					X	X

2.6.2 Research methods

The next phase of this study involved laboratory testing of lighting equipment and arrangements to determine the optimal means to illuminate flaggers. In addition, testing aimed to identify the minimum level of lighting needed to effectively illuminate flaggers. Described below is the recommended methodology for conducting the laboratory testing phase of the research:

2.6.2.1 Equipment selection

Four types of light equipment should be evaluated: a light tower, light stand, 12V portable light, and balloon light. One model/manufacturer and luminaire should be tested for each piece of equipment. The specific model/manufacturer of each piece of equipment and the luminaire selected for testing should be those which are commonly used in practice and are readily available for use in practice. The equipment can either be rented from local rental companies or borrowed from local contractors.

Prior to selecting the specific equipment to test, typical ODOT Maintenance flagging setups and operations should be observed. The intent of the observations is to verify the systems used, observe their use in practice, and gain insight into useful and effective systems. ODOT Maintenance can facilitate the field observations.

2.6.2.2 Equipment testing

Each of the four types of equipment should be tested. The design variables that should be evaluated in the testing are as follows:

- *Location*: Testing should be performed within two different surrounding light conditions:
  1) natural lighting only (i.e., a rural highway setting)
  2) natural lighting with additional artificial lighting nearby (i.e., an urban/suburban highway setting)

- *Output*: For each type of equipment, different amounts of light should be tested as follows:

Light tower:	1 to 4 – 1,000W bulbs
Light stand:	1 – 1,000W bulb; 1 – 1,500W bulb
12V portable light:	Lower watt bulbs (less than 500W)
Balloon light:	500W; 1,200W

- *Arrangement*: At each location, the arrangement of the equipment should be varied to determine the configurations that optimize flagger illumination. In all cases, the light should be aimed directly at the flagger. By fixing the direction of the light on the flagger, the luminaire aiming angle and rotation will be dependent on the luminaire location and height. Therefore, luminaire location and height should be varied to test the different arrangements. Luminaire locations in front of, in back of, directly above, and on the sides of the flagger should be tested. The luminaire should be tested at various heights, up to 30 feet for the light tower.

- *Measurements*: For each arrangement, measurements should be taken to determine each of the outcome measures. With the lighting equipment turned on, illuminance should be measured at the flagger, within a 12 m diameter area around the flagger, and at varying distances away from the flagger. Illuminance should also be measured at these locations under only the existing surrounding light to use for comparison in the analysis (i.e., the lighting equipment turned off). The level of illuminance should be measured using a light meter. Uniformity should be calculated based on the illuminance measurements.

Disabling glare should be measured in terms of veiling luminance. Discomforting glare, a subjective assessment that varies with each driver, should be measured using a panel of observers, including interested TAC members, and the researchers. Each person should be asked to identify the level of discomfort from the lighting systems based on their own visual observations.

A person wearing a vest and other required personal protective equipment, and holding a reflective paddle, should act as a flagger during the testing. Visual observations by the researchers should also be made at a distance of 300 m (1,000 ft.) away from the flagger to verify that the flagger is visible at that distance. An experienced flagger should be asked to judge the acceptability of the lighting systems from the flagger's position.

Ease of use should be assessed qualitatively based on the ease with which the equipment can be operated and maintained. A subjective assessment of how easy it is to operate and maintain each type of equipment compared to the other types of equipment should be made as the equipment is used during the course of the equipment testing.

Mobility should be measured in two ways. First, the time it takes to set up, break down, and re-locate the equipment a short distance should be measured. Support equipment and resources that are commonly available on construction and maintenance jobsites should be used during this process. Secondly, a subjective assessment should be made on the complexity of performing these operations for one type of equipment compared to another.

Cost should be calculated for both renting and owning the equipment. Costs of the lighting equipment and any miscellaneous supplies and equipment needed for its use should be included.

2.6.2.3 Analysis

The illuminance measurements recorded during the testing described above should be used to calculate glare and uniformity values. These values along with the illuminance level, cost, and assessments of ease of use and mobility should be used to determine the optimal type of equipment and configuration for illuminating flaggers. Optimal illumination should be defined as: a high illuminance level; little or no glare; a low uniformity ratio; easy to operate and maintain; can be quickly and easily relocated; acceptable to the experienced flagger; and requires minimal cost. Minimal illumination should be assessed using the illuminance level measurements, and should be defined as the lowest level of illumination needed to make the flagger visible by oncoming motorists from a safe distance.

3.0 DEMONSTRATION OF LIGHT SYSTEMS CURRENTLY USED

Prior to the start of testing, a visit was made to the ODOT Region 1 Maintenance Station near Banks, OR, to view current light systems employed by ODOT. The objectives of the visit were to view the light systems used by ODOT Maintenance, learn about the practices commonly employed by ODOT personnel to illuminate flaggers, and observe the light systems in operation. The meeting was held at night to simulate actual working conditions, and a rural setting northwest of Banks, OR, on Highway 47 was selected where the lights were set up.

Three different types of lights were set up and observed as shown in Figure 3.1. The first light examined was a 6-foot tall floodlight with two luminaires, each containing a halogen lamp (bulb). The luminaires were mounted on a pole with a portable generator attached at the base for power. This type of light is commonly used by ODOT workers while adding striping and other pavement markings to roadways. The second light observed consisted of a single luminaire floodlight with one halogen lamp mounted on a pole supported by an ODOT Maintenance truck. The pole elevated the luminaire to approximately 10-15 feet above the ground. The lamp was powered by the truck's battery. The third type of light was a single luminaire spotlight with a halogen lamp mounted on a pole support by a tripod at its base. Power for this light was also provided by the truck's battery.

Each light was set up and turned on as it would typically be used in a flagging operation. The ODOT Maintenance personnel described the issues and concerns related to use of the lights, including problems with glare, mobility and movement of the lights, location of the light relative to the flagger, and ease of use. With the lights shining on a flagger, the flaggers were viewed from a distance of approximately 1,000 feet to evaluate whether they were visible by oncoming traffic.

The lights are typically located just off of the shoulder on the side of the roadway in which the flagger is located. The lights are placed at a slight angle to the flagger (usually less than 30° angle), as opposed to being directly adjacent the flagger, to help illuminate the flagger's body on the side facing oncoming traffic. Actual location of the lights will vary depending on the shoulder width, adjacent terrain, and availability of maintenance vehicle parking. With the exception of the 6-foot tall light, the lights are typically elevated and directed to shine down on the flagger.

Ease of use and mobility are significant concerns of the workers. It is common that the flaggers will need to relocate as the work progresses along the roadway. Light systems that are easily set up and taken down are preferred. In addition, the lights need to be constructed to withstand harsh weather conditions and frequent use. Each of the light systems observed was relatively easy to set up and move, taking just a few minutes to get situated and turned on.

All three of the lights observed illuminated the flagger sufficiently such that the flagger could be viewed from a distance of 1,000 feet. The spotlight directed light within a small radius concentrated on the flagger, while the other lights illuminated more of the roadway and the shoulder on the other side of the road.

(a) (b) (c)

Figure 3.1: Typical lights used by ODOT Maintenance: (a) 6-foot tall, dual luminaire with portable generator; (b) single luminaire mounted on truck; and (c) single spotlight mounted on tripod

4.0 LIGHT EQUIPMENT TESTING

4.1 FIELD LABORATORY LOCATIONS

Testing was performed at two field laboratory locations selected to provide two different types of lighting environment: natural lighting only and natural lighting with additional background artificial lighting nearby. The location selected for a natural lighting only environment was a roadway at the Corvallis Airport in Corvallis, OR. The second test location, which represented an urban/suburban setting, was the parking lot at the OSU football stadium. Each of the test locations is described in detail below.

4.1.1 Corvallis Airport

The primary field laboratory location was a two lane roadway adjacent to the Corvallis Airport. Located a few miles south of Corvallis, OR, the airport is located in a rural area with little surrounding light. The roadway on which the testing was performed was of sufficient distance from airport lighting and surrounding area lighting that there was no impact on the testing (i.e., the light meters did not register any amount of light from the existing airport and surrounding lights).

This site was selected for several reasons. First, the site setting is similar to a rural roadway in which no artificial lighting is present. Only natural lighting exists from the moonlight. Second, the roadway on which the testing was performed contained only light traffic, allowed for observing the light systems from a great distance in both roadway directions, and was a two lane road similar to many rural roadways. Lastly, the natural lighting only setting allowed for taking baseline measurements of the lighting systems which could then be used to evaluate and compare other settings.

An aerial view of the roadway is shown in Figure 4.1. The testing was performed on a straight section of SW Plumley St., which is oriented in a north-south direction. A flagger location was identified and markings were placed on the roadway at 100-foot increments away from the flagger for a distance of 1,000 feet in each direction. The markings were used for taking glare measurements and to verify that the flagger was visible from a distance of 1,000 feet as required by the Manual of Uniform Traffic Control Devices (MUTCD).

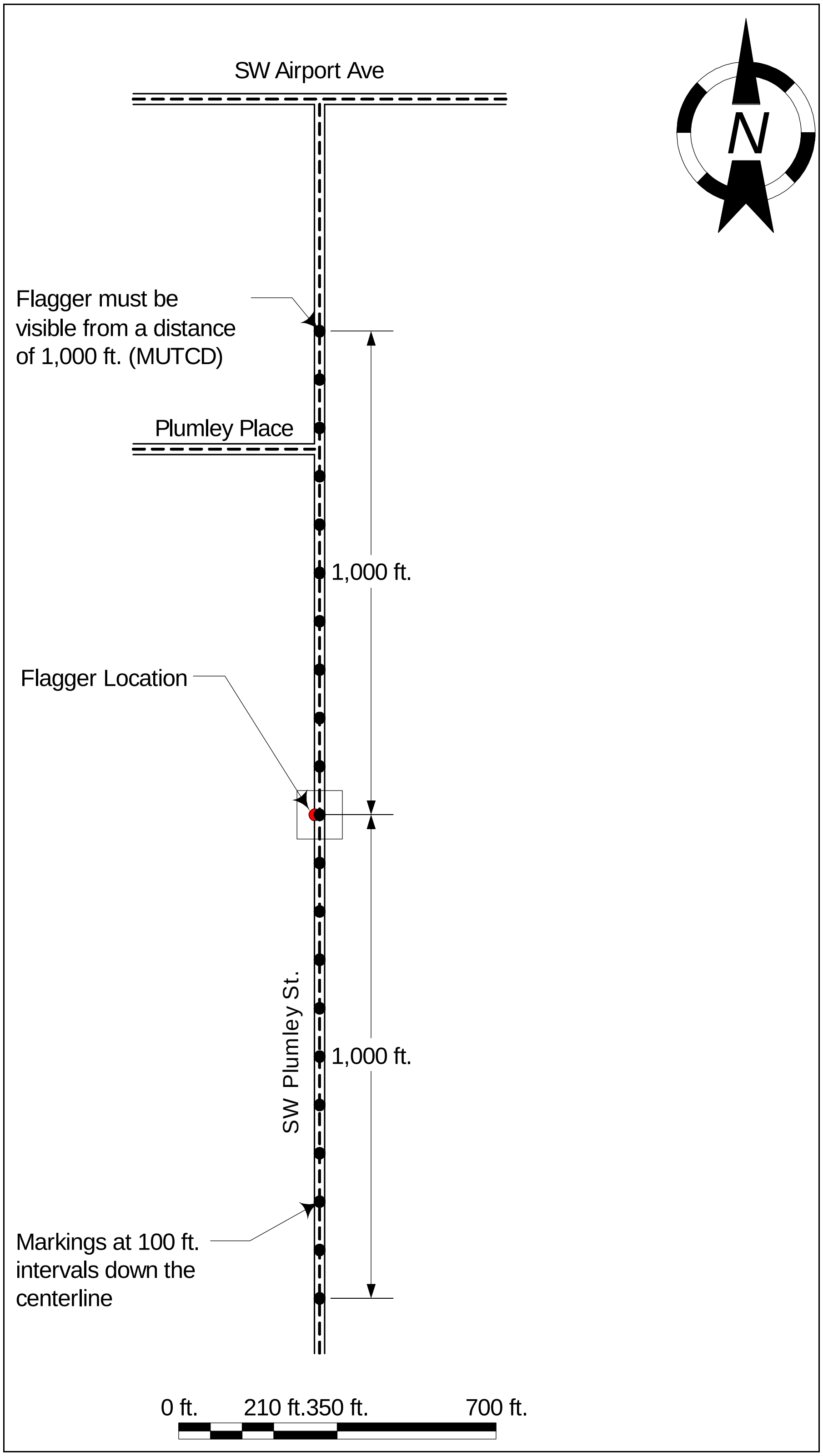

Figure 4.1: Roadway test location at Corvallis Airport

A test grid was marked on the roadway at the flagger location as shown in Figure 4.2 to measure illuminance in the flagging area. The grid extended for a distance of 50 feet in each roadway direction for a total length of 100 feet. For the first 30 feet in each roadway direction, grid points were marked at 5-foot increments. Between 30 and 50 feet from the flagger location, the grid point increments were increased to 10 feet. These markings were made along the following roadway lines: southbound outside of shoulder (SB-OS); southbound middle of shoulder (SB-MS); southbound edge of lane (SB-EL); southbound middle of lane (SB-Mid); centerline of the roadway (CL); northbound middle of lane (NB-Mid); and northbound edge of lane (NB-EL), resulting in a total of 119 grid points. The flagger location was considered to be on the southbound edge of lane (SB-EL) at the center of the grid, a location where the flagger would be standing if controlling traffic driving in the southbound direction. The grid was not extended through the northbound shoulder because it was felt that illumination of the northbound shoulder was not something typically done and would not impact flagger safety.

Initial measurements using light meters were taken of light levels throughout the grid and for a distance of 1,000 feet in each direction to record baseline readings. No amount of background light was measured throughout the grid and along the roadway in each direction.

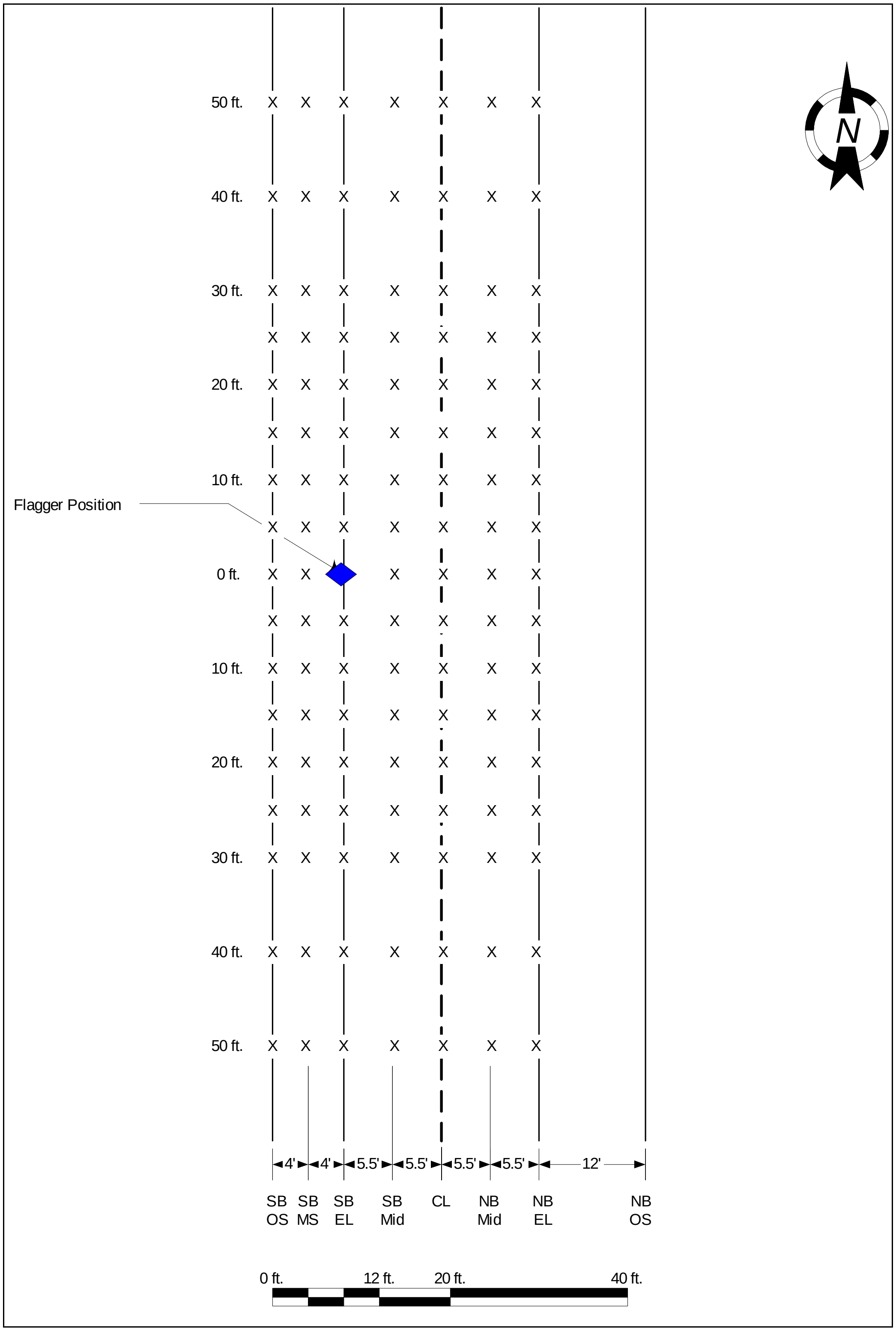

Figure 4.2: Grid layout on roadway at Corvallis Airport

4.1.2 OSU football stadium parking lot

An additional field laboratory testing location was set up at the parking lot adjacent the OSU football stadium. This site was selected to represent an urban/suburban roadway containing artificial background lighting. Figure 4.3 shows the layout of the test area in the parking lot. Located throughout this area of the parking lot are lamp posts to illuminate the parking stalls. Surrounding light from nearby lamp posts, the football stadium, and adjacent buildings also illuminated the test area to a limited extent.

A test grid, similar in length and width to that placed at the Corvallis Airport site, was marked on the parking lot. The grid was located between two rows of lamp posts within the parking area as shown in Figure 4.3.

Initial measurements using the light meters were taken of light levels throughout the grid to record baseline readings. Figure 4.4 shows the levels of illuminance recorded throughout the grid. At ground level, the lamps provided 3.3 to 3.8 Fc of (yellow) light.

For comparison to actual urban and suburban settings, light measurements were taken beneath a variety of different lights at various locations around OSU and Corvallis. Table 4.1 shows the light measurements taken directly beneath different street lights. For street lights emitting white light, the level of illumination at the ground surface ranged from 0.5 to 1.5 Fc with an average of 1.07 Fc. The level of illumination measured for lamp posts emitting yellow ranged from 0.7 to 6.4 Fc with an average of 4.61 Fc. Table 4.2 gives measurements at random locations in nearby parking lots. These measurements ranged from 0.51 to 15.14 Fc with an average of 5.26 Fc.

The light levels present at the OSU football stadium parking lot are within the typical range of levels measured for street lighting and parking lots, and close to the average illumination in each setting. The location of the lights is typical for parking lots but spaced closer together than typically found along streets. In urban and suburban settings, the actual light levels and layout under which flagging occurs can vary tremendously. The light can come from almost any direction and vary in output and color. It would not be practically feasible to test all surrounding light settings that might be experienced by flaggers in urban and suburban environments. For this study, urban/suburban environment testing was limited to the OSU football stadium parking lot.

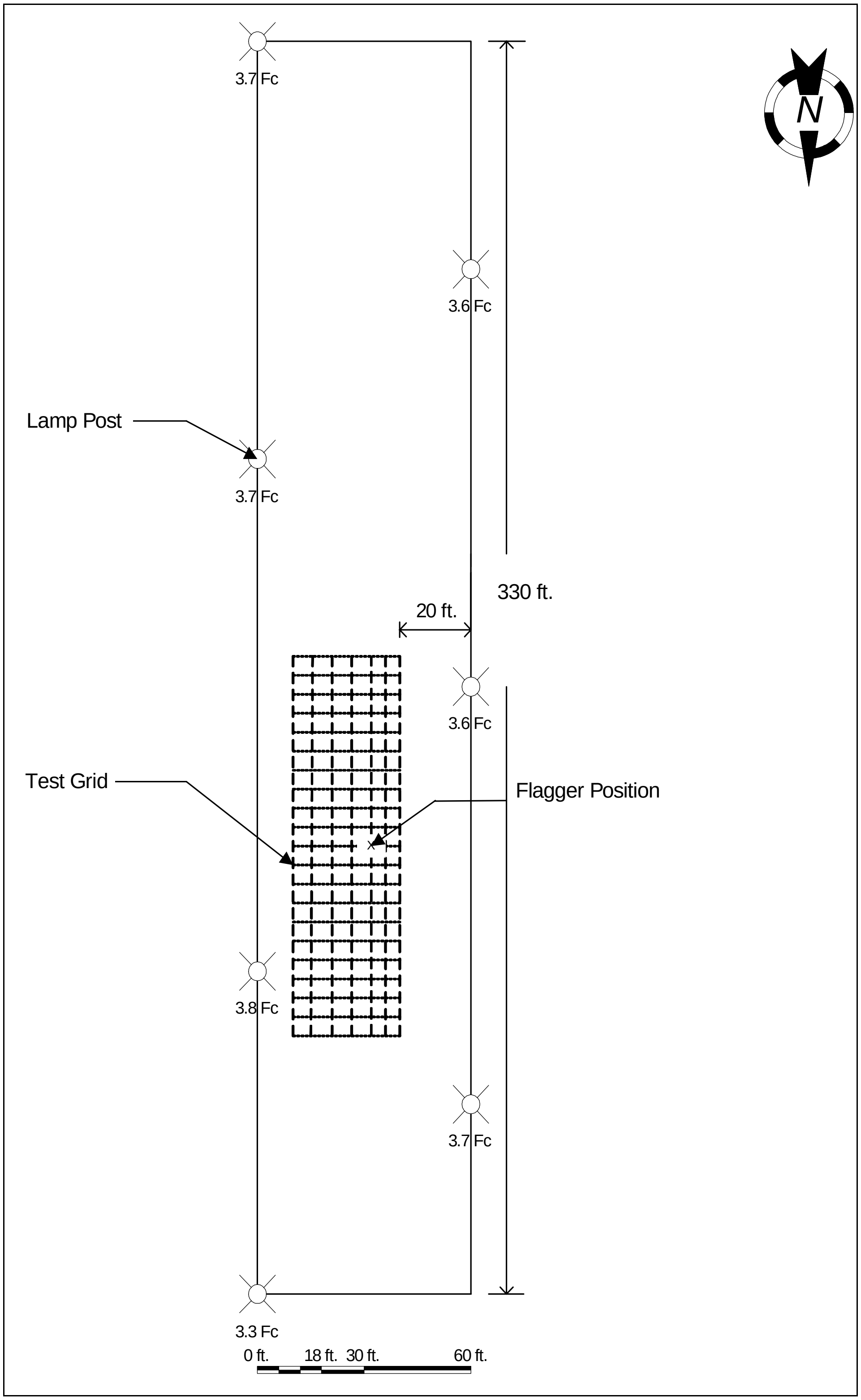

Figure 4.3: Test location and grid layout at OSU football stadium parking lot

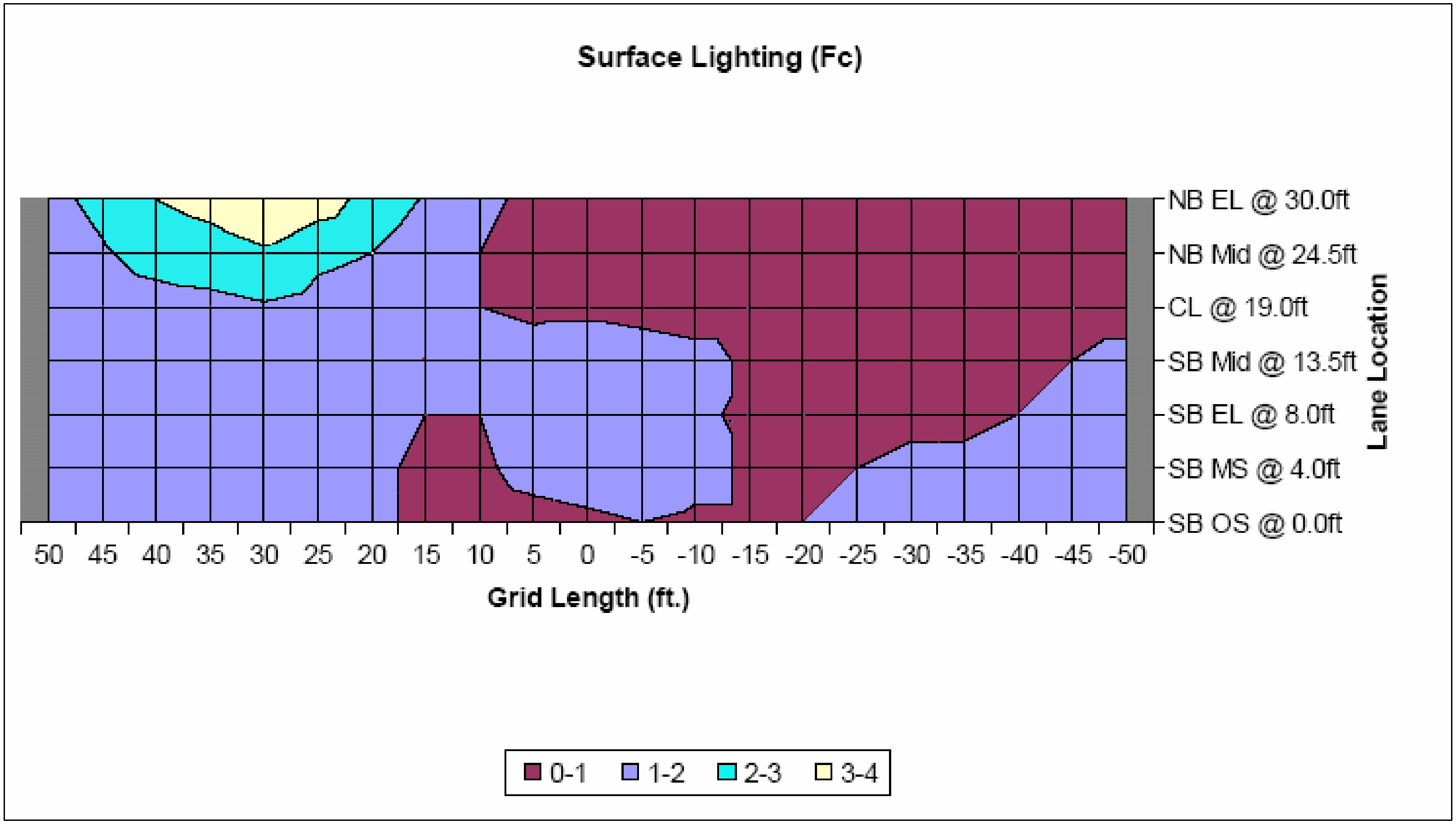

Figure 4.4: Baseline measurements at OSU football stadium parking lot

Table 4.1: Suburban street light levels of illumination around Corvallis

No.	Light Color	Location	Illuminance (Fc)[1]	Average Illuminance (Fc)
1	White	SW A Ave. -- SW 26th St. intersection	0.5	1.07
2		Monroe Ave. -- 23rd St. intersection	1.5	
3		25th Street at Chintimini Park	1.2	
4	Yellow	SW 26th Street	5.9	4.61
5		Washington Way (A)	6.4	
6		Washington Way (B)	5.9	
7		Monroe Ave. near Interzone	4.8	
8		Monroe Ave. – Kings Ave. intersection	4.2	
9		Monroe Ave. near Big Town Hero	4.7	
10		Monroe Ave. near Young's Kitchen	4.6	
11		25th Street	0.7	
12		25th Street – Tyler Ave. intersection	4.3	

[1] Readings were taken at the ground level directly under the street lights.

Table 4.2: Parking lot levels of illumination around Corvallis

No.	Light Color	Location	Illuminance (Fc)[1]	Average Illuminance (Fc)
1	Yellow	Safeway on Philomath Blvd	5.10	5.26
2		OSU Football Stadium	3.06	
3		OSU Football Stadium - mid light	0.51	
4		Downtown Dairy Queen	2.62	
5		Rite Aid	15.14	
6		Albertsons	4.08	
7		Circle Blvd. – East of Pendleton	5.47	
8		Western Ave. – West of 35^{th} Street	6.13	

[1] Readings were taken at the ground surface at a random point in the parking lots.

4.2 RESEARCH METHODS

Each of the design variables used to assess the outcome measures is described below along with how the variables were accounted for in the research.

4.2.1 Light equipment and luminaire selection

Based on the results of the literature search (Task 1) and survey of lighting equipment (Task 2), four different types of lighting systems were selected for testing. These include: a light tower, a balloon light (two different models), a 12-volt spotlight mounted on a light stand, and a 12-volt

High Intensity Discharge (H.I.D.) floodlight mounted on a light stand. Included as part of the testing in combination with these four lights was also a small, portable floodlight with a single 500-watt halogen lamp (bulb).

The survey of lighting equipment (Task 2) identified 13 different manufacturers of portable light towers, each offering several different models. Even though a large number of different light towers are available, they are all very similar. Portable light towers (also referred to as portable light plants) consist of a generator, a mast, and two to six luminaires (light fixtures) all of which are mounted on a trailer towed behind a vehicle. The luminaires are typically outfitted with 1,000 or 1,500 watt metal halide H.I.D. lamps. The lamps are not limited to metal halide H.I.D. and some light towers have the option of using high pressure sodium H.I.D. or tungsten halogen lamps.

The mast on many portable light towers can be raised as high as 30 feet, and most of the light towers have the ability to rotate 360 degrees. These capabilities allow the lighting to be adjusted as needed and can lead to the illumination of larger amounts of area. Light towers typically have an illumination range of 5 to 7 acres for towers containing four 1,000-watt light fixtures. If the number of watts is increased, the area illuminated also increases.

The light tower used for this study was a Genie TML-4000,[2] owned by the OSU Facilities Services Department. The tower contains four luminaires (light fixtures), each containing one 1,000-watt metal halide H.I.D. lamp. The luminaires are mounted on a mast that can extend up to 28.5 feet in height. Each luminaire is made of durable cast aluminum and contains a tempered glass lens. The mast is connected to a generator that powers the lights. The generator sits on a trailer for towing behind a vehicle. Figure 4.5 shows a picture of the light tower with the tower raised and all four luminaires turned on.

[2] Genie Industries, Redmond, WA

Figure 4.5: Light tower

Balloon lights, developed by Airstar Space Lighting,[3] contain a single luminaire inside an inflated balloon. The balloon is inflated with air or helium and can be mounted on a stand, tripod, or vehicle. The luminaire uses either a halogen lamp or an HMI lighting system. Balloon lights have an illumination range of 108,000 to 432,000 square feet and are glare free. Light is distributed over 360 degrees, and some balloons can be elevated to as high as 164 feet. The fabric on the lower half of the balloon is specially designed to filter the light to minimize glare.

Two different models of balloon lights were tested. The first was a Sirocco 200 shown in Figure 4.6. The light contains a luminaire mounted on a pole and supported by a worker wearing a backpack. Inside the backpack is a 12-volt, rechargeable battery that powers the 200-watt halogen lamp. The height of the luminaire in use depends on the height of the worker, approximately 8 feet high at the bottom of the balloon for a 6 foot tall person. The balloon self-inflates by a small fan inside the balloon, is approximately 1.5 feet in diameter, and consists of diffusing material on its lower half.

[3] Airstar America Inc., Austin, TX

Figure 4.6: Sirocco 200 (backpack model) balloon light

The second type of balloon light tested, shown in Figure 4.7, was a Sirocco 2000 mounted on a tripod. This is a 110-volt system containing two 1,000-watt halogen lamps surrounded by a shell manufactured of the same material as the backpack model. The balloon self-inflates and measures approximately 3 feet in diameter. The balloon can be raised to a height of 8 to 15 feet.

Figure 4.7: Sirocco 2000 (tripod model) balloon light

The spotlight selected for testing is manufactured by Havis-Shields.[4] The light contains two Collins Dynamics Kwik-Raze FX-Series, Model 06 luminaires mounted on top of a tripod. Each 12-volt DC luminaire contains one 100-watt halogen H-1 lamp, similar to that used for vehicle headlights. A light with two luminaires was selected in order to allow for testing of either one or two luminaires at a time. Lights with only one luminaire are also available as well as pole mounted lights for attachment to a truck. The tripod can support the luminaires up to a height of approximately 10 feet. Power was supplied to the light during testing by a car battery. Figure 4.8 shows the spotlight used in the research.

Figure 4.8: 12-volt spotlight

Similar to the spotlight, a second light stand was tested that contained two luminaires. This floodlight, also manufactured by Havis-Shields, consisted of two 12-volt DC Magnafire 3000 luminaires supported by a tripod as shown in Figure 4.9. Each luminaire contained a 70-watt, metal halide H.I.D. (high intensity discharge) lamp. As with the spotlight, a model is also available with a single luminaire. The tripod can support the luminaires up to a height of approximately 10 feet. Power was supplied to the light during testing by a car battery.

[4] Havis-Shields Equipment Corporation, Warminster, PA

Figure 4.9: 12-volt H.I.D. floodlight

While not considered as part of the initial testing arrangements, a small, portable floodlight was included in the testing in combination with the other light systems described above. It was felt that an additional light shining from the ground upward at the flagger would complement the other light systems shining from above. The second light selected for the testing was a small floodlight commonly used for illuminating workshop areas (see Figure 4.10). The 110-volt light, manufactured by Stanley Products,[5] contained a single 500-watt halogen lamp. A generator was used to supply power to the light during testing.

[5] The Stanley Works, New Britain, CT

Figure 4.10: Small, portable floodlight

4.2.2 Light equipment output

The amount of light output is important with respect to providing enough light to sufficiently illuminate the flagger. The MUTCD requires that flaggers be visible from a distance of 1,000 feet. However, too much light can create disabling glare for the motorist and possibly the flagger depending on the direction from which the light is coming. Excessive light may also "wash out" the words on reflective "STOP/SLOW" paddles (i.e., the light may be so intense that the motorist cannot read whether the paddle says "Stop" or "Slow").

The amount of light emitted from a light system depends on the number of luminaires within the system, the number of lamps (bulbs) per luminaire, and the output of each lamp. Lamp output, measured in watts, can vary to a great extent depending on the size and type of lamp. Typical light towers use 1,000-watt metal halide lamps, while smaller light stands might use anywhere from 40 to 500 watt halogen lamps. The light equipment selected for the study allowed for testing a range of light system outputs. Table 4.3 shows the light output capabilities of each piece of light equipment.

Table 4.3: Light output characteristics of light equipment tested

Light Equipment	Light Distribution	Type of Lamp (Bulb)	# of Luminaires	# of Lamps per Luminaire	Output per Lamp (Watts)	Max. Output (Watts)
Light Tower	Flood	Metal halide H.I.D.	4	1	1,000	4,000
12-volt Spotlight	Spot	Halogen	2	1	100	200
12-volt H.I.D. Floodlight	Flood	Metal halide H.I.D.	2	1	70	140
Balloon Light: Sirocco 2000	Balloon	Halogen	1	2	1,000	2,000
Balloon Light: Sirocco 200	Balloon	Halogen	1	1	200	200
110-volt Portable Floodlight[1]	Flood	Halogen	1	1	500	500

[1] Used only in combination with the other lights for testing flagger illumination, flagger uniformity, and glare.

Tungsten halogen lamps, commonly known as just halogen lamps, are available in almost every shape and size and produce a very attractive light which closely resembles sunlight. Halogen lamps are filled with halogen gas which reacts with the filament to produce a much brighter and more useful light source. Halogen lamps are also more efficient than incandescent lamps; they use less energy and last longer.

High-intensity discharge (H.I.D.) lamps are electric discharge sources which operate on a much higher arc pressure than fluorescent lamps. H.I.D. lamps produce full light output only at full operating pressure, generally several minutes after starting. Most H.I.D. lamps contain both an inner and outer bulb. The inner bulb is made of quartz or polycrystalline aluminum; the outer bulb is generally made of thermal-shock-resistant glass. Light output is practically unaffected by surrounding temperatures. H.I.D. lamps include those commonly known as mercury, metal halide, and high pressure sodium lamps. Mercury lamps are low in efficacy compared to other H.I.D. sources and, hence, are obsolete for most industrial lighting applications. Metal halide lamps are similar in construction to mercury lamps except that the arc tube contains various metal halides in addition to mercury. High-pressure sodium lamps produce light by electricity passing through sodium vapor.

Lamps differ with respect to the color of the light which they emit and the time they take to warm up. Tungsten halogen lights produce natural daylight white and are instant on. High pressure sodium lights are a soft orange and produce less glare. Metal halide lights are a bright white.

4.2.3 Light equipment arrangement (height, aiming angle, rotation) and location

When setting up a light system for a flagging operation, consideration is also given to the equipment location and arrangement. An appropriate location for the light must be selected to ensure that the flagger is illuminated without creating disabling glare for the motorist or for the flagger. In addition, the light equipment must be located beside the roadway where it is safe from traffic and can easily be placed, removed, and operated. If the unit is not self powered (i.e., does not have a generator attached) attention must be given to providing power to the light, whether from a portable generator or support vehicle. The generator or support vehicle must also be safely located nearby. The exact location of the light relative to the roadway will depend on the roadway dimensions and curvature, shoulder width and surface, and the terrain and foliage adjacent the roadway.

During the demonstration of light equipment currently used by ODOT Maintenance personnel, the personnel located the lights on the shoulder or just off the shoulder of the roadway. For the research, the light systems were located just off the shoulder of the roadway, approximately 13 feet from the flagger location.

Regardless of the light location, the luminaires are typically rotated to aim directly at the flagger. The physical location of the light will impact the angle at which the light shines relative to the roadway. The light could be located on or off the shoulder directly perpendicular to the roadway at the flagger location, or located up the roadway from the flagger. The angle of rotation, or offset angle, is the angle, measured in a horizontal plane, from a line perpendicular to the centerline of the roadway to the line of sight between the flagger and light. A light placed directly adjacent the flagger would have 0° offset angle. However, it is common to place the light up the roadway (towards oncoming traffic) at an approximately 15° to 30° offset in order to help illuminate the flagger for oncoming traffic. For offset angles greater than approximately 30°, the light shines too much into the eyes of the flagger and the motorists coming from the opposite direction.

The arrangement of the light at its location is also of concern. The light systems typically allow for varying both height and aiming angle of the luminaires. Height is the distance which the luminaires are elevated above the ground. From the literature search, responses to the survey of construction firms, and discussions with ODOT Maintenance personnel, the luminaires are elevated to as much as 20 to 30 feet so that they shine down on the flagger. This orientation helps minimize glare for the motorist and flagger, and spreads light around a large flagging area. The aiming angle of the luminaire is the angle of the light beam measured in a vertical plane. Since the luminaires are aimed directly at the flagger in the study, the aiming angle will vary with the height of the luminaire.

For this study, the direction of light was fixed on the flagger. By fixing the direction of light, the aiming angle is dependent on the light location and luminaire height. The light equipment was kept at a constant perpendicular distance from the roadway (approximately 13 feet) and moved up the roadway to different locations. The exact light location was set by the offset angle (i.e., the angle from a line perpendicular to the roadway to the line of sight between the light and flagger). Therefore, the two independent variables for the study were offset angle and luminaire height. Light equipment location and luminaire aiming angle were dependent variables.

The offset angles and luminaire heights evaluated in the study for each type of lighting equipment are shown in Table 4.4. For each offset angle, the light equipment was tested at each different height. The light tower, for example, was tested at heights of 15, 20, and 25 feet at 0° offset angle. The light tower was then tested at all three heights for both 15° and 30° offsets. The luminaire heights are limited to the capabilities of the light systems to elevate the luminaires. The balloon lights are designed such that they shine downward. Therefore, the balloon lights were only tested at 0° offset angle.

Table 4.4: Light equipment arrangements tested

Light Equipment	Offset Angle (°)	Luminaire Height
Light Tower	0°, 15°, and 30°	15 ft., 20 ft., and 25 ft.
12-volt Spotlight	0°, 15°, and 30°	6 ft. and 10 ft.
12-volt H.I.D. Floodlight	0°, 15°, and 30°	6 ft. and 10 ft.
Balloon Light: Sirocco 2000	0°	10 ft.
Balloon Light: Sirocco 200	0°	8 ft.

4.2.4 Operability and maintainability (ease of use)

Important to the use of lighting equipment is its operability and maintainability. Operability reflects how easy the equipment is to use for its intended function. The equipment should be relatively easy to use (i.e., turn on and off, adjust height and aiming angle, etc.), especially in inclement weather conditions and on rough terrain. Maintenance of the equipment is a concern as well. Maintainability relates to the ease with which the equipment can be maintained in working order. Replacement of the lamps (bulbs), cleaning, and repair and replacement of moving parts should all be considered.

4.2.5 Set-up, take down, and relocation (mobility)

Roadway maintenance and construction operations often require that the flagger station be relocated periodically. This requirement demands that the light equipment be easy to set-up, take down, and move. Factors that affect mobility are as follows: how complicated it is to set up and take down; how long it takes to set up and take down; the quality of its construction (i.e., whether it can withstand excessive movement and impact or is easy to break); and whether it needs to be towed or can just be hauled in the back of a truck.

4.3 OUTCOME MEASURES AND DATA COLLECTION

The outcome measures proposed following Tasks 1 and 2, and evaluated as part of the field laboratory testing, were: illumination, glare, uniformity, ease of use, mobility, and cost. Illumination and uniformity reflect the amount and consistency of the light over the work area, respectively. Because this study focuses not only on the light over the flagging area but to a great extent on the light on the flagger, for this research flagger illumination and flagger uniformity were added as outcome measures to be evaluated.

Urban and suburban settings can vary tremendously in the number, output, and type of background lights and their location relative to the flagging area. While each of the outcome measures described above could be evaluated at the selected urban/suburban field laboratory location, the results would not be transferable to other settings. Therefore, the outcome measures described above were not evaluated for each light system at the urban/suburban field laboratory location. It is critical in urban and suburban settings, however, that the illuminated flagger stands out in the driver's field of vision and does not "get lost" in the surrounding lights. The amount that the flagger stands out from the other lights greatly depends on the amount and type of light on the flagger relative to the surrounding lights. To assess how each light system performed in this respect, the visibility of the flagger from a long distance in an urban/suburban setting was included as an outcome measure and evaluated. Each outcome measure is described below along with the associated data collection efforts.

4.3.1 Work area illumination

The amount of light on a surface is measured in terms of illuminance. Illuminance is the amount of light falling on a surface and is usually measured in foot-candles (S.I. units) or lux (metric units). A foot-candle (Fc) is defined as the illuminance on a uniform surface 1 foot away from the light of one candle. One foot-candle equals 1 lumen/ft^2, and one lux is equal to 1 lumen/m^2. The illuminance of an object can be increased by increasing the intensity of the light source (i.e., increasing the number of lumens), increasing the number of sources, or by decreasing the distance between the source and the surface area. Light intensity is inversely proportional to the square of the distance from the light source. The horizontal illumination is the measurement with the photocell of the light meter parallel to the road surface.

With the light equipment turned on, illuminance was measured at each of the 119 grid points. The measurements were taken with a light meter held horizontally at the ground surface. The light meter readings were taken in foot-candles and directly recorded by a laptop computer for analysis. Readings were taken for eight different light equipment and lamp output configurations. For each configuration, the offset angle and luminaire height were varied, resulting in a total of 44 different test configurations. Table 4.5 lists each of the different configurations.

Table 4.5: Light equipment configurations tested

Light Equipment	Lamp Output (Watts)	Offset Angle (°)	Luminaire Height (Ft.)	# of Configurations Tested
Light Tower	2,000 and 4,000	0°, 15°, and 30°	15, 20, and 25	18
12-volt Spotlight	100 and 200	0°, 15°, and 30°	6 and 10	12
12-volt H.I.D. Floodlight	70 and 140	0°, 15°, and 30°	6 and 10	12
Balloon Light: Sirocco 2000	2,000	0°	10	1
Balloon Light: Sirocco 200	200	0°	8	1

4.3.2 Flagger illumination

In addition to the level of illumination on the ground surface, illumination of the flagger was also assessed. Flagger illumination reflects how well the flagger can be seen from a long distance. As stated previously, the flagger must be visible from a distance of 1,000 feet away. The ability to see a flagger depends not only on the light system, but also on the type of equipment and clothing worn by the flagger, which may vary. Therefore, the performance of the light systems relative to this outcome measure is dependent on other factors not assessed as part of this research study.

In this study, subjective assessment of flagger illumination was made during the flagger visibility testing in the urban/suburban field laboratory setting. A flagger wearing a reflective vest and pants was viewed from a long distance for each configuration of light equipment tested. The vest worn by the flagger was a Class 2 safety vest according to the ANSI/ISEA 107-1999 standard, the minimum classification allowed by ODOT for flagging operations (*ODOT 2003*). Figure 4.11 shows the flagger wearing the reflective vest; Class 2 pants were also worn during testing. ANSI categorizes the visibility and performance of reflective garments into three classes, Class 1, 2, and 3, relating to the minimum amount, type, and color of background material and retroreflective material depending on the worker's environment (*ISEA 1999*). The three classes are as follows:

> **Class 1:** Intended for use in activities that permit the wearer's full and undivided attention to approaching traffic and where: there is ample separation of the worker from traffic; traffic is traveling no faster than 25 mph; and the background behind the worker is not complex. These garments need to be conspicuous, use retroreflective materials not less than 25mm in width, and contain at least 217 square inches of background material and 155 square inches of retroreflective material.
>
> **Class 2:** This class of clothing is required when the work environment involves poor weather or visibility, distracting surroundings, a close proximity to moving traffic, or adjacent traffic moving at greater than 25 mph. The minimum width of the retroreflective material used on the garments cannot be less than 35mm. The garments must contain at least 775 square inches of background material and 201 square inches of retroreflective material.
>
> **Class 3:** This class provides the highest level of visibility. Class 3 garments are intended for workers who face serious hazards and high risk loads that require attention away from their work, and who are in environments with a close proximity to traffic moving faster than 50 mph. The width of the retroreflective material used on the garments must be at least 50mm. The garments must contain at least 1,240 square inches of background material and 310 square inches of retroreflective material.

Figure 4.11: Safety vest worn by flagger during testing

4.3.3 Glare

Glare is the "sensation produced by luminance within the visual field that is sufficiently greater than that to which the eyes are adapted" (*IESNA 1991*). Two types of glare are described: discomfort and disabling (*Bryden and Mace 2002*). Discomfort glare is measured subjectively and has no direct effect on the driver's vision. Discomfort glare does not affect a person's ability to see. Disabling glare reduces the contrast, and therefore the visibility of the object and visual performance. Disabling glare is measured in terms of veiling luminance, using units of candela per square meter (cd/m^2) or candelas per square foot (cd/ft^2). Veiling luminance is caused by the scattering of stray light within the eye originating from bright light sources, luminaires, or areas in the visual field (IESNA, 1991).

4.3.3.1 Motorist glare

For this study, discomfort glare was evaluated with a panel of three observers composed of ODOT personnel and flagging company employees. Standing at a distance of approximately 300 feet from the light location, the observers viewed each of the light equipment configurations (except the balloon lights). The observers were asked to rate the discomfort in looking at the lights using the following scale:

1 = No glare or very minimal glare
2 = Moderate amount of glare
3 = A lot of glare creating significant discomfort to the eyes

The observers' ratings were recorded and tabulated. Average observer ratings were calculated for each light configuration evaluated.

For disabling glare, the magnitude of the glare was calculated using the following formula (*IESNA 1991*):

$$L_v = 10\pi E/\theta^2 \qquad \textbf{(4-1)}$$

where:
- L_v = veiling luminance produced by a glare source in candelas (cd)
- E = illuminance in foot-candles on a plane through the center of the entrance pupil (perpendicular to the line of sight) contributed by the glare source.
- θ = the angular displacement in degrees between the line of sight and the glare source.

The illuminance values used in the formula (E), were measured with the light meter oriented vertically, perpendicular to the motorist's line of sight as if the motorist was looking down the roadway while driving. The meter was held at the height of the driver's eye, approximately 3.5 feet above the roadway. It was also held a distance of approximately 2 to 3 feet from the centerline of the roadway where the driver would normally be located in the vehicle.

Measurements were taken for both the northbound and southbound traffic at varying distances from the flagger. Starting at 1,000 feet away from the flagger (or at the point where the light meter registered some amount of light), illuminance measurements were taken at each of the 100-foot increments marked on the pavement moving in a direction closer to the flagger. At the grid, the measurements were taken at each of the grid lines (i.e., 50 feet from the flagger, 40 feet from the flagger, etc.) through the grid and then at 100-foot increments thereafter until no light was registered on the light meter. The light meter was held in the same position (vertically, aimed down the roadway, 3.5 feet above the ground, and 2 to 3 feet from the centerline) for all glare measurements.

Light meter readings were recorded and veiling luminance calculated using the formula above. The angular displacement (θ) used in the formula was calculated for each light meter reading based on the distance from the light, luminaire height, and offset angle.

4.3.3.2 Flagger glare

In addition to glare experienced by the motorist, flagger glare is also of concern. The location and arrangement of the light equipment may cause glare in the flagger's eyes which can limit their ability to see and direct oncoming traffic. For each light equipment configuration, the meter was placed vertically against the flagger's eye with the flagger standing at the flagger location and looking down the roadway toward oncoming traffic. Light meter readings were taken and flagger disabling glare was then calculated using the formula given above.

Flagger disabling glare was measured for each light equipment configuration alone and with the small, portable floodlight. The small floodlight was placed on the ground at a 45° offset angle up the roadway from the flagger (approximately 14 feet away from the flagger). The intent of the additional light was to assess a combination of lights, one shining down from above and the other shining up from the ground surface. It was felt that this might provide better lighting over the flagger's body without subjecting the driver to disabling glare. Light meter readings were taken at the flagger's eye with and without the small floodlight turned on.

The discomfort glare experienced by the flagger was subjectively evaluated in the study by an experienced flagger working for a flagging company. The flagger who participated in the visibility testing at the OSU football stadium parking lot was asked to describe the glare from the lights. This assessment was recorded and taken into consideration in the evaluation of each light equipment configuration.

4.3.4 Work area uniformity

The uniformity of the illuminance over the flagging area is another value that is commonly calculated to assess the quality of illumination. Uniformity is the ratio of the average illuminance to the minimum illuminance over the work area. It is important to provide consistent illumination over the flagging area to show the motorists the extent and nature of the flagging zone, and to illuminate the flagger if the flagger steps away from the edge of the lane. For illumination of the maintenance or construction work in progress, the uniformity ratio should not exceed 10:1, with 5:1 being more reasonable (*Bryden and Mace 2002*). For this study, the illuminance data collected at each grid point as described above was used to assess uniformity of the light over the flagging area.

4.3.5 Flagger uniformity

In addition to uniformly illuminating the flagging area, it is important that the flagger be illuminated consistently. Poor lighting may leave areas on the flagger that are not illuminated and therefore not visible to the motorist. It is essential that the flagger be fully illuminated so that the driver can easily see the flagger and recognize that they are a person. On the other hand, too much light on the paddle may wash out the wording.

To assess the consistency of light on the flagger, flagger uniformity was measured. This outcome measure is not addressed in the literature and was developed as part of this research study. For each light equipment configuration, light meter readings were taken at different points on the front and back of the flagger's body and paddle. As shown in Figure 4.12, readings were taken at the following locations: the flagger's head, left and right shoulder, left and right sides of the waist, left and right knee, and at the STOP/SLOW paddle. While the flagger stood facing the direction of the oncoming traffic, light meter readings were taken with the light meter held horizontally. Similar to the flagger glare measurements, flagger uniformity was also assessed with and without the small, portable floodlight turned on.

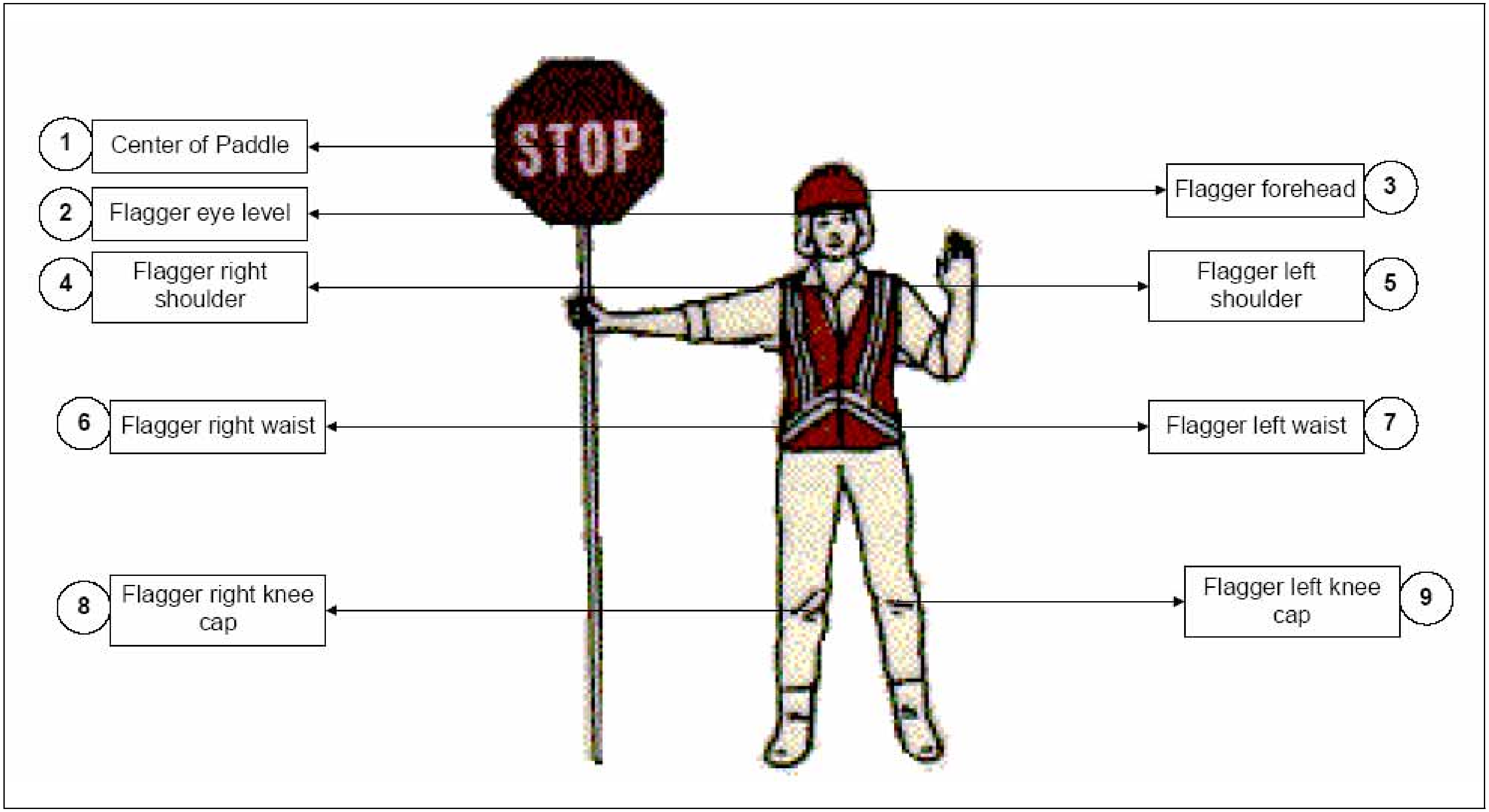

Figure 4.12: Flagger uniformity and glare measurement locations (front and back of flagger for uniformity measurements)

4.3.6 Urban/suburban visibility of flagger

As mentioned previously, it is important that in urban and suburban settings the illuminated flagger stands out in the motorist's field of vision and does not get lost in the surrounding lights. The visibility of the flagger in an urban/suburban setting was measured subjectively using a panel of five observers composed of ODOT personnel, flagging company employees, and one of the researchers. Standing at a distance of approximately 300 feet from the flagger, the observers viewed the flagger illuminated by each of the light equipment configurations. The 12-volt spotlight and 12-volt H.I.D. floodlight were evaluated both with and without the small, portable floodlight turned on. The portable floodlight was also evaluated on its own.

The observers were asked to rate the visibility of the flagger using the following scale:

1 = Flagger is clearly visible
2 = Flagger is visible, but some parts of the flagger are not visible
3 = Flagger is not clearly visible

The observers' ratings were recorded and tabulated. Average observer ratings were calculated for each light configuration evaluated.

4.3.7 Ease of Use

Ease of use was assessed qualitatively based on the ease with which the equipment can be operated and maintained. A subjective assessment of how easy it is to operate and maintain each type of equipment compared to the other types of equipment was made as the equipment was used during the course of the equipment testing. Features of the light system that made it easy or hard to operate or maintain were recorded.

4.3.8 Mobility

Mobility of the light systems was measured in two ways. First, the time it takes to set up and take down the equipment was measured. The researchers timed themselves while setting up and taking down the equipment. A normal, efficient pace was employed during the operations. The time to relocate the equipment was not measured. Relocation time will depend on the distance which the equipment is being moved and the means of transportation. The distance of travel can vary significantly with each flagging operation. Secondly, a subjective assessment was made by the researchers regarding the complexity of performing these operations for one type of equipment compared to another.

4.3.9 Cost

The cost of the lighting equipment was calculated. Included in the cost was any miscellaneous supplies and equipment needed for its use. For equipment that is readily available to rent, the cost of renting the equipment was also estimated. Estimated purchase and rental costs were based on information from local suppliers and rental businesses where appropriate.

4.3.10 Testing equipment

Several pieces of test equipment were used in the study to measure and record the results. The primary equipment used was a light meter. The light meter was used to measure the amount of light (illuminance) for all of the light equipment configurations and outcome measures. The light meter used in the study was an Extech Datalogging Light Meter, Model 401036.[6] The light meter can measure light intensity from 0.01 to 20,000 foot-candles or lux, and has four measurement ranges (20, 200, 2,000, and 20,000 Fc or Lux). Light readings are taken by a remote, high accuracy silicon photo-diode light sensor that has a basic accuracy of ±3%. Accompanying software allows for recording the light meter readings directly into a laptop computer.

The light meter was connected to a laptop computer to automatically record the data for analysis. To assist the researchers during the testing, the laptop was supported on a shoulder harness worn by the researchers. Assistance with the testing was also provided by a hand-made wooden support pole for the light meter. The pole supported the light meter at 3.5 feet above the ground for motorist glare measurements, and at the ground surface for grid illumination readings. The testing equipment is shown in Figure 4.13.

Figures 4.14, 4.15, and 4.16 show some of the testing taking place along with the light systems in operation.

[6] Extech Instruments Corporation, Waltham, MA

(a)

(b)

(c)

(d)

Figure 4.13: Test equipment: (a) laptop; (b) light meter; (c) light meter support pole; and (d) laptop shoulder harness

(a)

(b)

Figure 4.14: Illumination data collection: (a) roadway test grid (orange spots); (b) surface lighting data collection using light meter

Figure 4.15: Light tower at airport test site

Figure 4.16: Sirocco 2000 balloon lights at airport test site

4.4 LIGHT EQUIPMENT TESTING RESULTS

The data from each of the field laboratory tests of the different light equipment configurations were recorded for analysis. This section of the report provides the results of the tests. Given the large number of measurements taken for each of the 44 different light configurations tested, the amount of data collected is quite extensive. In this section of the report, only a summary of the results is provided, along with a representative sample of the results for individual light equipment configurations. The full set of data from the tests is provided in Appendix D.

4.4.1 Work area illumination

The illuminance measurements at each grid point were recorded and then plotted to create illuminance intensity graphs for each light equipment configuration. The intensity graphs show the illuminance levels graphically throughout the grid with different colors (or shades of gray for black and white printouts) representing different levels of illumination. For example, Figures 4.17, 4.18, and 4.19 show the light intensities for the light tower with 2,000 watts of output at a height of 15 feet for three different offsets – 0°, 15°, and 30°, respectively. The measured light intensities ranged from 0 Fc at a distance of 20-25 feet up to 159 Fc beneath the light tower at 15° offset.

In contrast to the light tower, the graphs for the 12-volt spotlight are much more concentrated and show much lower light intensities (see Figures 4.20, 4.21, and 4.22). These figures show the intensities for the spotlight with 100-watt output at a height of 6 feet for the 0°, 15°, and 30° offsets, respectively. The width of the illuminated area measures approximately 10 to 15 feet for the spotlight in these configurations as opposed to 35 to 45 feet for the light tower configurations shown in Figures 4.17, 4.18, and 4.19. In addition, the maximum measured light intensity for the spotlight in these configurations is only 11 Fc, compared to 159 Fc for the light tower configurations described above.

It is interesting to note that, because the spotlight is aimed at the chest of the flagger, the concentration of light as it falls on the ground surface with the flagger absent is not at the flagger location. The light from the spotlight is concentrated in the lane on the other side of the roadway. The light tower, however, provides a high concentration of light on the roadway surface both at the flagger location and over a wide section of the roadway from shoulder-to-shoulder.

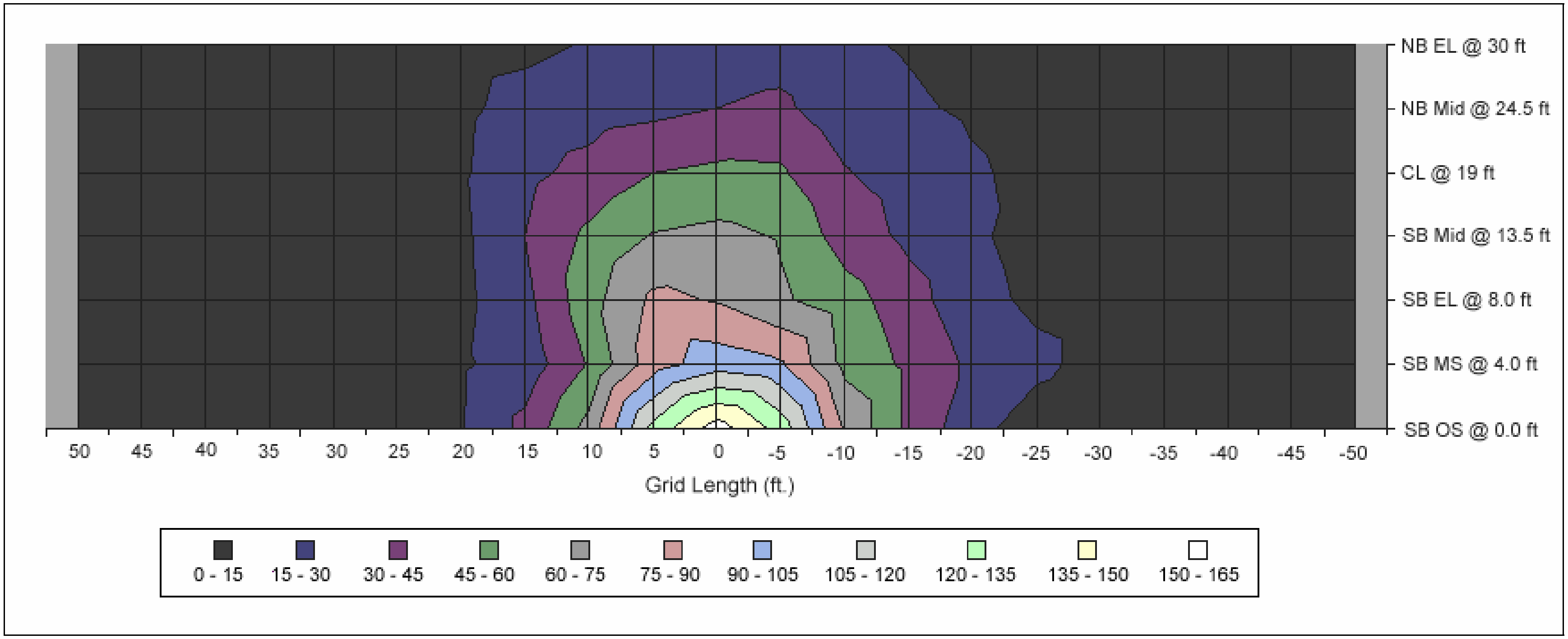

Figure 4.17: Surface lighting (Fc): light tower – 15 ft. high, 0° offset, 2,000 watts

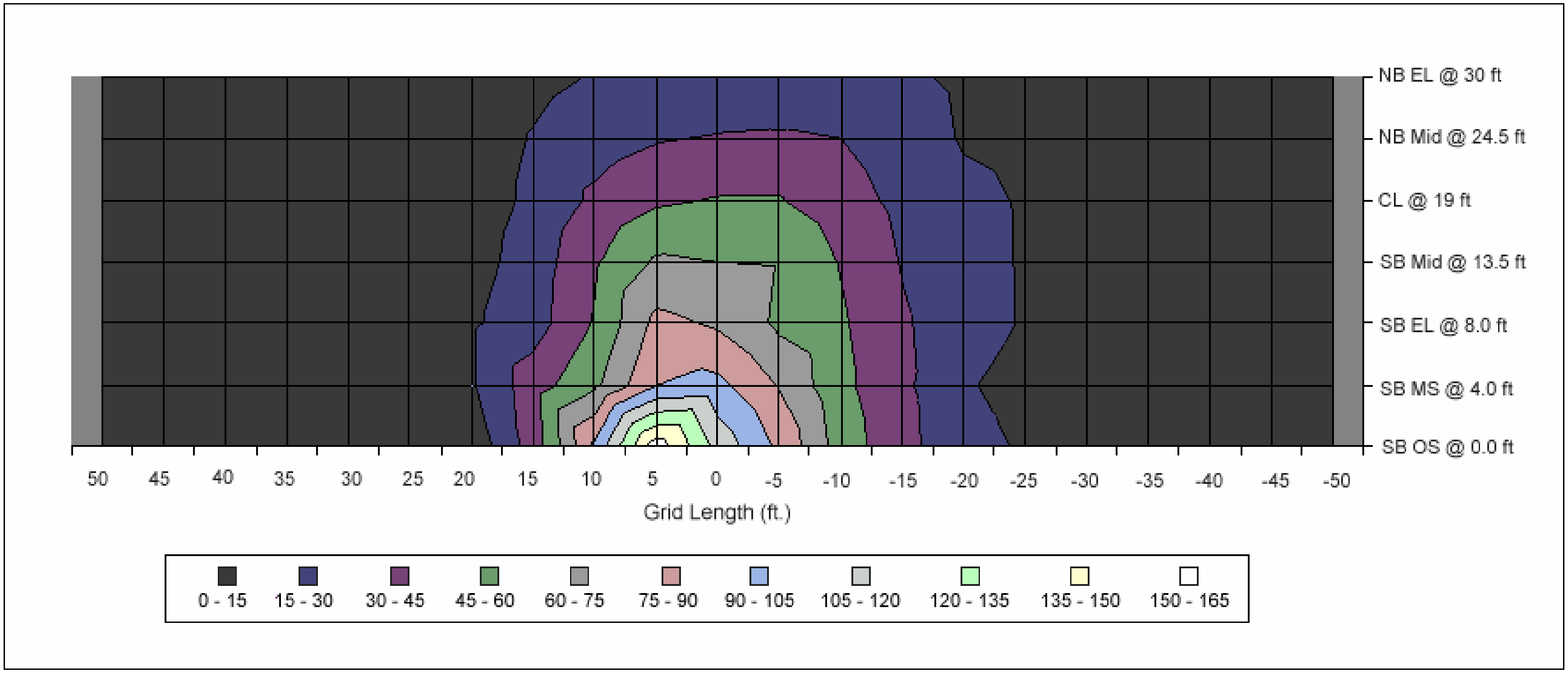

Figure 4.18: Surface lighting (Fc): light tower – 15 ft. high, 15° offset, 2,000 watts

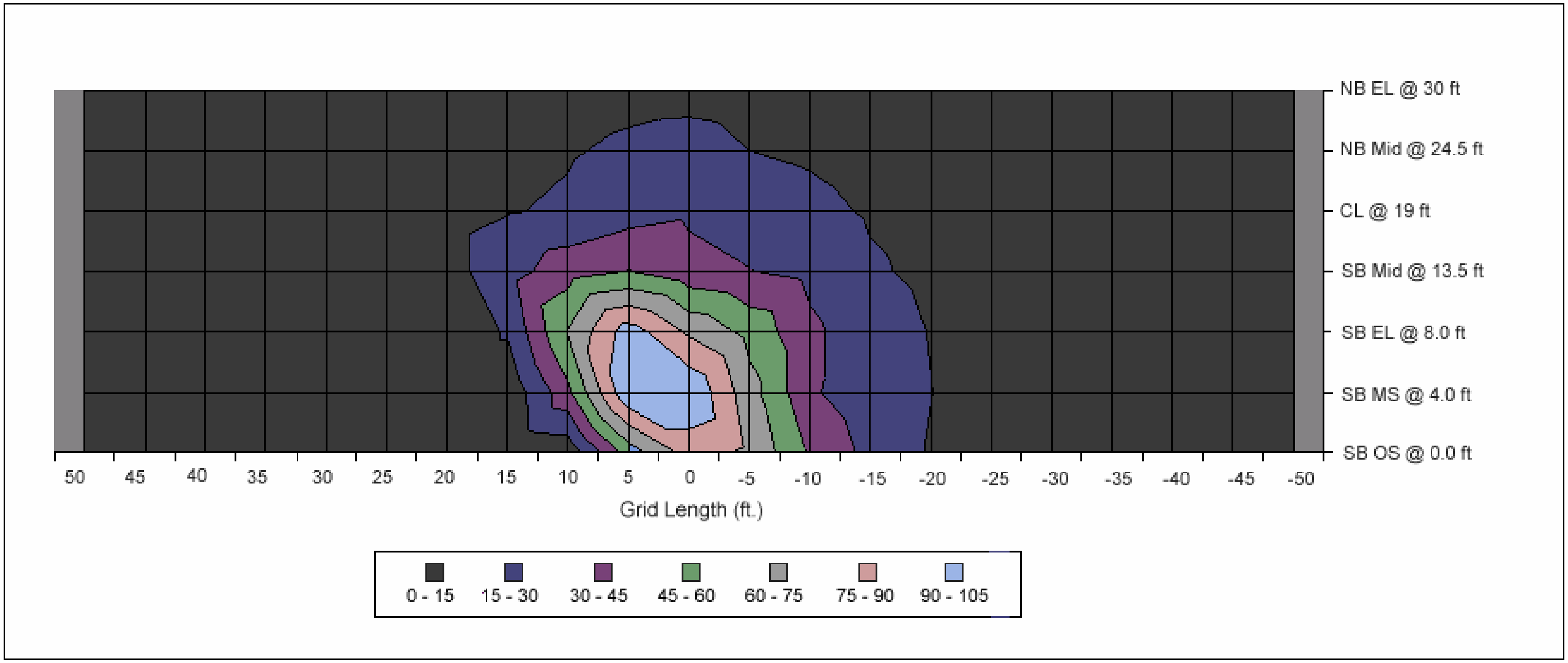

Figure 4.19: Surface lighting (Fc): light tower – 15 ft. high, 30° offset, 2,000 watts

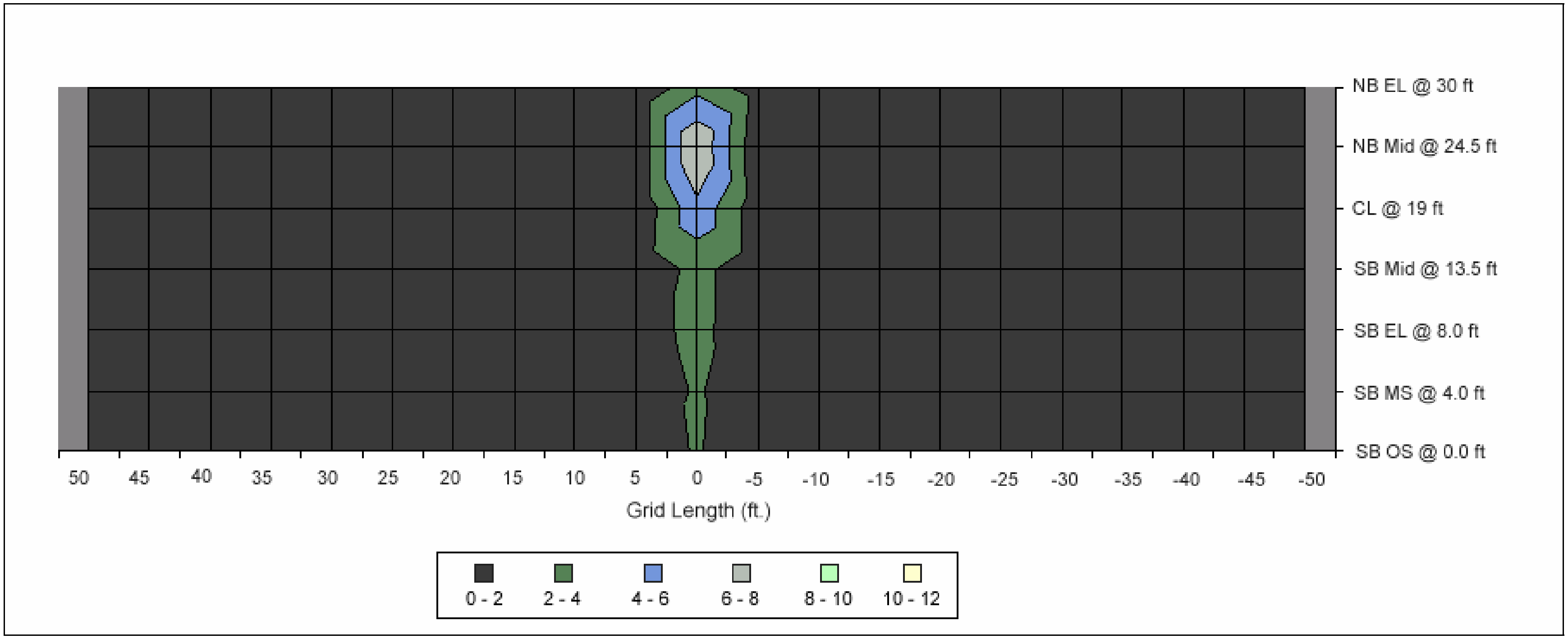

Figure 4.20: Surface lighting (Fc): 12-volt spotlight – 6 ft. high, 0° offset, 100 watts

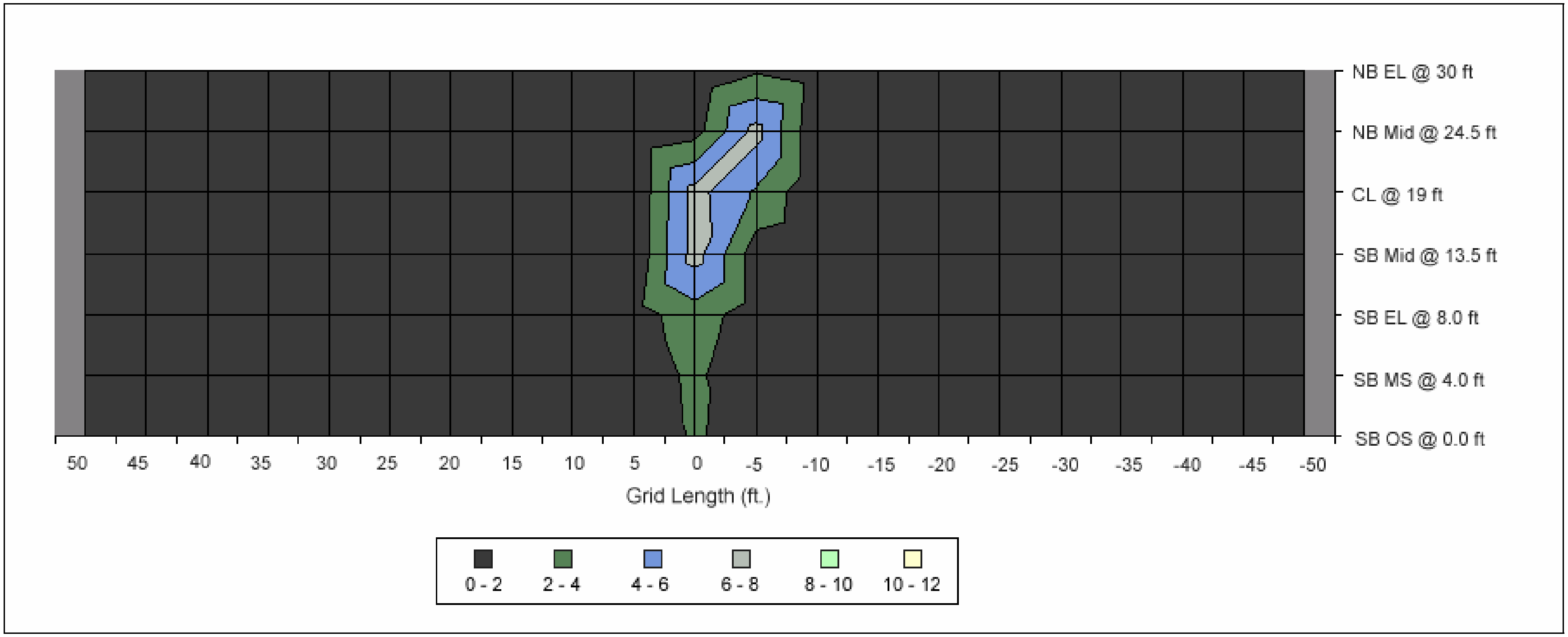

Figure 4.21: Surface lighting (Fc): 12-volt spotlight – 6 ft. high, 15° offset, 100 watts

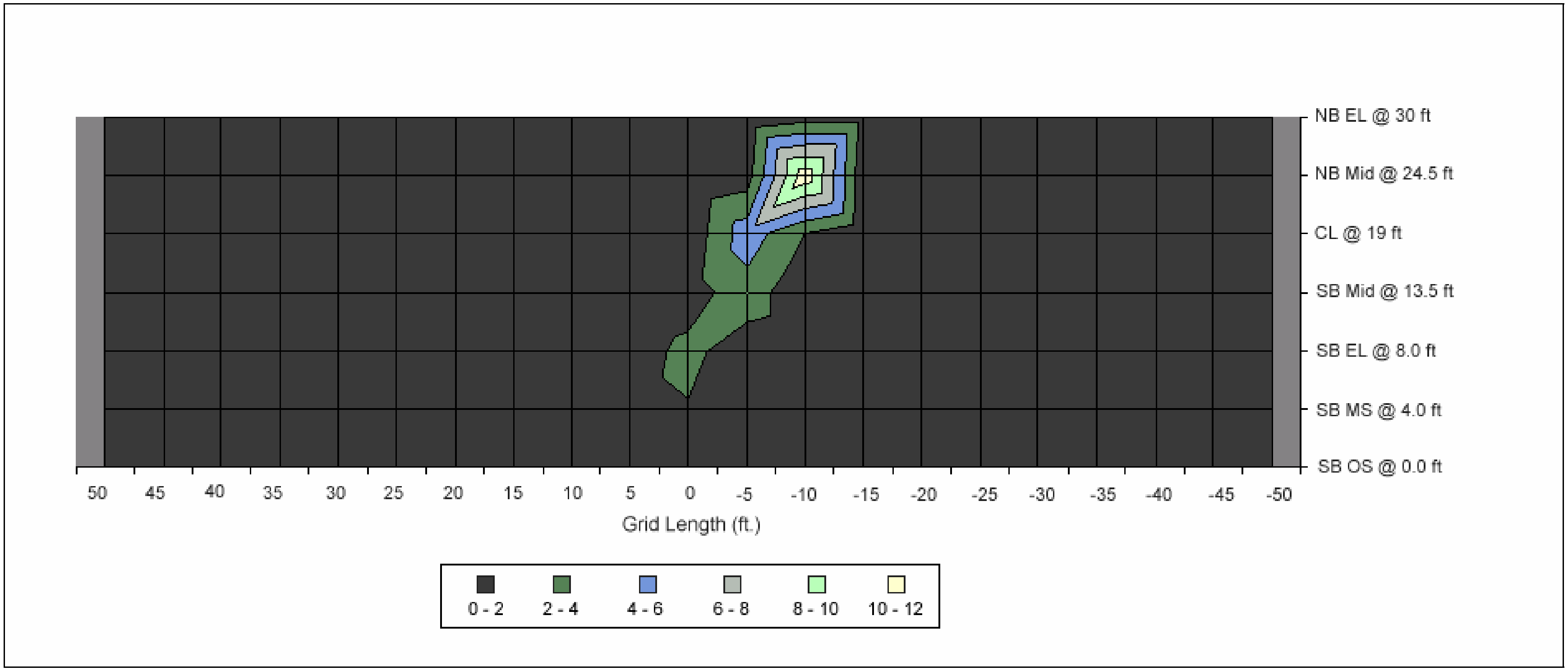

Figure 4.22: Surface lighting (Fc): 12-volt spotlight – 6 ft. high, 30° offset, 100 watts

Table 4.6 shows a summary of the results for each light equipment configuration tested. The table lists: the maximum illuminance over the grid; the illuminance at the flagger location; the average illuminance of all of the grid point measurements that are greater than or equal to 5.0 Fc; and the illuminance ratio. The lower illuminance limit of 5.0 Fc was selected because this is considered as the lowest value to safely illuminate the roadway surface for flagging operations. Five foot-candles is classified as Level I, the lowest illumination level and is recommended only for general illumination in the work zone and for areas where crew movement takes place (*Hanna 1996*). OR-OSHA standards for construction sites also specify 5.0 Fc for "General construction area lighting" and 3.0 Fc for "General construction areas, concrete placement, excavation and waste areas, accessways, active storage areas, loading platforms, refueling, and field maintenance areas" (*OR-OSHA 2002*). The OR-OSHA standards for construction do not specify worksite conditions or processes specific to the illumination of flaggers during nighttime operations.

The illuminance ratio, as defined for this research study, is the average illuminance of all grid point measurements that are greater than or equal to 5.0 Fc, divided by 5.0 Fc. This value indicates how many times greater the average illuminance is compared to the assumed minimum required illuminance of 5.0 Fc. A large illuminance ratio indicates illumination on the roadway surface that is much greater than the minimum required. The lowest illuminance value is 1.0, indicating that the average illuminance is equal to the minimum required illuminance. For light equipment configurations with an average illuminance less than 5.0 Fc, the illuminance ratio is shown as zero.

Table 4.6: Summary of illuminance measurements

No.	Light Equip.	Light Output (Watts)	Offset (°)	Height (ft)	Max. Illum. (Fc)	Illum. at Flagger Location (Fc)	Average Illuminance for Grid Points ≥ 5.0 Fc*	Illum. Ratio**
1	Light Tower	4,000	0	15	356	185	64	12.8
2				20	210	135	51	10.2
3				25	128	88	41	8.2
4			15	15	306	155	58	11.6
5				20	179	119	46	9.2
6				25	124	82	38	7.6
7			30	15	298	140	59	11.8
8				20	195	112	47	9.4
9				25	116	83	39	7.8
10		2,000	0	15	157	74	33	6.6
11				20	121	57	27	5.4
12				25	71	39	22	4.4
13			15	15	159	73	32	6.4
14				20	109	54	26	5.2
15				25	69	36	21	4.2
16			30	15	104	72	25	5.0
17				20	65	59	19	3.8
18				25	42	42	16	3.2
19	12-volt Spotlight	100	0	6	8	3	7	1.4
20				10	51	2	31	6.2
21			15	6	7	3	7	1.4
22				10	7	3	6	1.2
23			30	6	11	3	8	1.6
24				10	8	2	7	1.4
25		200	0	6	11	3	8	1.6
26				10	20	3	12	2.4
27			15	6	10	10	9	1.8
28				10	10	3	9	1.8
29			30	6	10	3	10	2.0
30				10	10	3	10	2.0
31	12-volt H.I.D. Floodlight	70	0	6	6	3	6	1.2
32				10	3	3	0	0.0
33			15	6	4	3	0	0.0
34				10	3	3	0	0.0
35			30	6	6	3	6	1.2
36				10	4	3	0	0.0
37		140	0	6	5	3	5	1.0
38				10	4	4	0	0.0
39			15	6	6	3	6	1.2
40				10	5	4	5	1.0
41			30	6	8	3	8	1.6
42				10	5	4	5	1.0
43	Sirocco 200	200	0	8	10	9	7	1.4
44	Sirocco 2000	2000	0	10	28	9	12	2.4

*The average illuminance of all grid point measurements that are ≥ 5.0 Fc. 5.0 Fc is the assumed minimum required illuminance on the roadway surface.

**(Average illuminance of all grid point measurements that are ≥ 5.0 Fc) / 5.0 Fc

4.4.2 Flagger illumination

For all of the light equipment configurations tested, the level of illumination was sufficient to make the flagger visible from a long distance. This was the case even without the benefit of vehicle headlights reflecting off of the flagger safety vest. At the airport test site, the researchers wearing Class 2 reflective vests (see Section 4.3.2 of this report for description of classifications), while performing the research were visible from a long distance when viewed in the direction of oncoming traffic. Similarly, at the OSU football stadium parking lot, all of the observers participating in the testing were able to see the flagger wearing a Class 2 reflective vest and pants. No specific quantitative measurements were taken for this outcome measure.

For 0° offset angles, the flagger is illuminated equally for motorists traveling in both directions. When the lights are set at 15° and 30° offset angles, however, illumination of the flagger for oncoming traffic was better than for traffic coming in the opposite direction. For example, when the flagger directs traffic driving in the southbound direction, a 15° offset of the equipment locates the light up the roadway slightly north of the flagger. The light then illuminates to a greater extent the north facing surface of the flagger, making the flagger more visible to the southbound driver. However, this offset angle decreases the amount of light falling on the south surface of the flagger, and thus decreases the visibility of the flagger for those drivers coming in the opposite (northbound) direction. The flagger is still visible to northbound drivers, but not to the extent that the flagger is visible to southbound drivers.

4.4.3 Motorist disabling glare

Glare measurements were taken from the perspective of motorists driving in both the northbound and southbound directions. At the location of each measurement, the angle between the driver's line of sight and the luminaire(s) was calculated. This angle was used to calculate the motorist glare, in terms of veiling luminance (cd), at each measurement location. The veiling luminance was then plotted versus measurement location on the roadway to indicate the amount of disabling glare experienced by the motorist while driving down the roadway.

For the 15° and 30° offset configurations, the lights were moved slightly up the roadway to the north of the flagger. Aiming the light back at the flagger directed more light in the southbound direction and into the eyes of the motorists approaching the flagger from the south (driving northbound). Thus, when the light equipment is offset at these angles, disabling glare typically increases for northbound drivers and decreases for southbound drivers.

For the 0° offset configurations, the light is shining perpendicular to the roadway. While in this case the amount of light shining in both directions is equal, the distance to the light source is different for the different driving directions. Northbound drivers are slightly farther away from the light source than southbound drivers because they are driving in different lanes. Therefore, for the same longitudinal distance from the light source, the angle between the driver's line of sight and the line to the light source is greater for northbound motorists than for southbound motorists. This difference results in less glare for northbound drivers than southbound drivers for 0° offset configurations.

Glare is also affected by the height of the luminaire(s). A greater luminaire height places the light out of the driver's direct line of sight to a greater extent. Therefore, light equipment configurations that are closer to the ground tend to cause more disabling glare for the motorist.

Figures 4.23 through 4.28 show the southbound and northbound glare plots for the light tower with 4,000-watt output elevated to 20 feet in height and situated at 0°, 15°, and 30° offsets, respectively. For comparison, the southbound direction plots for the 12-volt H.I.D. floodlight at 140-watts output and 0° offset for 6 and 10 foot heights are shown in Figures 4.29 and 4.30, respectively.

Table 4.7 shows a summary of the disabling glare results for each light equipment configuration tested. The table lists the maximum veiling luminance in candelas for each configuration when driving southbound and northbound. The Illuminating Engineering Society of North America (IESNA) recommends that veiling luminance be no greater than a third of the average pavement luminance (IESNA, 1993). Therefore, in well-lit areas where the level of pavement luminance is high, a higher level of glare becomes intolerable.

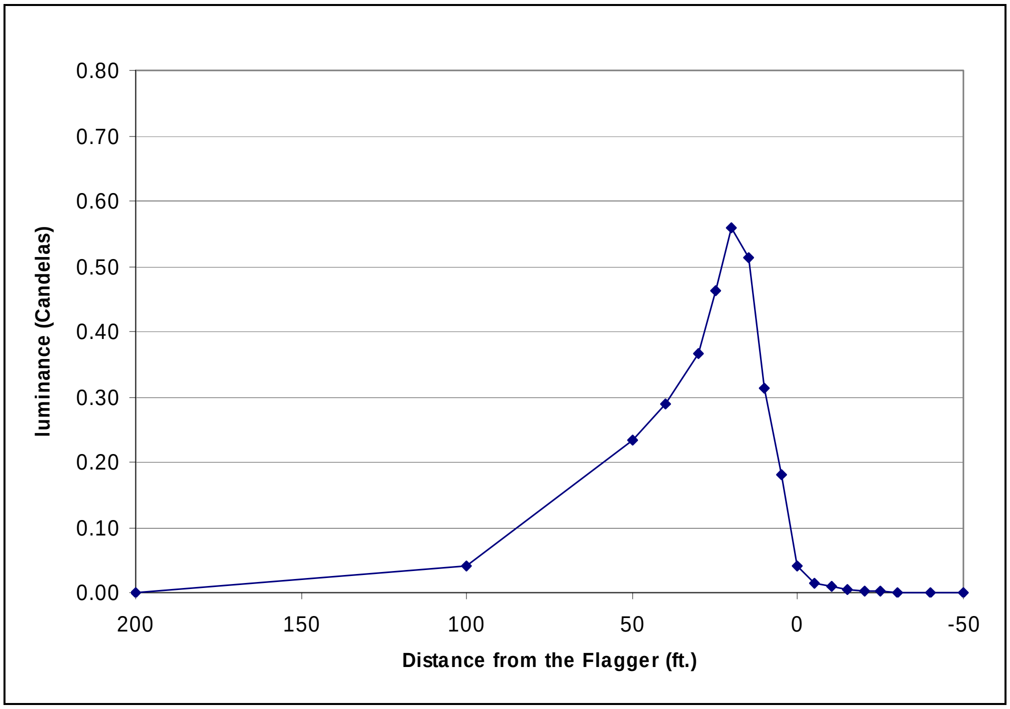

Figure 4.23: Disabling glare: light tower, 20 feet high, 0° offset, 4,000W, southbound

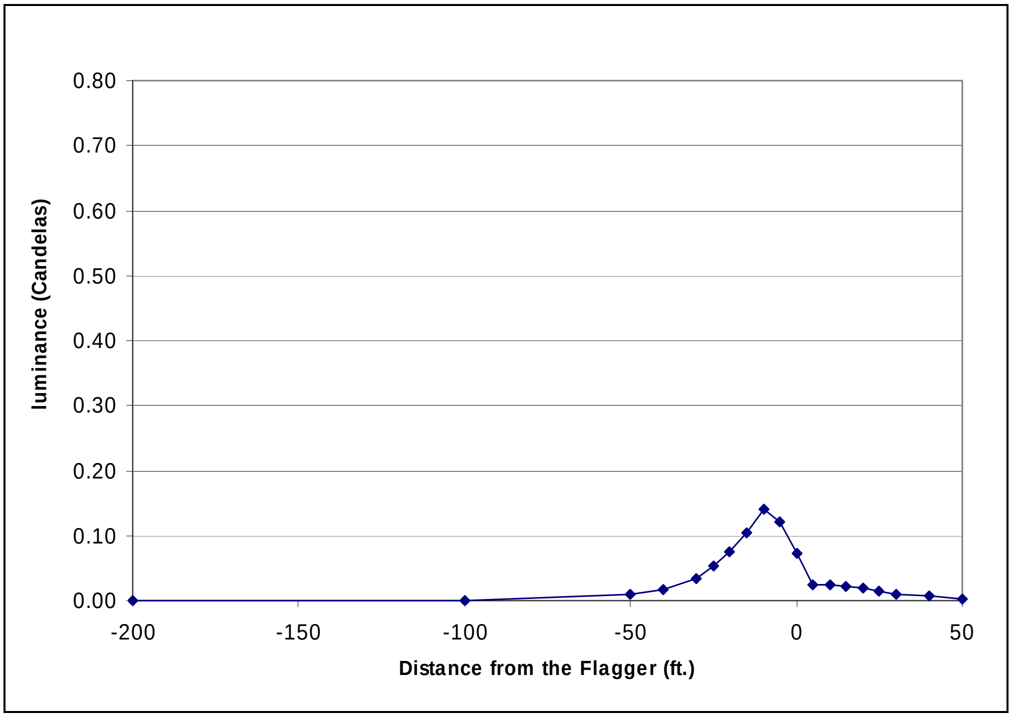

Figure 4.24: Disabling glare: light tower, 20 feet high, 0° offset, 4,000W, northbound

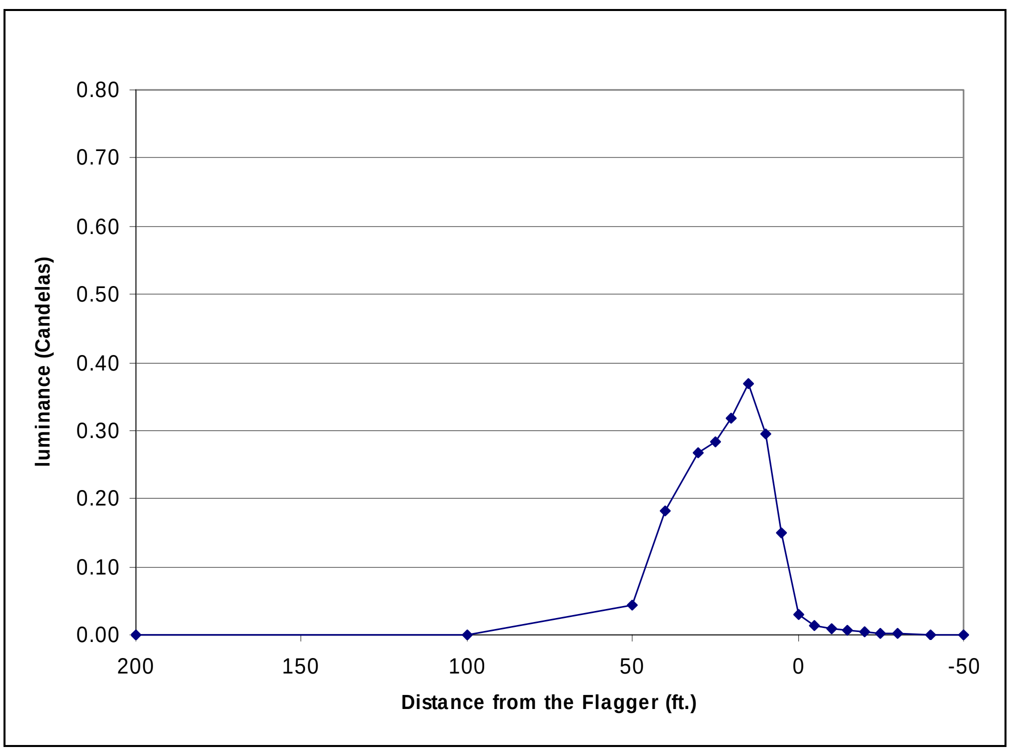

Figure 4.25: Disabling glare: light tower, 20 feet high, 15° offset, 4,000W, southbound

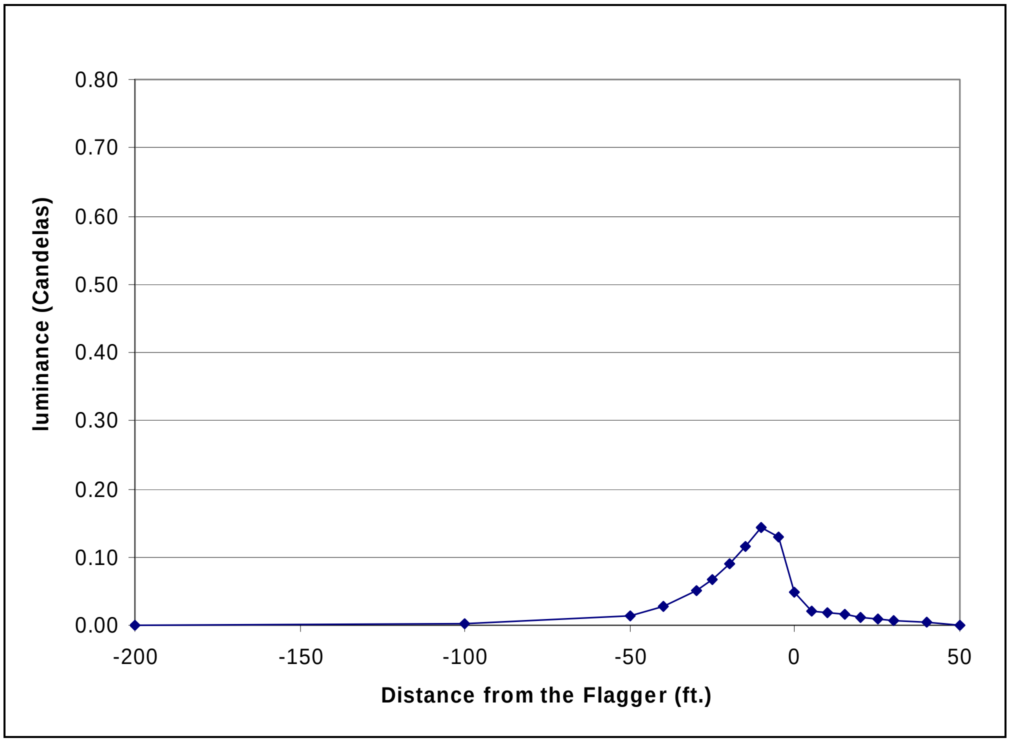

Figure 4.26: Disabling glare: light tower, 20 feet high, 15° offset, 4,000W, northbound

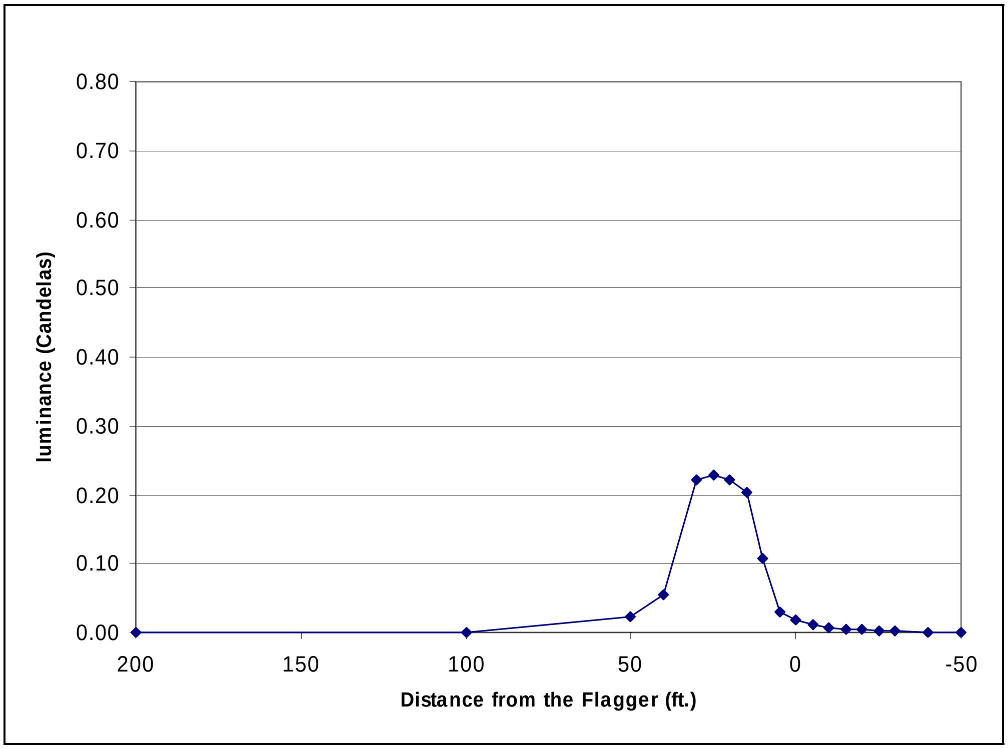

Figure 4.27: Disabling glare: light tower, 20 feet high, 30° offset, 4,000W, southbound

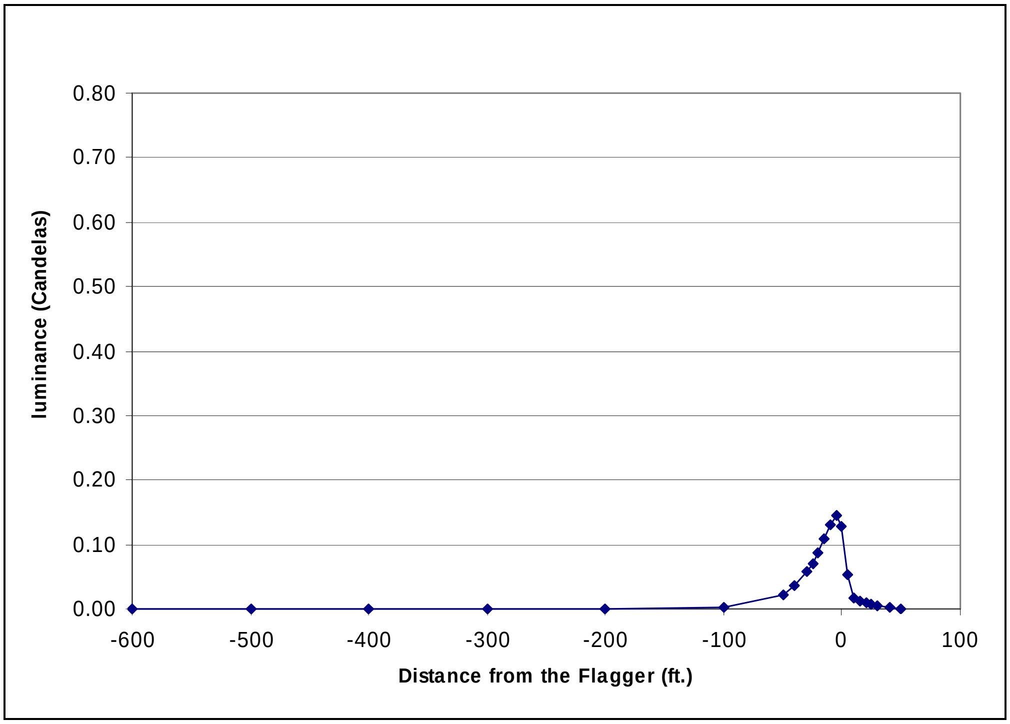

Figure 4.28: Disabling glare: light tower, 20 feet high, 30° offset, 4,000W, northbound

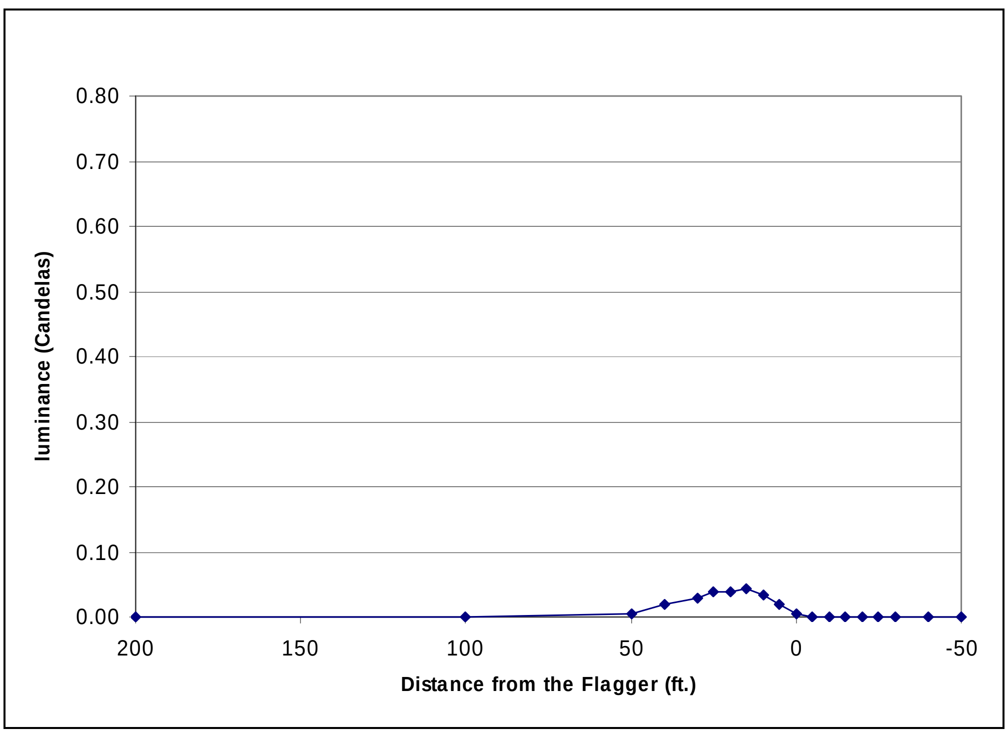

Figure 4.29: Disabling glare: 12-volt floodlight, 6 feet high, 0° offset, 140W, southbound

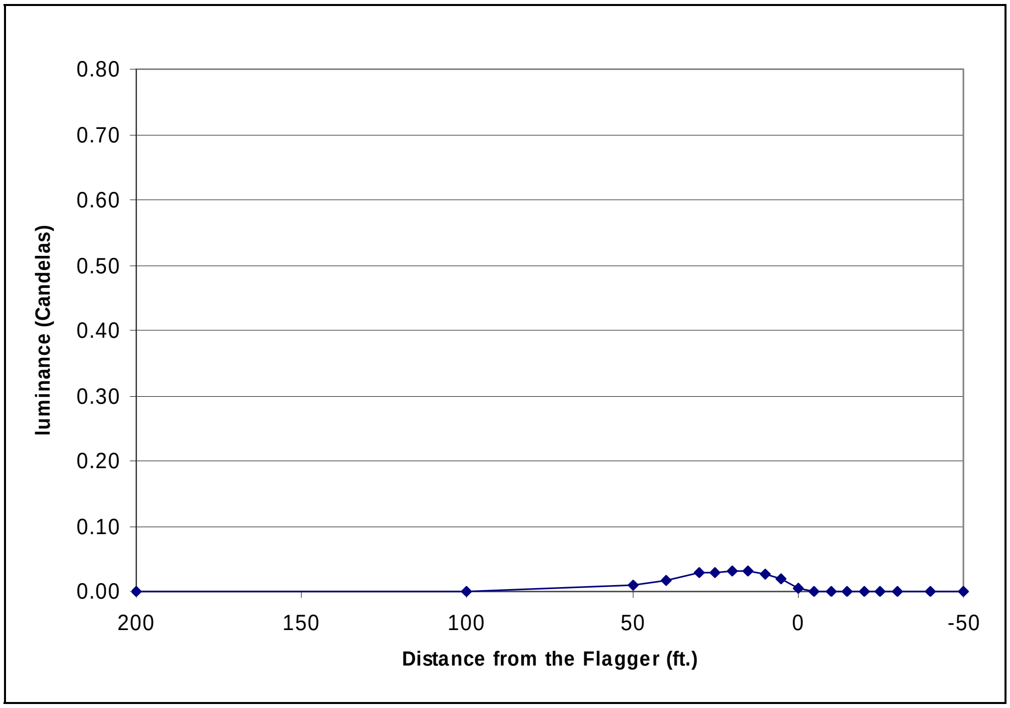

Figure 4.30: Disabling glare: 12-volt floodlight, 10 feet high, 0° offset, 140W, southbound

Table 4.7: Summary of motorist disabling glare measurements

No.	Light Equipment	Configuration			Maximum Veiling Luminance (Cd)	
		Light Output (Watts)	Offset (°)	Height (ft)	Driving Southbound	Driving Northbound
1	Light Tower	4,000	0	15	0.76	0.18
2				20	0.56	0.14
3				25	0.43	0.10
4			15	15	0.46	0.20
5				20	0.37	0.14
6				25	0.28	0.12
7			30	15	0.30	0.16
8				20	0.23	0.14
9				25	0.21	0.12
10		2,000	0	15	0.31	0.07
11				20	0.26	0.05
12				25	0.18	0.05
13			15	15	0.13	0.12
14				20	0.11	0.09
15				25	0.09	0.07
16			30	15	0.10	0.05
17				20	0.08	0.05
18				25	0.06	0.04
19	12-volt Spotlight	100	0	6	0.02	0.01
20				10	0.01	0.00
21			15	6	0.00	0.01
22				10	0.00	0.00
23			30	6	0.01	0.12
24				10	0.01	0.07
25		200	0	6	0.02	0.01
26				10	0.01	0.00
27			15	6	0.00	0.00
28				10	0.00	0.00
29			30	6	0.00	0.01
30				10	0.01	0.05
31	12-volt H.I.D. Floodlight	70	0	6	0.02	0.05
32				10	0.02	0.00
33			15	6	0.02	0.01
34				10	0.02	0.00
35			30	6	0.01	0.00
36				10	0.01	0.00
37		140	0	6	0.04	0.01
38				10	0.03	0.01
39			15	6	0.03	0.01
40				10	0.02	0.01
41			30	6	0.02	0.01
42				10	0.02	0.01
43	Sirocco 200	200	0	8	0.03	0.00
44	Sirocco 2000	2000	0	10	0.07	0.00

4.4.4 Motorist discomfort glare

Discomfort glare was assessed via subjective input from observers of the light equipment configurations at the airport test site. Each configuration was set up with the lights turned on. The observers, standing at a distance of approximately 300 feet from the flagger location, were asked to rate the discomfort of looking in the direction of the flagger. The results of the evaluations are provided in Table 4.8. For each light equipment configuration, the average observer rating was calculated.

While not included in the set of lights rated by the observers, the balloon lights did not produce any discomforting glare. This was evident during the illumination and motorist glare testing of the balloon lights. The balloon lights are designed with a special filter fabric to reduce glare. The lights were not discomforting in the immediate area throughout the grid and at a long distance up the roadway.

Table 4.8: Summary of motorist discomfort glare observer ratings

No.	Light Equipment	Configuration			Discomfort Glare Rating*			
		Light Output (Watts)	Offset (°)	Height (ft)	Observer 1	Observer 2	Observer 3	Avg.
1	Light Tower	4,000	0	15	1	1	1	1.0
2				20	1	1	1	1.0
3				25	1	1	1	1.0
4			15	15	2.5	2.5	3	2.7
5				20	2.5	2.5	2.5	2.5
6				25	1.5	2	2	1.8
7			30	15	3.5	3	5	3.8
8				20	3.5	3	3	3.2
9				25	3.5	3	3	3.2
10		2,000	0	15	2	1	2	1.7
11				20	1	1	1	1.0
12				25	1	1	1	1.0
13			15	15	3	2	3	2.7
14				20	2	1.5	2	1.8
15				25	1.5	1.5	1.5	1.5
16			30	15	3.5	3	5	3.8
17				20	3.5	3	3	3.2
18				25	3.5	3	3	3.2
19	12-volt Spotlight	100	0	6	0.5	1	1	0.8
20				10	0.5	1	1	0.8
21			15	6	0.5	1	1	0.8
22				10	0.5	1	1	0.8
23			30	6	1.5	1.5	2	1.7
24				10	2	1.5	2	1.8
25		200	0	6	0.5	1	1	0.8
26				10	0.5	1	1	0.8
27			15	6	0.5	1	1	0.8
28				10	0.5	1	1	0.8
29			30	6	1.5	1.5	2	1.7
30				10	1.5	1.5	2	1.7
31	12-volt H.I.D. Floodlight	70	0	6	0.5	1	1	0.8
32				10	0.5	1	1	0.8
33			15	6	1.5	1.5	1.5	1.5
34				10	1.5	1.5	2	1.7
35			30	6	2.5	2	2	2.2
36				10	2	2	2.5	2.2
37		140	0	6	0.5	1	1	0.8
38				10	0.5	1	1	0.8
39			15	6	2.5	1.5	1.5	1.8
40				10	2.5	2	1.5	2.0
41			30	6	3.5	2	3	2.8
42				10	3	2.5	2.5	2.7
43	Sirocco 200	200	0	8	N.A.	N.A.	N.A.	N.A.
44	Sirocco 2000	2000	0	10	N.A.	N.A.	N.A.	N.A.

* Please rate the light equipment for discomfort glare using the following scale:

1 = No glare or very minimal glare

2 = Moderate amount of glare

3 = A lot of glare creating significant discomfort to the eyes.

4.4.5 Flagger disabling glare

Light meter readings were taken at the flagger's eye with the flagger looking up the roadway at oncoming traffic. Using these measurements, flagger disabling glare was calculated in terms of veiling luminance in a manner similar to that done for motorist disabling glare. Table 4.9 shows a summary of the flagger disabling glare results.

For each light equipment configuration, the measurement was taken with only the light equipment turned on, and with both the light equipment and the small, portable floodlight turned on. The small, portable floodlight was located on the ground at a 45° offset angle from the flagger. The glare measurement was also taken with only the small, portable light turned on.

Table 4.9: Summary of flagger disabling glare measurements

No.	Light Equipment	Configuration			Veiling Luminance (Cd)	
		Light Output (Watts)	Offset (°)	Height (Ft)	Light Equipment Alone	Light Equipment Plus Small, Portable Floodlight
1	Light Tower	4,000	0	15	0.18	0.29
2	Light Tower	4,000	0	20	0.09	0.20
3	Light Tower	4,000	0	25	0.11	0.22
4	Light Tower	4,000	15	15	1.46	1.57
5	Light Tower	4,000	15	20	0.43	0.54
6	Light Tower	4,000	15	25	0.20	0.31
7	Light Tower	4,000	30	15	1.58	1.69
8	Light Tower	4,000	30	20	0.79	0.90
9	Light Tower	4,000	30	25	0.37	0.48
10	Light Tower	2,000	0	15	0.05	0.16
11	Light Tower	2,000	0	20	0.04	0.15
12	Light Tower	2,000	0	25	0.03	0.14
13	Light Tower	2,000	15	15	0.48	0.59
14	Light Tower	2,000	15	20	0.14	0.25
15	Light Tower	2,000	15	25	0.09	0.20
16	Light Tower	2,000	30	15	0.35	0.46
17	Light Tower	2,000	30	20	0.35	0.46
18	Light Tower	2,000	30	25	0.13	0.24
19	12-volt Spotlight	100	0	6	0.04	0.15
20	12-volt Spotlight	100	0	10	0.08	0.19
21	12-volt Spotlight	100	15	6	0.10	0.21
22	12-volt Spotlight	100	15	10	0.21	0.32
23	12-volt Spotlight	100	30	6	0.05	0.16
24	12-volt Spotlight	100	30	10	0.89	1.00
25	12-volt Spotlight	200	0	6	0.03	0.14
26	12-volt Spotlight	200	0	10	0.09	0.20
27	12-volt Spotlight	200	15	6	0.08	0.19
28	12-volt Spotlight	200	15	10	0.31	0.42
29	12-volt Spotlight	200	30	6	0.08	0.19
30	12-volt Spotlight	200	30	10	0.61	0.72
31	12-volt H.I.D. Floodlight	70	0	6	0.02	0.13
32	12-volt H.I.D. Floodlight	70	0	10	0.01	0.12
33	12-volt H.I.D. Floodlight	70	15	6	0.04	0.15
34	12-volt H.I.D. Floodlight	70	15	10	0.05	0.16
35	12-volt H.I.D. Floodlight	70	30	6	0.07	0.18
36	12-volt H.I.D. Floodlight	70	30	10	0.09	0.20
37	12-volt H.I.D. Floodlight	140	0	6	0.02	0.13
38	12-volt H.I.D. Floodlight	140	0	10	0.02	0.13
39	12-volt H.I.D. Floodlight	140	15	6	0.08	0.19
40	12-volt H.I.D. Floodlight	140	15	10	0.06	0.17
41	12-volt H.I.D. Floodlight	140	30	6	0.13	0.24
42	12-volt H.I.D. Floodlight	140	30	10	0.10	0.21
43	Sirocco 200	200	0	8	0.00	0.11
44	Sirocco 2000	2000	0	10	0.03	0.14
	Small, Portable Floodlight	500	45	0	0.11	N.A.

4.4.6 Flagger discomfort glare

Input on flagger discomfort glare was collected from the flagger participating in the testing at the OSU football stadium site. Out of all of the types of light systems tested at the football stadium site (which did not include the balloon lights), the flagger preferred the 12-volt H.I.D. floodlight. The light emitted is not as intense and the glare created was the least of all of the light systems he observed. For the other light systems, the flagger commented that when he looked at and then away from the light, his vision was temporarily blurry. This was especially true for the light tower at its lowest height (15 feet).

The glare produced by the small, portable floodlight was reported to be discomforting to the flagger as well. While this light does increase the illumination of the flagger, the light as located impacted the flagger's ability to clearly see oncoming traffic. The glare in the flagger's eye that is produced by the small, portable floodlight is 0.11 cd, a significant amount compared to the glare produced by some of the other light systems alone. It was felt that the small floodlight should not be used as tested. A smaller offset angle, a light filter, or a covering that limits the light to shine below the flagger's eye level would be needed if the small floodlight is used.

4.4.7 Work area uniformity

Uniformity is the ratio of the average illuminance over a work area to the minimum illuminance in the work area. As previously mentioned, for areas in which work will be conducted it is recommended that the uniformity ratio should not exceed 10:1, with 5:1 being more reasonable (*Bryden and Mace 2002*).

Illuminance measurements at each grid point were taken for each light equipment configuration as described previously in Section 4.4.1. Table 4.6 shows the maximum illuminance over the grid and the average illuminance for all grid points in which the measurements were greater than or equal to 5.0 Fc. In all of the 44 configurations tested, there were at least five points in the grid at which zero illuminance was measured. With a minimum illuminance of zero, it is not possible to calculate a meaningful uniformity ratio for the entire grid.

In addition to illuminating the flagger, the purpose of the lighting is to illuminate the flagging area surrounding the flagger. The flagger area should be sufficiently illuminated to give the oncoming driver an idea of the extent and conditions of the roadway in the flagger area and approaching work zone, and to illuminate the flagger as the flagger moves around the flagging area. Therefore, for this outcome measure, it was decided to focus specifically on the illuminated area immediately surrounding the flagger location rather than on the entire grid.

The area illuminated by each light equipment configuration varied in size and location. For some types of equipment, such as the light tower, the illuminated area was very extensive and approximately evenly distributed in all directions around the flagger. This was the case as well for the 12-volt H.I.D. floodlight and balloon lights, although the size of the area was much smaller for these lights than for the light tower. The 12-volt spotlight configurations concentrated the light in a much smaller area and across the roadway from the flagger.

Since the size and location of the illuminated area differs for each light equipment configuration, and because at the very edge of the lighted area the illuminance is essentially zero, use of the uniformity ratio as defined (average illuminance divided by minimum illuminance) does not provide valuable information for this situation. More meaningful data relative to this outcome measure would be the maximum and average illuminance values in the illuminated area, and the size of the area illuminated. Using this data, average illumination per square foot can be calculated by dividing the average illuminance by the size of the area illuminated in square feet. High illumination per square foot values would signify a large amount of light over a small area, such as that for a spotlight. Small illumination per square foot values would represent small amounts of light over larger areas, such as for a floodlight with low output lamps. All of these values – maximum illuminance, average illuminance, size of the area illuminated, and average illuminance per square foot – should be considered when evaluating the performance of a light equipment configuration relative to this outcome measure.

Another value that should be assessed in combination with those described in the preceding paragraph is the location of the illuminated area relative to the flagger location. The illuminated area should be centered on the flagger as much as possible to ensure a well lit area in all directions surrounding the flagger. It is important to illuminate the flagging area if the flagger steps away from the immediate flagger location. Using the illuminance plots, the distance from the centroid of the illuminated area to the flagger location can be calculated. A smaller distance represents an illuminated area that is more closely centered over the flagger location. In many configurations, the centroid of the illuminated area does not coincide with the location of the maximum illuminance level. Except for the spotlight configurations, the point of maximum illuminance is typically closer to the actual location of the light equipment than to the flagger. The centroid of the illuminated area, rather than the location of the maximum illuminance, is used in the distance calculation since the distance is intended to represent the spread of light over the roadway area relative to the flagger as opposed to the magnitude of the illumination.

Table 4.10 provides a summary of the work area uniformity measurements for each light equipment configuration. The table shows the average illuminance measured at all of the grid points with illuminance greater than or equal to 5.0 Fc, and the approximate size of the illuminated area for grid points with greater than or equal to 5.0 Fc. These values are used to calculate the average illuminance per square foot. Also shown in the table is the distance from the centroid of the lighted area to the flagger location for each configuration.

The average illuminance and size of illuminated area were greatest for the light tower configurations and significantly more than for the other light equipment. Because the area illuminated is very large, the average illuminance per square foot is small.

The 12-volt spotlight concentrates the light in a small area. While its average illuminance is not as great at the light tower, the average illuminance value divided by the small illuminated area results in a high average illuminance per square foot.

For some 12-volt H.I.D. floodlight configurations, the average illuminance and size of the illuminated area are zero because no illuminance values were recorded above 5.0 Fc, and thus do not meet the assumed minimum illuminance requirement of 5.0 Fc.

With regard to distance of the lighted area centroid to the flagger, the spotlight had the highest values, over 19 feet in one configuration. The large distances coupled with the small size of the illuminated area means that a flagger who walks away from the flagger location may not be illuminated.

Table 4.10: Summary of work area uniformity measurements

No.	Light Equip.	Light Output (Watts)	Offset (°)	Height (ft)	Average Illum. for Grid Points ≥ 5.0 Fc*	Approximate Illuminated Area for Grid Points ≥ 5.0 Fc (sq. ft.)	Average Illum. per sq. ft.**	Distance From Area Centroid to Flagger (ft.)
1	Light Tower	4,000	0	15	64	1,950	0.03	5.5
2				20	51	2,400	0.02	5.5
3				25	41	2,550	0.02	5.5
4			15	15	58	1,950	0.03	5.5
5				20	46	2,250	0.02	5.5
6				25	38	2,550	0.01	5.5
7			30	15	59	1,950	0.03	5.5
8				20	47	2,250	0.02	5.5
9				25	39	2,550	0.02	5.5
10		2,000	0	15	33	1,800	0.02	5.5
11				20	27	1,800	0.02	5.5
12				25	22	2,100	0.01	7.4
13			15	15	32	1,650	0.02	5.5
14				20	26	1,800	0.01	5.5
15				25	21	2,100	0.01	7.4
16			30	15	25	1,500	0.02	7.4
17				20	19	1,800	0.01	7.4
18				25	16	1,500	0.01	7.4
19	12-volt Spotlight	100	0	6	7	55	0.13	13.5
20				10	31	137.5	0.23	11.0
21			15	6	7	55	0.13	11.1
22				10	6	55	0.11	9.7
23			30	6	8	55	0.15	19.3
24				10	7	55	0.13	9.9
25		200	0	6	8	82.5	0.10	16.5
26				10	12	110	0.11	11.0
27			15	6	9	82.5	0.11	2.8
28				10	9	82.5	0.11	9.2
29			30	6	10	55	0.18	12.1
30				10	10	82.5	0.12	9.6
31	12-volt H.I.D. Floodlight	70	0	6	6	5	1.20	7.0
32				10	0	0	0.00	8.0
33			15	6	0	0	0.00	8.0
34				10	0	0	0.00	8.0
35			30	6	6	5	1.20	7.0
36				10	0	0	0.00	8.0
37		140	0	6	5	0	0.00	8.0
38				10	0	0	0.00	8.0
39			15	6	6	10	0.60	6.0
40				10	5	0	0.00	8.0
41			30	6	8	10	0.80	6.0
42				10	5	0	0.00	8.0
43	Sirocco 200	200	0	8	7	135	0.05	2.0
44	Sirocco 2000	2000	0	10	12	322.5	0.04	2.0

*The average illuminance of all grid point measurements that are ≥ 5.0 Fc. 5.0 Fc is the assumed minimum required illuminance on the roadway surface.

**(Average illuminance of all grid point measurements that are ≥ 5.0 Fc) / (Approximate illuminated area for grid points ≥ 5.0 Fc)

4.4.8 Flagger uniformity

Illuminance readings were taken at various points on the front and back of the flagger's body and paddle as previously shown in Figure 4.12. Using these measurements, a flagger uniformity ratio was calculated for both the front side of the flagger (facing oncoming traffic) and the back side of the flagger (away from oncoming traffic). The flagger uniformity ratio was calculated by dividing the average illuminance by the minimum illuminance.

A sample of the results is shown in Tables 4.11 through 4.13. These tables provide the illuminance levels measured for the 12-volt spotlight with 100-watt output at a height of 10 feet for 0°, 15°, and 30° offsets, respectively. Tables 4.14 through 4.16 provide the illuminance levels measured for the 12-volt H.I.D. floodlight with 70-watt output at a height of 10 feet for 0°, 15°, and 30° offsets, respectively. Values are given for the conditions both with and without the small, portable floodlight turned on.

For the 0° offset configuration, since the light is coming directly perpendicular to the roadway, the illuminance on the front side of the flagger is the same as that on the back side of the flagger. It should be noted that, for all light equipment configurations, when no illuminance was measured at a location on the flagger, a value of 0.1 Fc was recorded for that location. This was done in order to allow for calculating a uniformity ratio, which requires dividing by the minimum illuminance.

Table 4.17 shows a summary of the flagger uniformity ratios for all of the light equipment configurations. A lower uniformity ratio indicates better uniformity of the light on the flagger. The use of the small, portable floodlight typically decreased the flagger uniformity ratio, and use of this additional light would be recommended from the perspective of this outcome measure. The small, portable floodlight alone provides a uniformity ratio of 4.8.

Table 4.11: Flagger uniformity: 12-volt spotlight – 10 ft. high, 0° offset, 100 watts

No.	Location on Flagger or Paddle	Illuminance - Front Side of Flagger (Fc)		Illuminance - Back Side of Flagger (Fc)	
		With Small Light	Without Small Light	With Small Light	Without Small Light
1	Center of paddle	82.0	82.7	82.0	82.7
2	Forehead or back of head	44.0	46.3	44.0	46.3
3	Right shoulder	8.4	11.9	8.4	11.9
4	Left shoulder	6.3	7.6	6.3	7.6
5	Right waist	2.8	2.4	2.8	2.4
6	Left waist	4.0	3.8	4.0	3.8
7	Right knee	3.5	2.1	3.5	2.1
8	Left knee	3.7	2.4	3.7	2.4
	Average Illuminance	19.34	19.90	19.34	19.90
	Minimum Illuminance	2.8	2.1	2.8	2.1
	Uniformity ratio	6.91	9.48	6.91	9.48

Table 4.12: Flagger uniformity: 12-volt spotlight – 10 ft. high, 15° offset, 100 watts

No.	Location on Flagger or Paddle	Illuminance - Front Side of Flagger (Fc)		Illuminance - Back Side of Flagger (Fc)	
		With Small Light	Without Small Light	With Small Light	Without Small Light
1	Center of paddle	32.0	30.2	0.1	0.1
2	Forehead or back of head	31.0	29.7	39.5	36.3
3	Right shoulder	8.5	12.2	0.1	0.1
4	Left shoulder	6.6	6.5	7.3	9.7
5	Right waist	3.5	3.5	0.1	0.1
6	Left waist	4.5	3.3	3	3.4
7	Right knee	3.6	2.3	0.1	0.1
8	Left knee	4.1	2.3	2.1	2.2
	Average Illuminance	11.73	11.25	6.54	6.5
	Minimum Illuminance	3.5	2.3	0.1	0.1
	Uniformity ratio	3.35	4.89	65.38	65.00

Table 4.13: Flagger uniformity: 12-volt spotlight – 10 ft. high, 30° offset, 100 watts

No.	Location on Flagger or Paddle	Illuminance - Front Side of Flagger (Fc)		Illuminance - Back Side of Flagger (Fc)	
		With Small Light	Without Small Light	With Small Light	Without Small Light
1	Center of paddle	17.1	16.4	0.1	0.1
2	Forehead or back of head	28.0	27.4	80.0	83.2
3	Right shoulder	13.0	15.3	0.1	0.1
4	Left shoulder	18.9	16.4	32.5	22.7
5	Right waist	3.3	3.6	0.1	0.1
6	Left waist	4.8	4.2	8.9	4.5
7	Right knee	4.0	2.3	0.1	0.1
8	Left knee	5.3	2.6	1.2	0.2
	Average Illuminance	11.80	11.03	15.38	13.88
	Minimum Illuminance	3.3	2.3	0.1	0.1
	Uniformity ratio	3.58	4.79	153.75	138.75

Table 4.14: Flagger uniformity: 12-volt H.I.D. floodlight – 10 ft. high, 0° offset, 70 watts

No.	Location on Flagger or Paddle	Illuminance - Front Side of Flagger (Fc)		Illuminance - Back Side of Flagger (Fc)	
		With Small Light	Without Small Light	With Small Light	Without Small Light
1	Center of paddle	2.9	2.4	2.9	2.4
2	Forehead or back of head	6.8	8.0	6.8	8.0
3	Right shoulder	5.2	7.4	5.2	7.4
4	Left shoulder	5.6	6.3	5.6	6.3
5	Right waist	4.5	5.3	4.5	5.3
6	Left waist	5.3	5.7	5.3	5.7
7	Right knee	4.0	3.6	4.0	3.6
8	Left knee	4.4	4.3	4.4	4.3
	Average Illuminance	4.84	5.38	4.84	5.38
	Minimum Illuminance	2.9	2.4	2.9	2.4
	Uniformity ratio	1.67	2.24	1.67	2.24

Table 4.15: Flagger uniformity: 12-volt H.I.D. floodlight – 10 ft. high, 15° offset, 70 watts

No.	Location on Flagger or Paddle	Illuminance - Front Side of Flagger (Fc)		Illuminance - Back Side of Flagger (Fc)	
		With Small Light	Without Small Light	With Small Light	Without Small Light
1	Center of paddle	4.7	4.7	0.1	0.1
2	Forehead or back of head	6.0	5.5	8.3	9.0
3	Right shoulder	4.5	7.5	0.1	0.8
4	Left shoulder	4.2	8.6	5.6	7.9
5	Right waist	3.9	5.4	0.1	0.1
6	Left waist	6.0	6.9	4.3	6.4
7	Right knee	4.5	4.3	0.1	0.1
8	Left knee	4.9	4.8	2.5	4.2
	Average Illuminance	4.78	5.96	2.64	3.58
	Minimum Illuminance	3.9	4.3	0.1	0.1
	Uniformity ratio	1.22	1.39	26.38	35.75

Table 4.16: Flagger uniformity: 12-volt H.I.D. floodlight – 10 ft. high, 30° offset, 70 watts

No.	Location on Flagger or Paddle	Illuminance - Front Side of Flagger (Fc)		Illuminance - Back Side of Flagger (Fc)	
		With Small Light	Without Small Light	With Small Light	Without Small Light
1	Center of paddle	2.8	2.8	0.1	0.1
2	Forehead or back of head	4.0	4.0	8.0	8.1
3	Right shoulder	3.6	4.2	0.1	0.1
4	Left shoulder	3.8	4.0	2.7	6.2
5	Right waist	4.1	4.5	0.1	0.1
6	Left waist	5.2	6.9	3.5	5.0
7	Right knee	3.8	4.1	0.1	0.1
8	Left knee	4.9	4.6	2.1	3.3
	Average Illuminance	4.01	4.39	2.09	2.88
	Minimum Illuminance	2.8	2.8	0.1	0.1
	Uniformity ratio	1.43	1.57	20.88	28.75

Table 4.17: Summary of flagger uniformity ratios

No.	Light Equip.	Configuration			Flagger Uniformity Ratio				
					Front Side of Flagger		Back Side of Flagger		Average – Front And Back, Without Small Light
		Light Output (Watts)	Offset (°)	Height (Ft)	With Small Light	Without Small Light	With Small Light	Without Small Light	
1	Light Tower	4,000	0	15	1.4	1.4	1.4	1.4	1.4
2				20	1.6	1.8	1.6	1.8	1.6
3				25	2.1	2.1	2.1	2.1	2.1
4			15	15	1.1	1.1	8.7	9.1	5.1
5				20	1.3	1.4	12.0	12.4	6.9
6				25	1.4	1.4	5.2	4.5	3.0
7			30	15	1.2	1.2	931.5	936.6	468.9
8				20	1.2	1.1	697.8	699.0	350.1
9				25	1.2	1.2	527.8	521.5	261.4
10		2,000	0	15	1.4	1.4	1.4	1.4	1.4
11				20	1.1	1.2	1.1	1.2	1.2
12				25	1.7	2.2	1.7	2.2	2.2
13			15	15	1.2	1.2	6.0	6.4	3.8
14				20	1.1	1.2	5.8	6.3	3.8
15				25	1.4	1.5	6.9	6.8	4.2
16			30	15	1.2	1.2	580.3	582.8	292.0
17				20	1.2	1.2	295.4	294.1	147.7
18				25	1.1	1.1	229.3	223.0	112.1
19	12-volt Spotlight	100	0	6	78.5	167.3	78.5	167.3	167.3
20				10	6.9	9.5	6.9	9.5	9.5
21			15	6	54.2	139.4	54.4	54.0	96.7
22				10	3.4	4.9	65.4	65.0	35.0
23			30	6	84.5	71.5	193.6	22.5	47.0
24				10	3.6	4.8	153.8	138.8	143.6
25		200	0	6	75.6	76.8	75.6	76.8	76.8
26				10	6.2	7.5	6.2	7.5	7.5
27			15	6	89.8	178.3	66.9	63.6	121.0
28				10	5.0	6.5	135.6	137.4	72.0
29			30	6	133.4	104.0	15.0	8.8	56.4
30				10	3.9	3.9	49.4	52.6	56.5
31	12-volt H.I.D. Floodlight	70	0	6	13.2	29.3	13.2	29.3	29.3
32				10	1.7	2.2	1.7	2.2	2.2
33			15	6	12.8	33.4	25.4	21.6	27.5
34				10	1.2	1.4	26.4	35.8	18.6
35			30	6	17.4	28.5	15.8	16.5	22.5
36				10	1.4	1.6	20.9	28.8	15.2
37		140	0	6	16.7	34.6	16.7	34.6	34.6
38				10	1.2	1.7	1.2	1.7	1.7
39			15	6	65.0	38.5	29.0	22.6	30.6
40				10	1.4	1.5	31.4	49.1	25.3
41			30	6	17.4	11.6	19.8	15.9	13.8
42				10	1.8	2.0	25.8	39.4	20.7
43	Sirocco 200	200	0	8	58.5	207.6	58.5	207.6	207.6
44	Sirocco 2000	2000	0	10	3.7	8.1	3.7	8.1	8.1
	Portable Floodlight	500	45	0	4.8	N.A.	4.8	N.A.	N.A.

4.4.9 Urban/suburban visibility of flagger

The visibility of the flagger in an urban or suburban environment where artificial background lighting exists was assessed via subjective input from five observers of the light equipment configurations at the OSU football stadium parking lot test site. Each configuration was set up with the lights turned on and shining on a flagger holding a paddle. The flagger was wearing a Class 2 reflective vest and pants. The observers, standing at a long distance from the flagger, were asked to rate the visibility of the flagger. The results of the evaluations are provided in Table 4.18. For each light equipment configuration, the average rating was calculated.

Table 4.18: Summary of flagger visibility assessments by observers

No.	Light Equipment	Light Output (Watts)	Offset (°)	Height (ft)	Average Observer Rating*	Range of Observer Ratings
1	Light Tower	4,000	0	15	1.8	1.0 – 2.0
2				20	1.8	1.0 – 2.0
3				25	1.9	1.5 – 2.0
4			15	15	1.6	1.0 – 2.0
5				20	1.7	1.5 – 2.0
6				25	2.0	1.5 – 2.5
7			30	15	1.8	1.0 – 3.0
8				20	1.6	1.5 – 2.0
9				25	1.7	1.5 – 2.0
10		3,000	0	15	1.7	1.0 – 2.0
11				20	1.9	1.0 – 2.5
12				25	1.9	1.5 – 2.0
13			15	15	1.7	1.0 – 2.0
14				20	1.8	1.0 – 2.5
15				25	1.8	1.5 – 2.0
16			30	15	1.6	1.0 – 2.0
17				20	1.7	1.0 – 2.0
18				25	1.8	1.5 – 2.0
19		2,000	0	15	1.8	1.0 – 2.0
20				20	1.7	1.0 – 2.0
21				25	1.9	1.5 – 2.0
22			15	15	1.7	1.0 – 2.0
23				20	1.8	1.0 – 2.0
24				25	1.9	1.5 – 2.0
25			30	15	1.8	1.0 – 2.5
26				20	1.8	1.0 – 2.5
27				25	2.0	1.5 – 2.5
28		1,000	0	15	1.8	1.0 – 2.5
29				20	1.9	1.0 – 2.5
30				25	2.7	2.0 – 3.5
31			15	15	1.7	1.0 – 2.5
32				20	2.1	2.0 – 2.5
33				25	2.5	2.0 – 3.5
34			30	15	1.7	1.0 – 2.5
35				20	1.8	1.0 – 2.0
36				25	2.3	1.5 – 3.5
37	12-volt Spotlight plus small, portable floodlight	700	0	6	2.1	2.0 – 2.5
38				10	2.0	1.5 – 2.5
39			15	6	2.2	1.9 – 2.5
40				10	1.6	1.0 – 2.0
41			30	6	2.0	1.5 – 2.5
42				10	1.7	1.0 – 2.0
43		600	0	6	1.9	1.5 – 2.0
44				10	1.8	1.5 – 2.5
45			15	6	1.9	1.5 – 2.5
46				10	1.9	1.5 – 2.5
47			30	6	2.1	1.5 – 3.0
48				10	2.1	1.5 – 2.5

*Using the following scale, please rate the light equipment with respect to how visible it makes the flagger:
1 = Flagger is clearly visible; 2 = Flagger is visible, but some parts of flagger not visible; 3 = Flagger is not clearly visible

Table 4.18 (continued): Summary of flagger visibility assessments by observers

No.	Light Equipment	Light Output (Watts)	Offset (°)	Height (ft)	Average Observer Rating*	Range of Observer Ratings
49	12-volt Spotlight	200	0	6	2.9	2.5 – 3.0
50				10	2.6	1.5 – 3.0
51			15	6	2.9	2.7 – 3.0
52				10	2.8	2.0 – 3.5
53			30	6	2.9	2.6 – 3.0
54				10	2.4	2.0 – 3.3
55		100	0	6	3.0	3.0 – 3.0
56				10	2.9	2.5 – 3.0
57			15	6	3.0	2.8 – 3.0
58				10	2.9	2.5 – 3.3
59			30	6	3.0	2.8 – 3.3
60				10	2.7	2.5 – 3.3
61	12-volt H.I.D. Floodlight plus small, portable floodlight	640	0	6	1.5	1.0 – 2.0
62				10	1.4	1.0 – 2.0
63			15	6	1.1	1.0 – 1.3
64				10	1.3	1.0 – 1.5
65			30	6	1.1	1.0 – 1.3
66				10	1.4	1.0 – 3.0
67		570	0	6	1.7	1.0 – 2.0
68				10	1.5	1.0 – 2.0
69			15	6	1.6	1.0 – 2.0
70				10	1.6	1.0 – 2.0
71			30	6	1.7	1.3 – 2.5
72				10	1.8	1.0 – 2.5
73	12-volt H.I.D. Floodlight	140	0	6	2.6	2.0 – 3.5
74				10	2.5	2.0 – 3.5
75			15	6	2.2	1.5 – 3.5
76				10	2.4	1.5 – 3.5
77			30	6	1.9	1.5 – 2.0
78				10	1.8	1.5 – 2.0
79		70	0	6	2.6	2.0 – 3.5
80				10	2.7	2.0 – 3.5
81			15	6	2.0	1.5 – 2.5
82				10	2.4	2.0 – 3.5
83			30	6	1.9	1.5 – 2.0
84				10	2.2	1.5 – 3.5
85	Small, Portable Floodlight	500	45	0	1.7	1.5 – 2.0

*Using the following scale, please rate the light equipment with respect to how visible it makes the flagger:
1 = Flagger is clearly visible; 2 = Flagger is visible, but some parts of flagger not visible; 3 = Flagger is not clearly visible

4.4.10 Ease of use

Ease of use was assessed qualitatively based on the ease with which the equipment can be operated and maintained. A subjective assessment of each type of lighting equipment was made by the researchers during the course of the equipment testing. Described below are the assessments of each piece of equipment.

Light Tower: The light tower was the most difficult of all of the lights to use. This is due to the fact that it is not easily portable and requires two people to move the tower if not towed by a vehicle. Many steps are required to set it up before the equipment is ready to use and then there is a delay while the lights warm up. There are maintenance requirements associated with not only the lights, but also the generator.

12-volt Spotlight: The spotlight was very easy to use compared to the other equipment. It is easily portable and can be connected without difficulty to a vehicle battery for power. It is lighter than the light tower, balloon lights, and 12-volt H.I.D. floodlight. One disadvantage of this particular model is that the luminaire was difficult to rotate up or down because there was no adjusting knob. A wrench was needed to loosen a bolt in order to rotate the luminaire. Luminaires from other manufacturers may provide an adjusting knob to make it easier to rotate.

12-volt H.I.D. Floodlight: Similar to the spotlight, this light was also very easy to use. It is easy to turn on and off, and can be quickly connected to a truck battery. It is slightly heavier than the spotlight, but still lighter than the balloon lights and light tower. It is equipped with an adjusting knob to rotate the luminaire. One disadvantage of this light is that it takes a few minutes to power up to full brightness.

Sirocco 200 (backpack model): This light was fairly easy to use and operate. Because it sits on the flagger's back, it illuminates the flagger wherever the flagger goes. However, this light has several disadvantages. The battery pack is somewhat heavy and flaggers would quickly tire under its weight if not used to wearing it for long periods of time. The heavy backpack and light overhead also limit the flagger's mobility. The light was difficult to turn on and off without taking off the backpack. Battery power for this model limited the duration of use to approximately 20 minutes before the battery needed to be charged.

Sirocco 2000 (tripod model): This balloon light is easy for one person to set up and operate. It is lighter than the light tower but somewhat heavier than the spotlight and H.I.D. floodlight. Since it is not a 12-volt system, a generator is needed to provide power. Additional effort is needed to operate and maintain the generator. Similar to the backpack model, the balloon fabric and internal lamp fittings are delicate and susceptible to damage in rugged use. Lastly, during testing, the tripod was unable to support the balloon during strong gusts of wind, and in one instance the light toppled over.

Small, Portable Floodlight: This light is very ease to use and maintain. It is lightweight and made to withstand heavy use. A generator is needed for power, which requires additional effort to operate and maintain.

4.4.11 Mobility

Mobility of the light equipment is considered as the ease and speed with which the equipment can be set up, taken down, and moved to a new location. The time it takes to set up and take down the equipment was measured using a stopwatch. In addition, a subjective assessment was made regarding the complexity of performing these operations and effort required to move the equipment. The results are provided in Table 4.19.

Table 4.19: Summary of mobility measurements

Light Equipment	Set up		Take down	
	Description	**Time (sec. / min.)**	**Description**	**Time (sec. / min.)**
Light Tower	Unhook and level the tower	154 / 2.57	Turn off lights	5 / 0.08
	Aiming the lights	72 / 1.2	Lower mast	30 / 0.50
	Move mast to vertical	40 / 0.67	Make mast horizontal	33 / 0.55
	Extend mast fully	69 / 1.15	Bringing lights to normal position	60 / 1.0
	Turn lights on	128 / 2.13	Un-level and hook up	145 / 2.42
	Total	**463 / 7.72**	**Total**	**273 / 4.55**
12-volt Spotlight	Set tripod in position	25 / 0.42	Turn off light and generator, and unplug light	11 / 0.18
	Raise tripod to required height	13 / 0.22	Lower tripod	9 / 0.15
	Plug in, turn on generator and power up light	12 / 0.20	Take down tripod	13 / 0.22
	Total	**50 / 0.83**	**Total**	**33 / 0.55**
12-volt H.I.D. Floodlight	Set tripod in position	30 / 0.50	Turn off light and generator, and unplug light	11 / 0.18
	Aim the lights	10 / 0.17	Lower tripod	11 / 0.18
	Raise tripod to required height	15 / 0.25	Bring lights to normal position	8 / 0.13
	Plug in, turn on generator and power up lights	40 / 0.67	Take down tripod	20 / 0.33
	Total	**95 / 1.59**	**Total**	**50 / 0.83**
Sirocco 200 (backpack model)	Connect poles and place in backpack	102 / 1.70	Take off pack, turn off light, and unplug light from battery	34 / 0.57
	Plug light into battery, turn on light, put on backpack, and zip up pack.	54 / 0.90	Disconnect poles and place poles and light in case	81 / 1.35
	Total	**156 / 2.60**	**Total**	**115 / 1.92**
Sirocco 2000 (tripod model)	Set tripod in position and raise to required height	95 / 1.58	Lower and deflate balloon	43 / 0.72
	Plug in, inflate balloon, and turn on generator, and wait for lamp to light up	37 / 0.62	Unclamp and pack up balloon	80 / 1.33
			Take down tripod	29 / 0.48
	Total	**132 / 2.20**	**Total**	**152 / 2.53**
Small, Portable Floodlight	Set the light in position	15 / 0.25	Unplug and take back	10 / 0.17
	Plug in the light to the generator	8 / 0.13		
	Total	**23 / 0.38**	**Total**	**10 / 0.17**

4.4.12 Cost

Light equipment cost was calculated for both renting and purchasing the equipment. Table 4.20 shows the estimated costs of each piece of equipment. Purchase costs are based on average quotes from the manufacturers or suppliers of the equipment. Rental costs are based on the average cost to rent the equipment from local equipment rental businesses. Included are the cost of the lighting equipment itself and any miscellaneous supplies and support equipment needed for its use.

Table 4.20: Summary of light equipment costs

Light Equipment	Rent			Purchase
	Day	Week	Month	
Light Tower	$95	$280	$750	$8,700
12-volt Spotlight:				
Single luminaire with pole mount	-	-	-	$423
Single luminaire with tripod	-	-	-	$621
Dual luminaire with pole mount	-	-	-	$652
Dual luminaire with tripod	-	-	-	$849
12-volt H.I.D. Floodlight:				
Single luminaire with pole mount	-	-	-	$658
Single luminaire with tripod	-	-	-	$1,002
Dual luminaire with pole mount	-	-	-	$1,300
Dual luminaire with tripod	-	-	-	$1,644
Balloon Lights:				
Sirocco 200 (backpack model)	-	-	-	$990
Sirocco 2000 (tripod model)	-	-	-	$3800*
Small, Portable Floodlight	-	-	-	$15*
Portable Generator:				
3.5 – 3.7 kW	$35	$100	$410	$1,300
5.6 – 6.0 kW	$45	$140	$480	$1,625

*Generator required; cost not included.

4.5 DATA ANALYSIS

The purpose of the analysis for this phase of the research was to determine, based on the field laboratory testing, the light system(s) and configuration(s) that provide optimal illumination of flaggers during nighttime maintenance and construction operations. Optimal illumination is defined as: a high illuminance level, little or no glare, a low uniformity ratio, and high flagger visibility. Additionally, the light systems should be simple to operate and maintain, easy to relocate, acceptable to the experienced flagger, and require minimal cost. Design variable limits to sufficiently illuminate flaggers during nighttime operations were also determined. Limits are established for the minimum and maximum values for light output, offset angle, and luminaire height needed to make the flagger visible to oncoming motorists from a safe distance.

The field laboratory testing provided results for four different types of light systems: a light tower, 12-volt spotlight, 12-volt H.I.D. floodlight, and balloon lights. Using type of light system, light output, offset angle, and luminaire height as design variables, 44 different light equipment configurations were tested. For each light equipment configuration, measurements were taken to assess 12 outcome measures: illumination (work area and flagger), motorist glare (disabling and discomfort), flagger glare (disabling and discomfort), uniformity (work area and flagger), urban/suburban visibility of flagger, ease of use, mobility, and cost. In addition, a fifth type of light – a small, portable floodlight – was included in combination with each light system for assessing flagger illumination and uniformity.

Selection of the appropriate means to illuminate flaggers is based on the optimization of multiple outcome measures considered together. The dissimilar nature of the outcome measures, along with the large number of outcome measures included in the research, did not allow for directly combining the results associated with each outcome measure. The analytical procedure chosen for this phase of the study was to develop an aggregate rating of the light equipment configurations that could then be used to objectively rank and compare different configurations.

The first step in the analysis was to rate each light equipment configuration relative to each outcome measure. In this step, the rating was limited to optimization of only the outcome measure under consideration; all other outcome measures were temporarily disregarded. For each outcome measure, ratings were established based on careful review of the test data for all of the configurations and the recommended levels cited in the literature. For example, the following ratings were used to assess performance relative to motorist disabling glare:

1 = Maximum veiling luminance ≤ 0.05 candelas

2 = Maximum veiling luminance from 0.06 to 0.10 candelas

3 = Maximum veiling luminance from 0.11 to 0.20 candelas

4 = Maximum veiling luminance from 0.21 to 0.30 candelas

5 = Maximum veiling luminance > 0.30 candelas

Ratings equal to 1 represent the best performance relative to the outcome measure, while ratings equal to 5 indicate poor performance. A rating was given to each light equipment configuration based on the test results.

After rating a light equipment configuration for each outcome measure, the next step involved calculating an aggregate rating. An aggregate rating was calculated as the average of the ratings for each individual outcome measure. A lower aggregate rating indicates better overall performance in illuminating the flagger. This aggregate rating was then used to rank the light equipment configurations and determine the optimal light equipment configuration(s).

A description of the ratings relative to each outcome measure is provided below. Tables 4.21 and 4.22 show the ratings given to each light equipment configuration for each outcome measure and the aggregate rating calculated for each configuration based on the outcome measures combined. Also shown are the overall and individual rankings of each light equipment configuration that were used in determining the optimal configurations. Table 4.21 shows the aggregate ratings and overall and individual rankings considering all of the outcome measures. Table 4.22 shows the aggregate ratings and overall and individual rankings considering only the illumination, glare, uniformity, and visibility outcome measures (excluding ease of use, mobility, and cost).

Table 4.21: Light equipment ratings and rankings considering all outcome measures

No.	Light Equipment	Configuration			Outcome Measure							
		Light Output (watts)	Offset (°)	Height (ft)	Illumination		Motorist Disabling Glare		Motorist Discomfort Glare	Flagger Disabling Glare	Uniformity	
					Work Area	Flagger	North-bound	South-bound			Work Area	Flagger
1	Light Tower	4000	0	15	1	1	3	5	1.0	3	1	1
2				20	1	1	3	5	1.0	2	1	1
3				25	1	1	2	5	1.0	3	1	1
4			15	15	1	2	3	5	2.7	5	1	3
5				20	1	2	3	5	2.5	5	1	3
6				25	1	2	3	4	1.8	3	1	2
7			30	15	1	3	3	4	3.8	5	1	5
8				20	1	3	3	4	3.2	5	1	5
9				25	1	3	3	4	3.2	5	1	5
10		2000	0	15	1	1	2	5	1.7	1	1	1
11				20	1	1	1	4	1.0	1	1	1
12				25	1	1	1	3	1.0	1	1	1
13			15	15	1	2	3	3	2.7	5	1	2
14				20	1	2	2	3	1.8	3	1	2
15				25	1	2	2	2	1.5	2	1	2
16			30	15	1	3	1	2	3.8	5	1	5
17				20	1	3	1	2	3.2	5	1	5
18				25	1	3	1	2	3.2	3	1	5
19	12-volt Spotlight	100	0	6	4	1	1	1	0.8	1	5	5
20				10	1	1	1	1	0.8	2	3	3
21			15	6	4	2	1	1	0.8	2	5	5
22				10	4	2	1	1	0.8	4	5	5
23			30	6	3	3	3	1	1.7	1	5	5
24				10	4	3	2	1	1.8	5	5	5
25		200	0	6	3	1	1	1	0.8	1	4	5
26				10	2	1	1	1	0.8	2	4	3
27			15	6	4	2	1	1	0.8	2	4	5
28				10	4	2	1	1	0.8	5	4	5
29			30	6	4	3	1	1	1.7	2	5	5
30				10	4	3	1	1	1.7	5	4	5
31	12-volt H.I.D. Floodlight	70	0	6	4	1	1	1	0.8	1	5	5
32				10	5	1	1	1	0.8	1	5	1
33			15	6	5	2	1	1	1.5	1	5	5
34				10	5	2	1	1	1.7	1	5	4
35			30	6	4	3	1	1	2.2	2	5	5
36				10	5	3	1	1	2.2	2	5	4
37		140	0	6	5	1	1	1	0.8	1	5	5
38				10	5	1	1	1	0.8	1	5	1
39			15	6	4	2	1	1	1.8	2	5	5
40				10	5	2	1	1	2.0	2	5	5
41			30	6	4	3	1	1	2.8	3	5	4
42				10	5	3	1	1	2.7	2	5	5
43	Sirocco 200 (backpack model)	200	0	8	4	1	1	1	N.A.	1	2	5
44	Sirocco 2000 (tripod model)	2000	0	10	1	1	1	2	N.A.	3	1	3

Table 4.21 (continued)

No.	Outcome Measure				Aggregate Rating	Overall Rank	Individual Rank	Revised Spotlight Aggregate Ratings	Overall Ranking with Revised Spotlight Aggregate Ratings
	Urban/ Suburban Visibility of Flagger	Ease of Use	Mobility	Cost					
1	1.8	5	5	5	2.73	**30**	**8**		**30**
2	1.8	5	5	5	2.65	**24**	**5**		**24**
3	1.9	5	5	5	2.66	**25**	**6**		**25**
4	1.6	5	5	5	3.28	**41**	**15**		**41**
5	1.7	5	5	5	3.27	**40**	**14**		**40**
6	2.0	5	5	5	2.90	**34**	**9**		**34**
7	1.8	5	5	5	3.55	**44**	**18**		**44**
8	1.6	5	5	5	3.48	**42**	**16**		**42**
9	1.7	5	5	5	3.49	**43**	**17**		**43**
10	1.8	5	5	5	2.54	**17**	**4**		**17**
11	1.7	5	5	5	2.31	**8**	**2**		**8**
12	1.9	5	5	5	2.24	**6**	**1**		**6**
13	1.7	5	5	5	3.03	**37**	**11**		**37**
14	1.8	5	5	5	2.72	**29**	**7**		**29**
15	1.9	5	5	5	2.53	**16**	**3**		**16**
16	1.8	5	5	5	3.22	**39**	**13**		**39**
17	1.8	5	5	5	3.17	**38**	**12**		**38**
18	2.0	5	5	5	3.02	**36**	**10**		**36**
19	3.0	2	2	2	2.32	**9**	**4**		**9**
20	2.9	2	2	2	1.81	**1**	**1**	2.06	**1**
21	3.0	2	2	2	2.48	**14**	**6**		**14**
22	2.9	2	2	2	2.64	**22**	**9**		**22**
23	3.0	2	2	2	2.64	**22**	**9**		**22**
24	2.7	2	2	2	2.96	**35**	**12**		**35**
25	2.9	2	2	2	2.14	**5**	**3**		**5**
26	2.6	2	2	2	1.95	**2**	**2**	2.12	**3**
27	2.9	2	2	2	2.39	**11**	**5**		**11**
28	2.8	2	2	2	2.63	**20**	**7**		**20**
29	2.9	2	2	2	2.63	**20**	**7**		**20**
30	2.4	2	2	2	2.76	**32**	**11**		**32**
31	2.6	1	2	4	2.37	**10**	**3**		**10**
32	2.7	1	2	4	2.13	**4**	**2**		**4**
33	2.0	1	2	4	2.54	**17**	**6**		**17**
34	2.4	1	2	4	2.51	**15**	**5**		**15**
35	1.9	1	2	4	2.68	**26**	**8**		**26**
36	2.2	1	2	4	2.70	**27**	**9**		**27**
37	2.6	1	2	4	2.45	**13**	**4**		**13**
38	2.5	1	2	4	2.11	**3**	**1**		**2**
39	2.2	1	2	4	2.58	**19**	**7**		**19**
40	2.4	1	2	4	2.70	**27**	**9**		**27**
41	1.9	1	2	4	2.73	**30**	**11**		**30**
42	1.8	1	2	4	2.79	**33**	**12**		**33**
43	N.A.	4	3	2	2.40	**12**	**1**		**12**
44	N.A.	3	3	5	2.30	**7**	**1**		**7**

Table 4.22: Light equipment ratings and rankings considering only illumination, glare, uniformity, visibility

No.	Light Equipment	Configuration			Outcome Measure					
		Light Output (watts)	Offset (°)	Height (ft)	Illumination		Motorist Disabling Glare		Motorist Discomfort Glare	Flagger Disabling Glare
					Work Area	Flagger	North-bound	South-bound		
1	Light Tower	4000	0	15	1	1	3	5	1.0	3
2				20	1	1	3	5	1.0	2
3				25	1	1	2	5	1.0	3
4			15	15	1	2	3	5	2.7	5
5				20	1	2	3	5	2.5	5
6				25	1	2	3	4	1.8	3
7			30	15	1	3	3	4	3.8	5
8				20	1	3	3	4	3.2	5
9				25	1	3	3	4	3.2	5
10		2000	0	15	1	1	2	5	1.7	1
11				20	1	1	1	4	1.0	1
12				25	1	1	1	3	1.0	1
13			15	15	1	2	3	3	2.7	5
14				20	1	2	2	3	1.8	3
15				25	1	2	2	2	1.5	2
16			30	15	1	3	1	2	3.8	5
17				20	1	3	1	2	3.2	5
18				25	1	3	1	2	3.2	3
19	12-volt Spotlight	100	0	6	4	1	1	1	0.8	1
20				10	1	1	1	1	0.8	2
21			15	6	4	2	1	1	0.8	2
22				10	4	2	1	1	0.8	4
23			30	6	3	3	3	1	1.7	1
24				10	4	3	2	1	1.8	5
25		200	0	6	3	1	1	1	0.8	1
26				10	2	1	1	1	0.8	2
27			15	6	4	2	1	1	0.8	2
28				10	4	2	1	1	0.8	5
29			30	6	4	3	1	1	1.7	2
30				10	4	3	1	1	1.7	5
31	12-volt H.I.D. Floodlight	70	0	6	4	1	1	1	0.8	1
32				10	5	1	1	1	0.8	1
33			15	6	5	2	1	1	1.5	1
34				10	5	2	1	1	1.7	1
35			30	6	4	3	1	1	2.2	2
36				10	5	3	1	1	2.2	2
37		140	0	6	5	1	1	1	0.8	1
38				10	5	1	1	1	0.8	1
39			15	6	4	2	1	1	1.8	2
40				10	5	2	1	1	2.0	2
41			30	6	4	3	1	1	2.8	3
42				10	5	3	1	1	2.7	2
43	Sirocco 200 (backpack model)	200	0	8	4	1	1	1	N.A.	1
44	Sirocco 2000 (tripod model)	2000	0	10	1	1	1	2	N.A.	3

Table 4.22 (continued)

No.	Outcome Measure			Aggregate Rating	Overall Rank	Individual Rank	Revised Aggregate Ratings for Spotlight	Overall Ranking with Revised Aggregate Ratings for Spotlight
	Uniformity		Urban/Suburban Visibility of Flagger					
	Work Area	Flagger						
1	1	1	1.8	1.98	**11**	**8**		**9**
2	1	1	1.8	1.87	**7**	**5**		**6**
3	1	1	1.9	1.88	**8**	**6**		**7**
4	1	3	1.6	2.70	**30**	**15**		**30**
5	1	3	1.7	2.69	**29**	**14**		**29**
6	1	2	2.0	2.20	**16**	**9**		**16**
7	1	5	1.8	3.07	**43**	**18**		**43**
8	1	5	1.6	2.98	**40**	**16**		**40**
9	1	5	1.7	2.99	**41**	**17**		**41**
10	1	1	1.8	1.72	**5**	**4**		**5**
11	1	1	1.7	1.41	**2**	**2**		**2**
12	1	1	1.9	1.32	**1**	**1**		**1**
13	1	2	1.7	2.38	**18**	**11**		**18**
14	1	2	1.8	1.96	**10**	**7**		**8**
15	1	2	1.9	1.71	**3**	**3**		**3**
16	1	5	1.8	2.62	**26**	**13**		**26**
17	1	5	1.8	2.56	**23**	**12**		**23**
18	1	5	2.0	2.36	**17**	**10**		**17**
19	5	5	3.0	2.42	**20**	**4**		**20**
20	3	3	2.9	1.74	**6**	**1**	2.08	**12**
21	5	5	3.0	2.64	**27**	**6**		**27**
22	5	5	2.9	2.86	**36**	**9**		**36**
23	5	5	3.0	2.86	**36**	**9**		**36**
24	5	5	2.7	3.28	**44**	**12**		**44**
25	4	5	2.9	2.19	**15**	**3**		**15**
26	4	3	2.6	1.93	**9**	**2**	2.16	**14**
27	4	5	2.9	2.52	**22**	**5**		**22**
28	4	5	2.8	2.84	**34**	**7**		**34**
29	5	5	2.9	2.84	**34**	**7**		**34**
30	4	5	2.4	3.01	**42**	**11**		**42**
31	5	5	2.6	2.38	**18**	**3**		**18**
32	5	1	2.7	2.06	**13**	**2**		**11**
33	5	5	2.0	2.61	**25**	**6**		**25**
34	5	4	2.4	2.57	**24**	**5**		**24**
35	5	5	1.9	2.79	**31**	**8**		**31**
36	5	4	2.2	2.82	**32**	**9**		**32**
37	5	5	2.6	2.49	**21**	**4**		**21**
38	5	1	2.5	2.03	**12**	**1**		**10**
39	5	5	2.2	2.67	**28**	**7**		**28**
40	5	5	2.4	2.82	**32**	**9**		**32**
41	5	4	1.9	2.86	**36**	**11**		**36**
42	5	5	1.8	2.94	**39**	**12**		**39**
43	2	5	N.A.	2.14	**14**	**1**		**13**
44	1	3	N.A.	1.71	**3**	**1**		**3**

4.5.1 Work area illumination

The analysis of work area illumination focused on the amount of illuminance on the roadway surface. For this outcome measure, ratings were based on illuminance measurements over the work area only without regard to the illuminance level specifically at the flagger location. With the lights shining on the flagger's body, the amount of light on the ground surface beneath the flagger does not exactly represent the amount of light on the flagger. This is especially true for the spotlight which, without the flagger in place, created a concentration of light in the opposite lane across the roadway.

Each light equipment configuration was given a rating from 1 to 5 based on the maximum illuminance throughout the work area. The following ratings were used to assess performance relative to work area illumination:

1 = Maximum illuminance > 20 Fc
2 = Maximum illuminance from 16 to 20 Fc
3 = Maximum illuminance from 11 to 15 Fc
4 = Maximum illuminance from 6 to 10 Fc
5 = Maximum illuminance ≤ 5 Fc

These ratings reflect the illuminance levels suggested for nighttime highway work, as noted in the first interim report for this study, and the assumed minimum illuminance of 5.0 Fc required (*Hanna 1996*).

The ratings given to each light equipment configuration are shown in Table 4.21. All 18 light tower configurations received a rating of 1 for this outcome measure. The illuminance levels were very high for the light tower, providing much more than 20 Fc in most cases and more light than all of the other light systems at both the 2,000-watt and 4,000-watt light outputs. In many of the light tower configurations, the amount of light provided is much more than needed, which did not result in a corresponding increase in rating.

The other light systems provided light levels in the range more closely matching the recommended illuminance of 10 Fc for general construction (*IESNA 1991*). The 12-volt spotlight configurations showed much less illuminance on the work area than the light tower, and the spotlight configurations received ratings of typically 3 and 4. In a couple of instances, the center of the area illuminated by the spotlight was located directly on a grid point were a measurement was taken. For these configurations, the maximum illuminance level is very high, and given ratings of 1 and 2.

The 12-volt H.I.D. floodlight illuminance levels were slightly less than the spotlight, and the floodlight configurations were given ratings of 4 and 5. It should be noted, however, that many of the configurations with 70-watts output did not illuminate the roadway surface to the assumed minimum amount of 5.0 Fc. A lamp output greater than 70-watts would be required to sufficiently illuminate the work area using this type of light.

Lastly, the balloon lights did fairly well at illuminating the work area. The Sirocco 2000 tripod model received a rating of 1, while the Sirocco 200 backpack model does not put out as much light and received a rating of 4.

4.5.2 Flagger illumination

All of the light equipment configurations illuminated the flagger to an extent sufficient for oncoming motorists to see the flagger at a great distance. Therefore, all of the light equipment configurations met the required criteria for this outcome measure. To distinguish between the different configurations in terms of performance relative to this outcome measure, an assessment was made that considered illumination of both the front and back sides of the flagger. While illumination on the front side of the flagger for the traffic which the flagger is intending to control (the oncoming traffic) is of primary concern, the flagger must also be illuminated on the back side to be visible to motorists driving in the opposite direction.

The extent to which the flagger is illuminated on both sides is impacted by the offset angle. Therefore, for the analysis each light equipment configuration was rated based on the offset angle. The following ratings were used:

1 = 0° offset angle
2 = 15° offset angle
3 = 30° offset angle

Configurations with 0° offset angles illuminate the flagger equally on both sides and were given the highest rating of 1. Configurations with 15° and 30° offset angles do not illuminate the back side of the traffic as well for motorists driving in the opposite direction and, hence, were given ratings of 2 and 3, respectively. Table 4.21 shows the ratings given to each light equipment configuration for this outcome measure.

4.5.3 Motorist disabling glare

The analysis of motorist disabling glare was based on the maximum veiling luminance calculated along the roadway. No guidelines were found in the literature regarding suggested maximum veiling luminance levels for drivers during flagging operations. Therefore, ratings were based on a careful review of the range of veiling luminance measurements for all 44 configurations in comparison with the discomfort glare ratings given by the observers. The following ratings were used to assess performance relative to motorist disabling glare:

1 = Maximum veiling luminance ≤ 0.05 candelas
2 = Maximum veiling luminance from 0.06 to 0.10 candelas
3 = Maximum veiling luminance from 0.11 to 0.20 candelas
4 = Maximum veiling luminance from 0.21 to 0.30 candelas
5 = Maximum veiling luminance > 0.30 candelas

Ratings were given for both the northbound and southbound driving directions as shown in Table 4.21. The northbound driving direction received generally better ratings than the southbound direction.

The light tower with 4,000-watt output created the most glare of all of the different light systems. Only a small number of light tower configurations received ratings of 1, with the majority receiving ratings of 3, 4, and 5. In contrast, the glare from the other light systems was much less. The 12-volt spotlight, H.I.D. floodlight, and balloon lights were rated highly in terms of motorist disabling glare, with most receiving ratings of 1. For example, the maximum veiling luminance created by the 12-volt H.I.D. floodlight was 0.04 candelas for the southbound direction. Additionally, for the northbound direction, calculated veiling luminance for this type of light was practically zero.

4.5.4 Motorist discomfort glare

For this outcome measure, the analysis used the average of the ratings provided by the observers. The observers were asked to rate the light equipment for discomfort glare using the following scale:

1 = No glare or very minimal glare
2 = Moderate amount of glare
3 = A lot of glare creating significant discomfort to the eyes

The ratings given to each light equipment configuration are shown in Table 4.21. For all of the different light equipment, the average observer ratings tended to increase as the offset angle increased (a higher observer rating indicating more discomforting glare). In general, poor ratings were given for all light equipment configurations with 15° and 30° offsets. This difference in ratings was more pronounced for the light tower configurations than for the other equipment. Also, in most cases the average observer rating did not change, or slightly changed, as the light was raised to a higher elevation.

The observers generally preferred the 12-volt spotlight and 12-volt H.I.D. floodlight to the light tower. Overall, the light tower rated lower than the other lights at both the 2,000 and 4,000-watt output levels.

4.5.5 Flagger disabling glare

Flagger disabling glare was calculated by measuring the illuminance at the flagger's eye and calculating the associated veiling luminance. The light equipment configurations were rated according to the amount of veiling luminance calculated. No guidance is given in the literature on suggested maximum levels of flagger glare. While the results show that the range of veiling luminance values is greater for flagger glare than for motorist glare, the ratings should not be different. It is just as important that the flagger not be blinded by the glare as it is for the motorists. The flagger must be able to see the approaching traffic without difficulty in order to effectively control the traffic. Therefore, the ratings for this outcome measure are the same as those used for evaluating motorist disabling glare, which are as follows:

1 = Maximum veiling luminance ≤ 0.05 candelas
2 = Maximum veiling luminance from 0.06 to 0.10 candelas
3 = Maximum veiling luminance from 0.11 to 0.20 candelas
4 = Maximum veiling luminance from 0.21 to 0.30 candelas

5 = Maximum veiling luminance > 0.30 candelas

Maximum veiling luminance values for the light equipment alone without the small, portable floodlight were used for this analysis. This was done in order be consistent with the other outcome measures which do not reflect use of the small, portable floodlight. An evaluation of the use of the small, portable floodlight in combination with the light equipment is discussed later in this report.

The ratings given to each light equipment configuration are shown in Table 4.21. In general, better ratings are associated with configurations with 0° offset for all types of light equipment. For the light tower, the glare at the flagger's eye increases with increased offset angle and is at its maximum for 30° offset. The least glare of all of the light tower configurations is experienced when the tower luminaires are 25 feet high.

The light tower typically created more glare for the flagger than the other light systems, even at the taller luminaire heights. While the spotlight and floodlight were located closer to the flagger's eye, the light output was much less than that from the light tower, producing less glare.

The flagger glare created by the 12-volt spotlight is at its maximum when the spotlight is at 30° offset. However, unlike the light tower, the calculated glare is greater when the system is at the greater height. The conditions are similar for the 12-volt H.I.D. floodlight, which shows optimum conditions at 0° offset, 6-foot height, and either 70 or 140-watts. The glare produced at the flagger's eye is almost zero for both types of balloon lights.

4.5.6 Flagger discomfort glare

The data collected for this outcome measure consisted of qualitative comments provided by the flagger during testing at the OSU football stadium test site. Sufficient data was not available to quantitatively analyze the performance of the light equipment configurations relative to flagger discomfort glare. The qualitative data collected centered around the discomfort associated with using the small, portable floodlight in combination with the other lights. With respect to the light equipment alone without the small, portable floodlight, the available data was minimal, consisting of general comments from the flagger participating in the study. Therefore, for flagger glare the quantitative analysis did not incorporate discomfort glare and was based on the flagger disabling glare ratings only.

4.5.7 Work area uniformity

Evaluation of the light equipment configurations relative to this outcome measure should consider the magnitude of illuminance, the size of the illuminated area, and the position of the flagger relative to the illuminated area. Optimal conditions for this outcome measure would be to have as much light as possible spread across as much roadway area as possible with the center of the illuminated area on or nearby the flagger location. The illuminance values on the roadway surface should average at least the suggested minimum of 5.0 Fc over the illuminated area. The amount of illuminance on the roadway surface was assessed previously in the work area illumination outcome measure. Therefore, for work area uniformity, only the size of the illuminated area and distance between the flagger and illuminated area centroid are considered.

A flagger stops oncoming traffic while initially standing on the edge of the lane. After the first vehicle is stopped, the flagger is trained to walk out to the centerline of the roadway while vehicles queue up. Therefore illumination to the centerline of the roadway is required. In addition, to give the motorists driving in the opposite direction an idea of the extent and conditions of the roadway in the flagging area and approaching work zone, the illuminated area should extend to the opposite edge of the roadway. If the light equipment is located just off the shoulder adjacent the flagger, the light must also cover the width of the shoulder. To provide sufficient illumination across the roadway, and for motorists approaching the flagging area from each direction, an illuminated area of 160 square feet was assumed as optimal. For a 30 to 40-foot wide roadway including shoulders, this would illuminate a 40 to 50-foot length of roadway. Such a size would sufficiently illuminate the roadway for the motorist, and provide illumination for the flagger when not at the specific flagger location. A 40 to 50-foot width is similar to current ODOT specifications which require that an illuminated area be provided that is at least 12 m (40 feet) in diameter at ground level (*ODOT 2002*).

To reflect this criteria, the following ratings were used for assessing this outcome measure:

1 = Size of illuminated area > 160 square feet
2 = Size of illuminated area from 121 to 160 square feet
3 = Size of illuminated area from 81 to 120 square feet
4 = Size of illuminated area from 41 to 80 square feet
5 = Size of illuminated area ≤ 40 square feet.

Since the minimum suggested illuminance is 5.0 Fc, the size of the illuminated area is calculated only for those grid points with greater than or equal to 5.0 Fc.

The distance from the flagger location to the illuminated area is of primary concern with the spotlight. The roadway surface illuminated by the spotlight is concentrated in a small area across the roadway. Minimal illumination is provided on the roadway surface in the immediate vicinity of the flagger location, and the flagger is susceptible to not being illuminated at all if not directly standing in the flagging station area. For the other light systems, the distance from the flagger location to the illuminated area is not as great. To take into consideration the large distances from the flagger location to the illuminated area created by the spotlight, the rating given to each spotlight configuration was downgraded by a value of 1 (e.g., from a rating of 4 based on the size of the illuminated area only to a rating of 5 when considering distance from the illuminated area to the flagger as well). The ratings given to each light equipment configuration are shown in Table 4.21.

The ratings show that the light tower performed the best with respect to this outcome measure. All of the light tower configurations spread light to a great distance in all directions and, as a result, received ratings of 1.

The 12-volt spotlight performed poorly, receiving ratings of primarily 4 and 5. As previously mentioned, the illuminated area of the spotlight was small and centered a long distance from the flagger. The 12-volt H.I.D. floodlight received poor ratings as well. While the area illuminated was fairly high, the amount of illuminance on the roadway surface was less than or close to the minimum of 5.0 Fc. Therefore, all of the configurations for this type of light received ratings of 5.

The balloon lights spread the light a good distance and centered close to the flagger location. The backpack model received a rating of 2, while the tripod model performed well and received a rating of 1.

4.5.8 Flagger uniformity

Flagger uniformity is an outcome measure developed for this research study. No guidance on appropriate flagger uniformity values is provided in the literature. The literature does suggest that work area uniformity ratios should not exceed 10:1, with 5:1 being more reasonable (*Bryden and Mace 2002*). Using these suggested values as a guide, the following ratings were set for the analysis of flagger uniformity:

1 = Average uniformity ratio ≤ 2.5
2 = Average uniformity ratio from 2.6 to 5.0
3 = Average uniformity ratio from 5.1 to 10.0
4 = Average uniformity ratio from 10.1 to 20.0
5 = Average uniformity ratio > 20.0

For this analysis, average uniformity ratios for the light equipment alone without the small, portable floodlight were used. This was done in order to obtain an aggregate rating incorporating all outcome measures, some of which do not reflect use of the small, portable floodlight. An evaluation of the use of the small, portable floodlight in combination with the light equipment is discussed later in this report.

The ratings (shown in Table 4.21) reveal that the light tower configurations with 0° offset, which received ratings of 1 for all luminaire heights and output levels, performed the best. The ratings were poorer for all light equipment configurations with 15° and 30° offsets. This is predominantly due to the lack of light on the back side of the flagger at these offset angles.

Close observation of the data for the light tower reveal that the flagger uniformity ratio is smallest for the 30° offset on the front side of the flagger. However, the flagger's back side is not uniformly illuminated and many zero readings were recorded for this offset angle. Even though the uniformity ratio at 0° offset is slightly lower than that for 15° and 30°, the 0° offset angle illuminates the flagger equally on both sides. For this outcome measure and type of light equipment, 0° offset and 15-foot height for both 2,000 and 4,000-watts is the optimum. As the offset angle increases, the back side of the flagger continues to become darker.

For the 12-volt spotlights and floodlights, the ratings were better for 10-foot tall luminaire heights than for 6-foot heights. A luminaire height of 6 feet is lower than the paddle height and approximately at the level of the flagger's forehead. This typically resulted in lower illuminance readings at these flagger surface locations, leading to larger flagger uniformity ratios.

An interesting and similar observation of the 12-volt spotlight and floodlight systems is that the smallest uniformity ratio occurs at 30° offset for the front side, but was very high on the backside. Also, for the 6-foot high configurations, the luminaire(s) are at the same height or slightly below the light meter for the forehead, back of head, and paddle measurements. This decreased the illuminance levels measured at these locations, and resulted in increased flagger uniformity ratios. The optimum 12-volt spotlight or floodlight configuration for this outcome measure would be 10 feet high at 0° offset.

For the balloon lights, the flagger uniformity ratios were very high for the Sirocco 200 backpack model, and much less for the Sirocco 2000 tripod model. The backpack supporting the lamp and housing the battery blocked much of the light on the back side of the flagger. On the front side of the flagger, the light shining down from a short distance above the flagger's head did not produce significant illuminance at all locations on the flagger's body. As a result, the backpack model is not recommended from a flagger uniformity ratio perspective. For the tripod model, the ratios are much more reasonable. The use of the small, portable floodlight brought down the uniformity ratio and hence use of the small floodlight is acceptable for this light equipment configuration.

4.5.9 Urban/suburban visibility of flagger

For this outcome measure, the analysis is based on the average ratings provided by the observers. The observers were asked to rate the light equipment for how visible it makes the flagger, using the following scale:

1 = Flagger is clearly visible
2 = Flagger is visible, but some parts of the flagger are not visible
3 = Flagger is not clearly visible

Table 4.21 shows the ratings given to each light equipment configuration. Additional light outputs were tested for this outcome measure to assess a wide range of output values.

Similar to flagger disabling glare and flagger uniformity, the ratings for this outcome measure were based on the light equipment alone without the small, portable floodlight. This was done in order to obtain an aggregate rating incorporating all outcome measures, some of which do not reflect use of the small, portable floodlight. An evaluation of the use of the small, portable floodlight in combination with the light equipment is discussed later in this report.

Based on the average observer ratings, the 12-volt H.I.D. floodlight in combination with the small, portable light was rated the best at illuminating the flagger such that the flagger was easily visible amongst the surrounding lights. The light tower at 2,000, 3,000, and 4,000-watt outputs were also highly rated. The observers did not feel that the 12-volt spotlight illuminated the flagger as well, especially without the small, portable floodlight. For all configurations in which the small, portable floodlight was used in combination with the other light equipment, the flagger was rated as more visible than with the light equipment alone. In fact, the small, portable floodlight, when used on its own was highly rated for illuminating the flagger. For all light equipment configurations, the ratings generally improved as the offset angle increased and as the luminaire height increased.

4.5.10 Ease of use

The data collected with respect to ease of use was qualitative in nature and based on a subjective assessment while operating the equipment both in the laboratory prior to testing and during testing at the field sites. Using this descriptive data, a rating was given to each piece of equipment that signified how easy the equipment is to operate and maintain. The ratings ranged from 1 to 5, with 1 reflecting equipment that is simple to use and could be operated efficiently, and 5 representing equipment that required many and/or complicated steps to operate. Using these criteria, the equipment was given the ratings shown in Table 4.23.

Table 4.23: Light equipment ease of use ratings

Light Equipment	Ease of Use Rating
Light Tower	5
12-volt Spotlight	2
12-volt H.I.D. Floodlight	1
Sirocco 200 Balloon Light (backpack model)	4
Sirocco 2000 Balloon Light (tripod model)	3
Small, Portable Floodlight	1

The light tower received the lowest rating of 5 because of the many steps required to operate it and the maintenance requirements associated with the generator. The best ratings were given to the 12-volt H.I.D. floodlight and the small, portable floodlight. Compared to the 12-volt spotlight, the luminaires on the H.I.D. floodlight were easy to adjust. Also, accurate aiming of the H.I.D. floodlight was not as critical because it spreads the light over a wide area. The spotlight, on the other hand, needs to be aimed very carefully because it emits a small concentration of light and could easily miss the flagger. The balloon lights are slightly more difficult to operate, especially the backpack model, and were given ratings of 3 and 4.

4.5.11 Mobility

The mobility data includes both qualitative information about the requirements for setting up and taking down the equipment, and quantitative measurements of the time it takes to perform these operations. Ratings were given to each piece of equipment based on the number and complexity of steps, and time required to set up and take down the equipment. The requirements for moving the equipment from one location to another were also considered when rating the equipment. The ratings ranged from 1 to 5, with 1 reflecting equipment that is highly mobile (i.e., can be easy and efficiently set up, taken down, and moved), and 5 representing equipment that requires significant effort to move. Using the mobility data shown in Table 4.19, the equipment was given the ratings shown in Table 4.24.

Table 4.24: Light equipment mobility ratings

Light Equipment	Mobility Rating
Light Tower	5
12-volt Spotlight	2
12-volt H.I.D. Floodlight	2
Sirocco 200 Balloon Light (backpack model)	3
Sirocco 2000 Balloon Light (tripod model)	3
Small, Portable Floodlight	1

Similar to ease of use, the light tower received a poor rating of 5 for mobility. Because of its size and weight, the light tower must be towed by another vehicle from one location to another. Once at the appropriate location, numerous steps are required to stabilize the unit, raise the tower, and turn on the lights. There is also a delay of a couple of minutes while the lights power up to full brightness. The same number of steps is required to take down the equipment.

Average to good ratings were given to the other light systems. The balloon lights did not rate as well as the others primarily because they are more delicate and must be handled with care when transporting them, and there is a delay while they power up to full brightness. The backpack model also requires some extra steps associated with connecting the light to the backpack for both support and power.

4.5.12 Cost

Equipment cost was evaluated relative to how expensive the equipment is to purchase. Since all of the equipment was not readily available to rent, only purchase cost was included in the analysis. The following ratings were used based on what was thought to be reasonable cost for purchasing the equipment:

1 = Cost ≤ \$500
2 = Cost from \$501 to \$1,000
3 = Cost from \$1,001 to \$1,500
4 = Cost from \$1,501 to \$2,000
5 = Cost > \$2,000

Using the cost data provided in Table 4.20, the ratings given to each equipment for this outcome measure are shown in Table 4.25.

Table 4.25: Light equipment cost ratings

Light Equipment	Cost Rating
Light Tower	5
12-volt Spotlight	2
12-volt H.I.D. Floodlight	4
Sirocco 200 Balloon Light (backpack model)	2
Sirocco 2000 Balloon Light (tripod model)	5*
Small, Portable Floodlight	3*

*Includes cost of generator for power.

Since the standard light tower comes with four luminaires, the same cost was used for the 2,000 and 4,000-watt output configurations. The 2,000-watt configurations are simply the same piece of equipment with only two lamps turned on.

The 12-volt spotlight and H.I.D. floodlight models tested each had two luminaires. For the configurations in which both luminaires were turned on (i.e., 200-watt output for the 12-volt spotlight, and 140-watt output for the H.I.D. floodlight), the costs of the lights with dual luminaires mounted on a tripod were used when rating the lights. For the configurations in which only one luminaire was turned on (i.e., 100-watt output for the 12-volt spotlight, and 70-watt output for the H.I.D. floodlight), the costs of the lights with a single luminaire mounted on a tripod were used when rating the lights. The ratings would slightly improve if a pole mount connected to a truck is used instead of a tripod.

The cost of the equipment varied significantly depending on the type of equipment. The most expensive types of equipment to purchase are the light tower ($8,700) and Sirocco 2000 balloon light ($3,800). The other lights range from as low as $15 for the small, portable floodlight to $1,644 for the 12-volt H.I.D. floodlight with dual luminaires mounted on a tripod. For the 12-volt spotlight and H.I.D. floodlight models, the pole mount for direct attachment to a truck costs less than the tripod mount.

For the Sirocco 2000 and the small, portable floodlight, a generator is required for power. Purchase price for a generator ranges from $1,300 to $1,625 depending on the size of generator selected. A 3.5 kW generator is sufficient to power the lights alone; a larger generator may be required if the generator will be used to power additional equipment at the same time.

The light tower and generator are commonly found at rental equipment businesses and can be rented by the day, week, or month. Some of the other equipment is not readily available to rent. If purchase is the only option, the affordability of using the equipment for short term operations, or by small firms, may be impacted.

4.5.13 Addition of small, portable floodlight

The small, portable floodlight was included in some of the tests at both the airport and football stadium test sites. It was hypothesized that an additional light shining up from the roadway surface would help illuminate areas on the flagger's body that were not illuminated, or were dimly illuminated, by a light shining from a higher elevation or from a different offset angle. The additional light was not intended to illuminate the roadway surface. While a second light is not typically employed for short-term maintenance flagging operations that require frequent re-location of the flagger, the extra light might be considered when flagging will remain in a single location for a longer duration.

The small, portable floodlight was used in combination with the other light equipment when measuring flagger glare (disabling and discomfort), flagger uniformity, and urban/suburban visibility of the flagger. The small floodlight was additionally evaluated on its own in terms of ease of use, mobility, and cost.

With respect to flagger glare, the amount of disabling glare was greater for all combinations with the small floodlight present. The veiling luminance values increased by 0.11 candelas. Discomfort glare for the flagger was also a concern. The flagger participating in the tests commented that it was discomforting to have the small floodlight shining in his eyes, and he recommended against using the small floodlight as tested. To reduce the glare, the flagger recommended decreasing the offset angle for the small floodlight, and either partially shielding the light so that it shines below eye level or adding a filter to cut down on the amount of light output.

Flagger uniformity improved with the addition of the small floodlight. The small floodlight alone provides a uniformity ratio of 4.8 and, when added with the other lights, the uniformity ratio typically decreased. The use of this additional light is recommended from the perspective of this outcome measure.

The small floodlight also improved performance related to urban/suburban visibility of the flagger. The flagger was rated as being more visible from the surrounding background of lights with the small floodlight turned on than with it turned off. When evaluated on its own without any of the other lights present, the small floodlight was highly rated for illuminating the flagger.

With regards to ease of use and mobility, the small floodlight received the best ratings. In terms of cost, it is very cheap to purchase, although requires a generator or other power source. If the other light used in combination with it also requires a generator for power, the additional cost of operating the small floodlight would be very minimal. On the other hand, if the other light is powered from a different source, the added cost and impact on mobility of the generator may be prohibitive.

4.6 OPTIMAL LIGHT EQUIPMENT CONFIGURATIONS

4.6.1 Overall ranking considering all outcome measures

The aggregate rating calculated for each light equipment configuration was used to rank the configurations for comparison. The rankings of each configuration are shown in Table 4.21. The first ranking (overall rank) compared all of the 44 configurations tested together, without use of the small, portable floodlight. This ranking distinguishes the optimal means for illuminating flaggers based on all of the outcome measures for all of the light equipment configurations. The light equipment configurations which received the top five overall rankings were as follows:

1. 12-volt Spotlight, 100-watts output, 0° offset, 10 feet high (aggregate rating: 1.81)
2. 12-volt Spotlight, 200-watts output, 0° offset, 10 feet high (aggregate rating: 1.95)
3. 12-volt H.I.D. Floodlight, 140-watts output, 0° offset, 10 feet high (aggregate rating: 2.11)
4. 12-volt H.I.D. Floodlight, 70-watts output, 0° offset, 10 feet high (aggregate rating: 2.13)
5. 12-volt Spotlight, 200-watts output, 0° offset, 6 feet high (aggregate rating: 2.14)

The aggregate ratings calculated for the 12-volt spotlight configurations ranked #1 and #2 as shown above (1.81 and 1.95) were much better than the ratings calculated for the other spotlight configurations. This difference is based primarily on the work area illuminance measurements recorded for these two configurations. For these two configurations, the center of the area illuminated by the spotlight happened to be located directly on a grid point were a measurement was taken, which resulted in very high illuminance values at these grid points compared to all of the other grid points and all of the other spotlight configurations. If a flagger were present, the light would have illuminated the flagger and not the roadway surface. Because of this large discrepancy, these values were not considered to accurately represent the work area illumination for the spotlight. If work area illuminance values consistent with the other measurements are substituted for these outliers, the aggregate ratings for these two configurations increase to 2.06 and 2.12. These values are more in line with the other configurations. This change in the aggregate ratings results in the following revised overall ranking:

1. 12-volt Spotlight, 100-watts output, 0° offset, 10 feet high (aggregate rating: 2.06)
2. 12-volt H.I.D. Floodlight, 140-watts output, 0° offset, 10 feet high (aggregate rating: 2.11)
3. 12-volt Spotlight, 200-watts output, 0° offset, 10 feet high (aggregate rating: 2.12)
4. 12-volt H.I.D. Floodlight, 70-watts output, 0° offset, 10 feet high (aggregate rating: 2.13)
5. 12-volt Spotlight, 200-watts output, 0° offset, 6 feet high (aggregate rating: 2.14)

Considering all of the outcome measures together, most of the light tower configurations were not ranked highly, except for the 2,000-watt, 0° offset configurations at heights of 25 feet (aggregate rating = 2.24; overall ranking = #6) and 20 feet (aggregate rating = 2.31; overall ranking = #8). The Sirocco 2000 balloon light (tripod model) was also highly ranked (aggregate rating = 2.30; overall ranking = #7).

It is interesting to note that the above list contains only configurations with 0° offsets. In fact, no configuration with either 15° or 30° offsets was ranked in the top ten. The highest ranked configuration located at either 15° or 30° offsets, was the spotlight with 200-watts output, 15° offset, and 6-foot height (ranked #11). The greater offsets resulted in increases in both motorist and flagger glare, and poorer flagger illumination (less light shining on the back side of the flagger).

4.6.2 Individual ranking considering all outcome measures

A second ranking (individual rank) was made considering all outcome measures but assuming that only a single type of light equipment was available for use. For example, a maintenance crew might only have a single spotlight available for an operation that needs to take place immediately. In another situation, the surrounding terrain and shoulder conditions may constrain the operation to use of a light tower. In these cases, the design variables are reduced to light output, offset angle, and luminaire height. Therefore, for this analysis, ranking of the configurations did not consider all of the 44 light equipment configurations at the same time. The ranking was limited to configurations within each individual light system and amount of output. For example, for the different configurations of the 12-volt H.I.D. floodlight – a total of 12 different configurations – aggregate ratings were calculated in a manner similar to the overall evaluation described previously. The aggregate ratings were then used to rank the 12 H.I.D. floodlight configurations and determine the optimal floodlight configuration. As shown in Table 4.21, the three highest ranked configurations for each of the different light systems are listed below:

Light Tower:	1. 2,000-watts output, 0° offset, 25 feet high (aggregate rating: 2.24) 2. 2,000-watts output, 0° offset, 20 feet high (aggregate rating: 2.31) 3. 2,000-watts output, 15° offset, 25 feet high (aggregate rating: 2.53)
12-volt Spotlight:	1. 100-watts output, 0° offset, 10 feet high (aggregate rating: 2.06) 2. 200-watts output, 0° offset, 10 feet high (aggregate rating: 2.12) 3. 200-watts output, 0° offset, 6 feet high (aggregate rating: 2.14)
12-volt H.I.D. Floodlight:	1. 140-watts output, 0° offset, 10 feet high (aggregate rating: 2.11) 2. 70-watts output, 0° offset, 10 feet high (aggregate rating: 2.13) 3. 70-watts output, 0° offset, 6 feet high (aggregate rating: 2.37)

Sirocco 200 (backpack): 200-watts output, 0° offset, 8 feet high (aggregate rating: 2.40)

Sirocco 2000 (tripod): 2,000-watts output, 0° offset, 10 feet high (aggregate rating: 2.30)

4.6.3 Overall ranking considering only illumination, glare, uniformity, and visibility

Safety of the flagger, motorist, and maintenance and construction personnel is the most important concern and primarily reflected in the illumination, glare, uniformity, and visibility outcome measures. These measures indicate the level and quality of illumination of the flagger and flagging area. When ranking the light equipment using the aggregate ratings for only these outcome measures (i.e., excluding ease of use, mobility, and cost), the overall ranking changes. Table 4.22 shows the overall ranking for this subset of outcome measures with the five highest ranked configurations as follows:

1. Light tower, 2,000-watts output, 0° offset, 25 feet high (aggregate rating: 1.32)
2. Light tower, 2,000-watts output, 0° offset, 20 feet high (aggregate rating: 1.41)
3 (tie). Light tower, 2,000-watts output, 15° offset, 25 feet high (aggregate rating: 1.71)
3 (tie). Sirocco 2000, 2,000-watts output, 0° offset, 10 feet high (aggregate rating: 1.71)
5. Light tower, 2,000-watts output, 0° offset, 15 feet high (aggregate rating: 1.72)

There is no change in the ranking of the top five configurations when the ratings for the 12-volt spotlight are corrected to account for the outlying values.

For this ranking, the light tower with 2,000-watts output performs very well compared to the other systems, receiving four out of the top five highest ranked configurations. This light equipment with 0° offset at any height is highly ranked. While the light tower did not perform well with respect to glare, it illuminates the flagger to a great extent and in a consistent manner.

4.6.4 Individual ranking considering only illumination, glare, uniformity, and visibility

Table 4.22 also shows the individual ranking for each light equipment configuration when only considering illumination, glare, uniformity, and visibility. The individual ranking is based on the aggregate ratings for only a specific type of light equipment. When excluding ease of use, mobility, and cost, the three highest ranked configurations for each type of light system are the same as shown above when all outcome measures are considered together. There is no change in the ranking of the three highest rated configurations.

4.6.5 Use of small, portable floodlight

Use of the small, portable floodlight in combination with the light systems tested improves the ratings related to some outcome measures but not for others. Flagger uniformity and visibility in an urban/suburban setting are improved. However, glare for both the motorist and flagger are increased. Based on these results, use of the small, portable floodlight as tested (45° offset, 500-watt output, no covering or filter) is not considered optimal for flagger illumination. Modifications to the light and adjustments to its location would perhaps improve its performance relative to the outcome measures.

4.7 DESIGN VARIABLE LIMITS

In addition to knowing what the optimal light equipment configurations are, it is worthwhile to understand the acceptable limits with respect to each design variable. Project circumstances may dictate the type of equipment or configuration employed and may prevent using the optimal configuration. In this case, an understanding of the acceptable design variable limits is critical to providing sufficient illumination of the flagger without compromising safety. In addition, it may be preferred that the standard specifications and guidelines to be developed later in the study incorporate a range of acceptable values for each design variable in order to accommodate site- or project-specific conditions.

The primary inputs affecting illumination of the flagger are: type of light equipment and luminaire, lamp output, luminaire height, and offset angle. These variables can also be easily and accurately controlled and monitored by maintenance and construction personnel. The suggested limits associated with these variables are described below. The suggested limits assume that the lights will be aimed directly at the flagger without regard to location and height. In addition, flagger and motorist safety are considered, whereas ease of use, mobility, and cost are not considered.

4.7.1 Type of light equipment and luminaire

All of the types of light equipment tested are acceptable for use in illuminating flaggers. Each type of light can be utilized in nighttime flagging operations and function for the intended use. The light tower, 12-volt spotlight, and 12-volt H.I.D. floodlight are commonly used types of light systems, while the balloon lights are somewhat of a specialty item.

4.7.2 Lamp output

While the light tower effectively illuminated the flagger and roadway surface, the other light systems were effective as well with a lower amount of light output. The amount of light emitted from the light tower was more than enough for the intended use, and it created significant motorist and flagger glare. The light output of the top five rated light equipment configurations was much less, ranging from 70 to 200-watts when all outcome measures are considered. Visibility of the flagger in the urban/suburban setting, however, was poorly rated for configurations with light outputs in this low range. In addition, assuming a 5.0 Fc minimum roadway illuminance requirement, 70-watts of output is insufficient in almost all configurations. Therefore, for rural settings in which there is no surrounding artificial light, it is suggested that lamp output be not less than 250 watts and no greater than 500 watts. This range will ensure that enough light is provided without creating unacceptable disabling and discomfort glare. For urban and suburban settings in which artificial light from lamp posts surrounds the flagging area, the lamp output should be increased to approximately 500 to 2,000-watts. This increase in output will ensure that the flagger stands out from the surrounding lights without creating too much glare.

4.7.3 Luminaire height

The light tower, with very high light outputs compared to the other types of lights, typically received better ratings with the luminaires elevated to a greater height. The other light equipment showed similar results – 10 foot high configurations typically received better ratings than 6 foot high configurations. A higher luminaire leads to less motorist and flagger glare, and a larger illuminated area. Therefore, luminaire height should range from 10 to 25 feet in height. However, the greater the distance of the luminaires from the flagger and roadway surface, the lower the level of illuminance on the flagger and roadway. Therefore, greater luminaire heights should be accompanied by an increase in lamp output.

4.7.4 Offset angle

The highest ranked configurations were those which had no offset (i.e., 0° offset angle). A little offset improves the illumination of the flagger and flagger uniformity, while a large offset can create significant glare for not only the motorist, but the flagger as well. An offset range of 0° to 15° is recommended. The 30° offset tended to increase the motorist discomfort glare and flagger disabling glare to levels above what is acceptable for safe flagging operations. In addition, greater offset angles result in less illumination of the back side of the flagger for traffic coming in the opposite direction.

4.8 EQUIPMENT TESTING SUMMARY

A variety of options are available when selecting, locating, and orienting light equipment to illuminate flaggers during nighttime maintenance and construction operations. Each type of light equipment has features and provides opportunities that benefit illumination of the flagger. When selecting the specific type of light equipment and configuration to use, motorist and flagger safety are the primary concerns. Safety can be assessed by measuring the level of illumination and uniformity over the work area and on the flagger's body, and the amount of glare experienced by the motorist and flagger. Consideration should also be given to ease of use, mobility, and cost of the equipment.

Four different types of light equipment – a light tower, 12-volt spotlight, 12-volt H.I.D. floodlight, and balloon lights – were evaluated. Three input variables – lamp output, offset angle, and luminaire height – were varied to make a total of 44 different light equipment configurations. Each configuration was evaluated in terms of illumination, glare, uniformity, visibility in an urban/suburban setting, ease of use, mobility, and cost. The results from the tests were used to rate each configuration with respect to each outcome measure and then rank the performance of each configuration in terms of how well it illuminates flaggers.

The 12-volt spotlight and 12-volt H.I.D. floodlight were the highest ranked types of equipment when all outcome measures were considered. These types of light systems are easy to operate and transport, and are better designed for short-term flagging operations and for operations that need to be relocated frequently. When ease of use, mobility, and cost are excluded, the light tower with 2,000-watts output performed the best. The decreased mobility and ease of use of this type of light equipment make it more applicable to flagging operations that remain in place for a longer period of time, e.g., for several days or longer.

Optimal configurations typically were those at 0° offset with the luminaires elevated to 10 feet or higher. Greater offset angles result in increased glare for the motorist and flagger. Higher luminaire heights and lamp outputs from 250 to 2,000-watts were found to be optimal depending on the roadway setting and amount of artificial background lighting. The lamp output typically produced by the light tower with 4,000-watts output is much more than needed and creates a substantial amount of glare for the flagger and motorists.

Use of a small, portable floodlight in combination with the light equipment is not recommended unless the amount of glare in the flagger's eyes is substantially reduced. The glare can be reduced by decreasing the offset angle, or installing a filter or shield to minimize or eliminate the amount of light shining in the flagger's eyes.

4.9 RECOMMENDATIONS FOR NEXT PHASE OF RESEARCH

The next phase of the research was to conduct field testing of the light systems during actual maintenance and/or construction flagging operations. The study results thus far reflected use of the light systems under controlled conditions that did not represent all situations in which the equipment would be used. Additional information was needed about how the equipment would perform outside of the controlled laboratory setting. The intent of the next phase was to evaluate the performance of the light equipment under working conditions by those who would be operating the equipment. The assessment was not intended to duplicate the tests already conducted at the airport and football stadium parking lot test sites. More importantly, the additional testing was aimed at acquiring more information about selected types of light equipment for use in developing practical recommendations and guidelines that would accommodate standard flagging operations and associated concerns.

The earlier results indicated that the 12-volt spotlight, 12-volt H.I.D. floodlight, and light tower with 2,000-watts performed well in illuminating flaggers. Out of all of the different types of light equipment tested, the 12-volt spotlight and 12-volt H.I.D. floodlight received the highest rankings relative to all of the outcome measures. While the 12-volt H.I.D. floodlight did not provide sufficient illuminance over the roadway surface using 70-watts, it did illuminate the roadway sufficiently using 140-watts. When only considering illuminance, glare, uniformity, and visibility, the light tower with 2,000-watts output was highly ranked. The glare produced by the light tower with this output, however, was greater than the spotlight and floodlight, but it illuminated the roadway and flagger very well. Therefore, the next phase of testing concentrated on these three types of light equipment only. Additional information was sought to verify that these types of lights could be used effectively and would perform well in practice.

Using the 12-volt spotlight, 12-volt H.I.D. floodlight, and light tower with 2,000-watts output as the sample of equipment to evaluate, the steps for the next phase of the research are described below.

4.9.1 Site selection

The initial step was to select maintenance and/or construction project sites for the testing, based on input from the ODOT Technical Advisory Committee and the nature of current ODOT projects that involve nighttime flagging. In addition, the sites needed to be available during the timeframe planned for this phase of the research. Two different test sites were recommended: one in a rural setting that lacked artificial background lighting, and the other in an urban/suburban setting that had background lighting from lamp posts, signs, or other common roadside features.

4.9.2 Equipment testing

Each type of light equipment (the 12-volt spotlight, 12-volt H.I.D. floodlight, and light tower with 2,000-watts output) should be tested at both of the selected test sites. Included in the testing should also be the light equipment that the flagging crew intended to use for the particular flagging operation, if different. This additional light equipment should be used for comparison in the evaluation of the test lights.

Each type of light equipment should be located and configured according to the optimal configurations identified previously in this interim report. The additional light equipment used by the flagger should be located and set up however is typically done.

During the flagging operation, assessments should be made of the illumination of the flagger and flagging area, motorist and flagger glare, and the operability and mobility of the equipment.

Illumination of the flagger and flagging area, and motorist glare should be assessed by surveying the passing motorists. When stopped by the flagger, the motorists should be asked to rate how well the flagger and flagging area is illuminated, and the extent of discomfort glare from the light equipment. Motorist responses should be recorded and used to evaluate the performance of the light equipment. For flagger glare, the flagger should be asked to rate the level of discomfort glare for each type of light equipment.

Operability and maneuverability of each type of light equipment should be measured in two ways. First, the time it takes the flagger to set up, take down, and relocate the equipment a short distance should be measured. Support equipment and resources that are commonly available on maintenance and/or construction sites should be used during this process. Secondly, the flagger should be asked to make a subjective assessment of the complexity of performing these operations for one type of equipment compared to another. This assessment should focus on how mobile the equipment is, and whether moving the equipment increases the risk exposure of the flagger.

Lastly, the researchers should make a subjective assessment of the impact of the roadway and surroundings on the use and performance of the light equipment. Features such as roadway alignment and curvature, shoulder size and surface, surrounding terrain and foliage, and other similar features should be considered.

4.9.3 Analysis

The data gathered from the tests should be reviewed and analyzed to make modifications, if needed, to the optimal configurations and design variable limits determined from the airport and parking lot tests. Modifications to the configurations should be suggested if they improve the overall safety of the motorist and flagger, and are needed to accommodate typical flagging practice.

5.0 PROJECT SITE TESTING

5.1 PROJECT SITE TESTING LOCATIONS

To identify potential project site testing locations, the researchers solicited input from the TAC and other ODOT personnel, and reviewed documentation describing scheduled ODOT projects and maintenance activities. All types of projects and maintenance activities were considered as long as they contained nighttime flagging operations and were ongoing during this phase of the study. Using these criteria, two projects were identified: OR-212 Road Widening Project, and Hwy. 34 (Philomath Blvd.) Re-surfacing Project. Both of these projects are described in more detail below.

Following testing on these two projects, further efforts to locate projects on which to conduct testing did not yield any other potential test projects. No other projects with nighttime flagging operations during the timeframe of the study were identified by the TAC or through other sources. As a result, only two test projects were used in this phase of the study. However, the results gained from the two test projects, described below, provided sufficient data to evaluate the light equipment. In addition, as described in later sections of this report, comments provided by the flaggers who were working on the two test projects severely discouraged additional testing and use of two of the light systems selected for testing.

5.1.1 OR-212 Road Widening Project

The OR-212 Road Widening Project, located on Highway 212 between Clackamas and Boring, entailed widening the roadway between Royer Road (MP 3.0), and S.E. 242nd Avenue (MP 4.7). The project additionally included the installation of guardrail at some locations and paving of 7 miles of highway between Rock Creek Junction (MP 0.0), and Richey Road (MP 7.0). Traffic control was provided by flaggers and/or pilot vehicles, and nighttime delays lasted up to 20 minutes. At the time the field testing was conducted, project activities were taking place approximately six miles from Interstate Highway 205, just east of Damascus.

At the time the testing was performed, work on the project was commencing along Hwy. 212 just east of SE Regner Terrace Drive. Figure 5.1 shows the location of the flagger relative to Hwy. 212 and SE Regner Terrace Drive. The flagger was located at the intersection of Hwy. 212 and SE Regner Terrace Drive to control traffic traveling in the eastbound direction on Hwy. 212. Traffic entering Hwy. 212 from SE Regner Terrace Drive was minimal and, when it did occur, the flagger controlled the movements of it as well.

The light equipment used by the flaggers at the flagging station was a typical light tower with four 1,000-watt lamps. The light tower was located immediately adjacent the flagger in the compacted gravel shoulder area. Directly above the light tower was a power line that limited the height to which the tower could be raised. In addition, the light tower sat adjacent a fire hydrant which, along with SE Regner Terrace Drive, also limited where it could be located.

While not always successful, the flagger tried to stop eastbound traffic on Hwy. 212 before it entered the intersection with SE Regner Terrace Drive, rather than stopping right in front of the flagger. To do this, the flagger placed a red light on a traffic cone located on the west side of the intersection to signal to the drivers where to stop.

The flagging station for traffic traveling in the westbound direction was located to the east approximately one-half mile away on Hwy. 212. The flaggers were in constant radio communication during the flagging operations.

The part of the project on which the testing was performed was located in suburban/rural surroundings. Residential areas were located in the vicinity to the south, west, and east. On the north side was an area of vegetation. Regularly spaced street lights illuminated the roadways along with light from nearby houses. A traffic light was located at the other flagging station to the east.

As the vehicles approached, the flagger would step out slightly into the lane to signal the drivers to stop. After the first car stopped, the flagger would step out farther into the lane to make sure following drivers could see the "Stop/Slow" paddle. When the stopped traffic was free to go, the flagger would step back to the edge of the lane and wave the traffic through by using a red-colored light.

For this operation, the flaggers were employed by a firm hired by the general contractor to provide flagging personnel. The flaggers did not choose the location of the light tower, set it up, or move it to new locations as required. This work was performed by another worker employed by the general contractor.

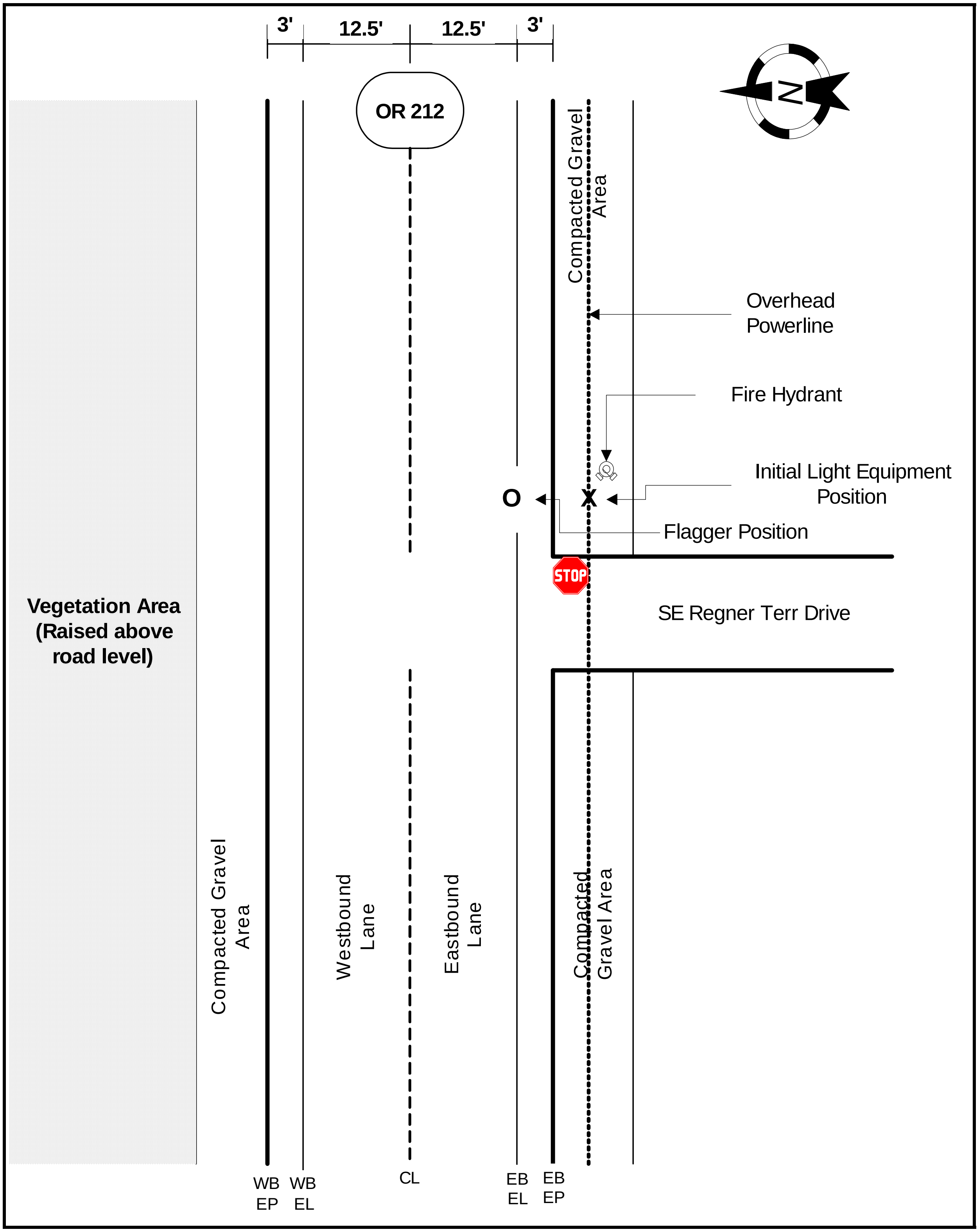

Figure 5.1: Flagging location at OR-212 road widening project

5.1.2 Hwy. 34/Philomath Blvd. Re-Surfacing Project

The Highway 34/Philomath Blvd. Re-surfacing Project was located on Highway 34 (Philomath Blvd.) between SW 35th Street and SW 53rd Street in Corvallis. The project consisted of re-surfacing the roadway in both directions. At the time the testing was performed, work on the project was commencing along the shoulder of Hwy. 34 approximately midway between 35th and 53rd Streets.

Figure 5.2 shows the location of the flagger and roadway layout. The flagger was located on the north side of Hwy. 34 to control traffic traveling in the westbound direction on Hwy. 34. The existing light equipment used at the flagging station was a typical light tower with four 1,000-watt lamps. The light tower was located immediately adjacent the flagger on the edge of the paved shoulder. There were no other roadside features in the immediate vicinity that impacted the flagger or light orientation.

The flagging station for traffic traveling in the eastbound direction was located to the west approximately one-half mile away on Hwy. 34. The flaggers were in constant radio communication during the flagging operations.

The part of the project on which the testing was performed was located in suburban surroundings. Residential areas were located in the vicinity on all sides. Regularly spaced street lights illuminated the roadway along with light from nearby houses. The speed limit on this section of the roadway was posted as 45 mph.

As the vehicles approached, the flagger would step out slightly into the lane to signal the drivers to stop. After the first car stopped, the flagger would step out farther into the lane to make sure following drivers could see the “Stop/Slow” paddle. When the stopped traffic was free to go, the flagger would step back to the edge of the lane and wave the traffic through by using a red-colored light.

For this operation, the flaggers were employed by a firm hired by the general contractor to provide flagging personnel. The flaggers did not choose the location of the light tower, set it up, or move it to new locations as required. This work was performed by another worker employed by the general contractor.

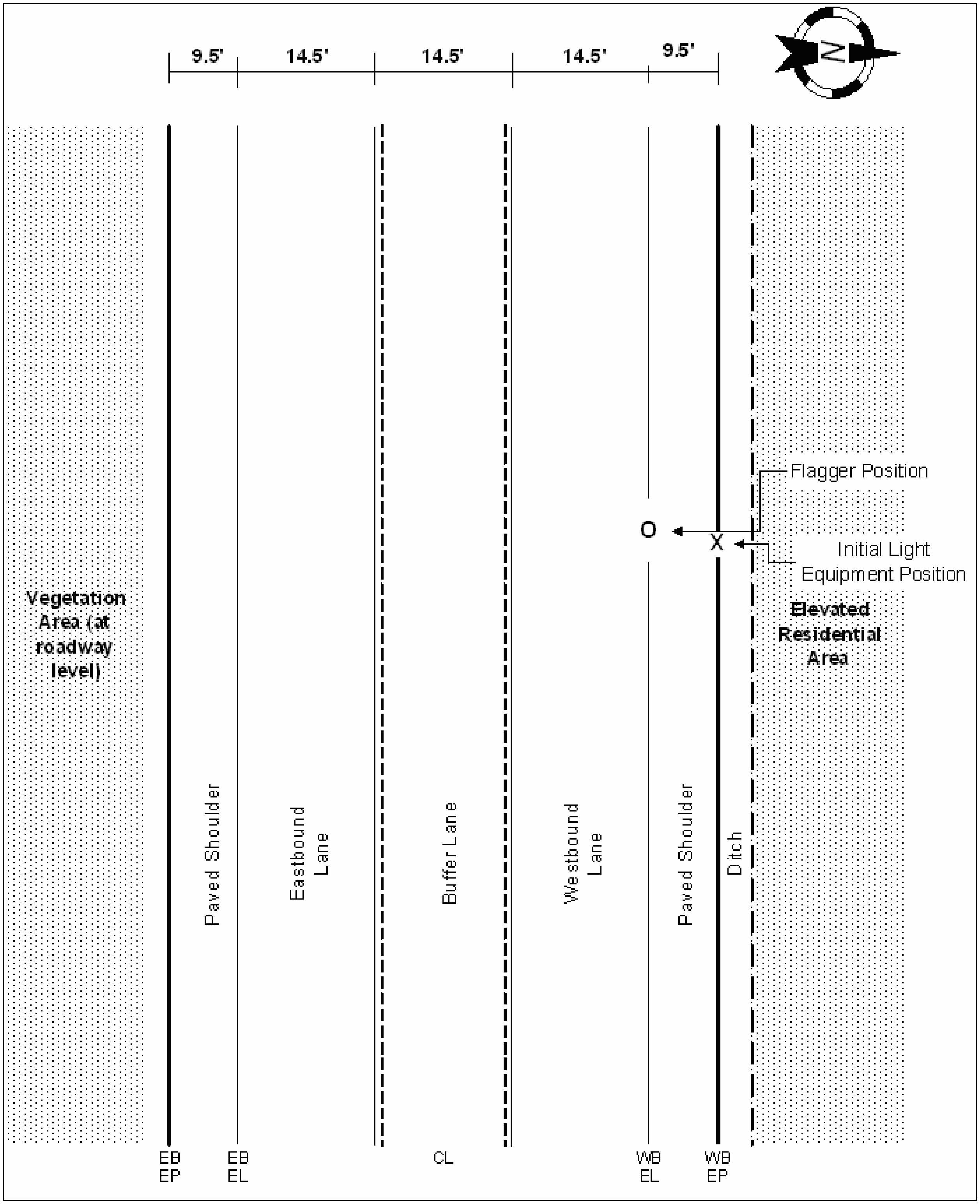

Figure 5.2: Flagging location at Hwy. 34/Philomath Blvd. re-surfacing project

5.2 RESEARCH METHODS

The purpose of this phase of the study (Task 4) was to evaluate selected light equipment under actual working conditions. As described previously, the types of light equipment that were recommended for further testing based on the results of Task 3 were the 12-volt spotlight, 12-volt H.I.D. floodlight, and the light tower with 2,000-watts output. Therefore, the testing in Task 4 concentrated on these three types of light equipment.

The results of Task 3 indicated optimal configurations of the different types of light equipment based on lamp output, offset angle, and luminaire height. The test configurations chosen for the field testing in Task 4 were those that were highly ranked in the Task 3 analysis. The selected test configurations for the equipment in Task 4 are shown in Table 5.1.

Table 5.1: Planned light equipment test configurations

Light Equipment	Lamp Output (Watts)	Offset Angle (°)	Luminaire Height (ft.)
Light Tower	2,000	0°	25
Light Tower	2,000	15°	25
12-volt Spotlight	100	0°	10
12-volt Spotlight	200	0°	10
12-volt H.I.D. Floodlight	140	0°	10

The planned research methodology was to set up the different light equipment in the configurations shown in Table 5.1 at each of the test project sites. For each configuration, evaluation of the light equipment was then based on the following outcome measures:

- Illumination of the flagger
- Illumination of the flagging area
- Driver glare from the light equipment
- Flagger glare from the light equipment
- Operability of the light equipment
- Maneuverability of the light equipment
- Impact of site features on use and effectiveness of the light equipment

The intent was not to collect additional illumination, glare, and uniformity data, but to gather more subjective data from flaggers and drivers associated with the light equipment when used in an actual flagging operation.

5.3 DATA SOURCES AND COLLECTION

The data sources for this phase of the study consisted of input provided by the passing motorists and the flaggers, along with observations by the researchers of the flagging operation and surrounding site features. Data used to evaluate each of the specified outcome measures was collected as described below.

5.3.1 Illumination of the flagger and flagging area, and driver glare

Illumination of the flagger and the flagging area, and glare in the motorist's eyes due to the light equipment, was assessed by surveying the passing motorists. When stopped by the flagger, the researchers walked up to the drivers and asked the motorists questions about the flagger illumination. The motorists were asked the following three questions:

1. Please rate on a scale of 1-5 how well the *flagging area* is illuminated by the light equipment, where: 1 = excellent, 2 = good, 3 = average/moderate/sufficient, 4 = fair, and 5 = poor.
2. Please rate on a scale of 1-5 how well the *flagger* is illuminated by the light equipment, where: 1 = excellent, 2 = good, 3 = average/moderate/sufficient, 4 = fair, and 5 = poor.
3. Please rate on a scale of 1-5 the amount of *discomfort glare* from the light equipment, where: 1 = no glare, 2 = slight glare, 3 = moderate glare, 4 = fair amount of glare and a bit uncomfortable while driving, and 5 = significant glare and very uncomfortable while driving.

In addition, the motorists were asked to provide additional comments related to the illumination of the flagger.

Only the motorists in the first two vehicles stopped by the flagger were surveyed for two reasons. First, the amount of time allowed to survey the motorists was limited by how long they were stopped by the flagger. After the motorists were stopped, the researchers had to enter the roadway, ask the questions, record the responses, and exit the roadway. The amount of time in the queue typically allowed each researcher to survey only one motorist. Secondly, while the first motorist stopped had a clear view of the flagger and flagging area, the following motorists' views were partially obstructed by the vehicles in front of them. In addition, the following motorists' reactions to the flagger and illuminated area are impacted in part by the brake lights of the vehicles in front of them. The second motorist stopped was also interviewed because it was felt that their view and perception of the flagger and flagging station were not significantly impacted by the vehicle in front of them.

5.3.2 Flagger glare

Discomfort glare in the flagger's eyes was assessed by interviewing the flagger. For each of the different light equipment configurations, the flagger was asked to comment on the amount of glare caused by the light equipment during flagging operations. This was an open-ended question with no preset rating levels given.

5.3.3 Operability and maneuverability of the equipment

Data related to the operability and maneuverability of the light equipment was also collected by surveying the flaggers. The flaggers were asked to comment on the operability and maneuverability of the light equipment for the conditions encountered in a typical flagging operation. This included setting up and turning on the equipment, and also moving it to a different location. This was an open-ended question with no preset rating levels given.

5.3.4 Impact of site features

The researchers conducted a subjective assessment of the roadway and surroundings in the immediate vicinity of the flagging station. Roadside features, such as roadway alignment and curvature, shoulder size and surface, surrounding terrain and foliage, power lines, and surrounding lights, were noted and an assessment was made regarding their impact on the flagging operation.

5.3.5 Other considerations

In addition to that described above, additional information related to the light equipment and flagging operation was collected to assist in the analysis. The flaggers were also asked, "Do you face any additional risks while operating any of the light equipment?" This question was intended to get a sense of whether they felt comfortable and safe using the equipment. Additionally, the flaggers were asked about the level of glare produced by the headlights of the passing vehicles. This question was intended to allow the comparison of the level of glare from the light equipment with that created by the vehicles.

Lastly, the researchers conducted subjective assessments of the flagging operations. This assessment considered various criteria including the chosen location of the flagging station, the location of the light equipment relative to the flagger, the actions of the flagger to control traffic, and the response of the motorists to the flagger when approaching the flagging station.

5.4 RESULTS

The data from each of the test projects were recorded at the site and then combined with the data from the other project for analysis. This section of the report describes the limitations on the research efforts imposed by the test projects and provides the results of the tests.

5.4.1 Limitations on the testing

The extent and nature of testing performed on the test projects was limited due to the characteristics of the test projects and input of the flaggers and traffic control personnel. As a result, the planned testing was modified and abbreviated. The impacts to the testing are described below.

The 12-volt spotlight and 12-volt H.I.D. floodlight, which provide 200 and 140-watts of light respectively, emit substantially less light than the light tower. Figure 5.3 illustrates the difference in light emitted by the light systems. In typical flagging operations, a light tower is used with all four lamps turned on, providing 4,000-watts of light. The light emitted from the light tower is also spread over a much larger surface area than the other two types of light equipment, especially the 12-volt spotlight. While the previous testing performed under controlled conditions at the airport and parking lot test sites indicates that the 12-volt systems are sufficient, the difference in the amounts of light is noticeable.

When the 12-volt systems were set up on the first test project (OR-212 Road Widening Project), the flaggers felt very unsafe under the smaller amount of light, compared to the light tower. The flaggers felt that the 12-volt systems did not provide enough light to sufficiently illuminate themselves and the flagging area. The flaggers asked that we stop the testing with the 12-volt systems and turn the light tower back on. The flaggers on the second test project (Hwy. 34/Philomath Blvd. Re-surfacing Project) had the same reaction. The traffic control manager for the flagging company on the Hwy. 34 project also sternly requested that the light tower be turned back on.

As a result, testing on the 12-volt systems was stopped on the test projects before all of the planned testing could be completed. For the 12-volt H.I.D. floodlight, no illumination and glare data was recorded on the OR-212 Road Widening Project, and input from only four motorists was recorded on the Hwy. 34/Philomath Blvd. Re-surfacing Project. For the 12-volt spotlight, minimal illumination and glare data was recorded on the OR-212 Road Widening Project, and no data was recorded on the Hwy. 34/Philomath Blvd. Project. In addition, given the concerns expressed by the flaggers about the low amount of light, the 12-volt spotlight with 100-watts output was not tested as initially planned. Only the spotlight with 200-watts of output was tested.

The flaggers did not feel unsafe when using the light tower with 2,000-watts output. Therefore, input from the motorists and flaggers for the light tower was recorded as planned.

Figure 5.3: Comparison of light output of different light systems

On the OR-212 Road Widening Project, an overhead power line ran above the southern edge of the roadway above the flagging station (see Figure 5.1). The power lines were approximately 18 feet above the ground surface, and limited the height to which the light tower could be raised. Given the location of the flagging station relative to the adjacent fire hydrant and intersecting roadway (SE Regner Terrace Drive), the light tower could not be moved out from underneath the power lines. Consequently, rather than testing the light tower at 25 feet as initially planned, the light tower was tested with the luminaires at a height of only 15 feet.

5.4.2 Motorist survey

The input provided by the stopped motorists in response to the three questions asked is provided in Tables 5.2 – 5.5 for the OR-212 Road Widening Project, and in Table 5.6 for the Hwy. 34/Philomath Blvd. Re-surfacing Project. The motorists designated as "first" position were those that stopped first in the queue of vehicles. Those identified as "second" position were second in line.

Table 5.2: Motorist ratings – OR-212 test site, 12-volt spotlight, 10 ft. height, 0° offset angle, 200-watts

Motorist ID	Position	Rating (1 To 5)			Comments
		How well is the flagging area illuminated? [a]	How well is the flagger illuminated? [b]	What amount of discomfort glare from the light equipment? [c]	
1	First	4	3	1	Passes by every night. Light tower is better.
2	First	2	2	1	Lighting is o.k.
3	Second	4	4	2	Hardly could see the lighting and flagger not visible at all.
4	Second	3	4	1	No glare at all.
Average rating		3.25	3.25	1.25	

[a] 1 = excellent, 2 = good, 3 = average/moderate/sufficient, 4 = fair, and 5 = poor.
[b] 1 = excellent, 2 = good, 3 = average/moderate/sufficient, 4 = fair, and 5 = poor.
[c] 1 = no glare, 2 = slight glare, 3 = moderate glare, 4 = fair amount, and 5 = significant glare.

Table 5.3: Motorist ratings – OR-212 test site, 12-volt spotlight, 10 ft. height, 15° offset angle, 200-watts

Motorist ID	Position	Rating (1 To 5)*			Comments
		How well is the flagging area illuminated? [a]	How well is the flagger illuminated? [b]	What amount of discomfort glare from the light equipment? [c]	
1	First	2	2	2	Lives nearby. Not as visible as light tower. Not enough light on flagger and roadway.
2	Second	2	2	1	No glare. Lighting o.k.
Average rating		2.00	2.00	1.50	

[a] 1 = excellent, 2 = good, 3 = average/moderate/sufficient, 4 = fair, and 5 = poor.
[b] 1 = excellent, 2 = good, 3 = average/moderate/sufficient, 4 = fair, and 5 = poor.
[c] 1 = no glare, 2 = slight glare, 3 = moderate glare, 4 = fair amount, and 5 = significant glare.

Table 5.4: Motorist ratings – OR-212 test site, light tower, 15 ft. height, 0° offset angle, 2,000-watts

Motorist ID	Position	Rating (1 To 5) How well is the flagging area illuminated? [a]	How well is the flagger illuminated? [b]	What amount of discomfort glare from the light equipment? [c]	Comments
1	First	3	3	4	
2	First	2	2	4	More light on this side of the roadway.
3	First	2	1	4	
4	First	3	4	4	Contrast is confusing. Need more light
5	First	3	3	3	Good lighting. Easy to see coming over the hill.
6	Second	1	1	1	Does not bother the driver at all. Lighting is good.
7	Second	1	1	3	Bright light, sometimes goes blind for a few seconds.
8	Second	2	2	4	Very bright; cannot look at it.
9	Second	2	1	2	Not much glare. Flagger easily visible.
10	Second	1	1	2	Little bit of glare.
Average rating		2.00	1.90	3.10	

[a] 1 = excellent, 2 = good, 3 = average/moderate/sufficient, 4 = fair, and 5 = poor.
[b] 1 = excellent, 2 = good, 3 = average/moderate/sufficient, 4 = fair, and 5 = poor.
[c] 1 = no glare, 2 = slight glare, 3 = moderate glare, 4 = fair amount, and 5 = significant glare.

Table 5.5: Motorist ratings – OR-212 test site, light tower, 15 ft. height, 15° offset angle, 2,000-watts

Motorist ID	Position	Rating (1 to 5) How well is the flagging area illuminated? [a]	How well is the flagger illuminated? [b]	What amount of discomfort glare from the light equipment? [c]	Comments
1	First	4	1	4	
2	First	2	3	3	Need advanced warning.
3	First	2	2	2	Lighting is o.k.
4	First	2	1	1	Could see the flagger from a distance.
5	First	2	-	-	
6	First	1	1	2	No problem seeing the flagger.
7	Second	3	3	2	
8	Second	3	3	3	Not that visible.
9	Second	1	1	2	Normally do not look directly at the light.
10	Second	3	1	2	Normally do not look directly at the light.
11	Second	2	3	1	Light does not bother me.
Average rating		2.27	1.90	2.20	

[a] 1 = excellent, 2 = good, 3 = average/moderate/sufficient, 4 = fair, and 5 = poor.
[b] 1 = excellent, 2 = good, 3 = average/moderate/sufficient, 4 = fair, and 5 = poor.
[c] 1 = no glare, 2 = slight glare, 3 = moderate glare, 4 = fair amount, and 5 = significant glare.

Table 5.6: Motorist ratings – Hwy. 34/Philomath Blvd. re-surfacing project, 12-volt H.I.D. floodlight, 10 ft. height, 15° offset angle, 140-watts

Motorist ID	Position	Rating (1 to 5)			Comments
		How well is the flagging area illuminated? [a]	How well is the flagger illuminated? [b]	What amount of discomfort glare from the light equipment? [c]	
1	First	3	1	4	Lives nearby. Not as visible as the light tower. Not enough light on the flagger and roadway.
2	First	2	2	1	
3	Second	1	3	1	Big light generalizes the entire area; small light concentrates only on the flagger.
4	Second	2	2	2	
Average rating		2.00	2.00	2.00	

[a] 1 = excellent, 2 = good, 3 = average/moderate/sufficient, 4 = fair, and 5 = poor.
[b] 1 = excellent, 2 = good, 3 = average/moderate/sufficient, 4 = fair, and 5 = poor.
[c] 1 = no glare, 2 = slight glare, 3 = moderate glare, 4 = fair amount, and 5 = significant glare.

5.4.3 Flagger glare from the light equipment

The flaggers provided the following responses when asked about the discomfort glare created by the different types of light equipment:

- Light tower:
  - Lots of glare.
  - Used to the amount of glare.
  - Never looks directly into the light.
  - No glare from the light.

- 12-volt spotlight:
  - Not much glare.
  - None.

- 12-volt H.I.D. floodlight:
  - No glare at all.
  - None.

5.4.4 Light equipment operability and maneuverability

When asked about the operability and maneuverability of the different light systems, the flaggers provided the following responses:

- Light tower:
  - Easy to turn on just by the switch.
  - Takes time to warm up, sometimes 2 minutes and sometimes 30 minutes.

    - Takes approximately 1.5 minutes to set up at the flagging point.
    - No problem in the overall handling of the light tower. It's also easy to hook up with the truck and move it from place-to-place.
    - Easy to use overall.

- 12-volt spotlight:
    - It's portable and easy to use compared to the light tower.
    - Can be used in places where it is difficult to place light towers.
    - It would take less time to set up than a light tower.
    - Easier.
    - Can carry in own vehicle. No towing is required. Easy operations.

- 12-volt H.I.D. floodlight:
    - It's portable and easy to use compared to the light tower.
    - Can be used in places where it is difficult to place light towers.
    - It would take less time to set up than a light tower.
    - The telescoping based to adjust the height is helpful.

5.4.5 Flagging risks

In response to the question, "Do you face any additional risks while operating any of the light equipment?" the flaggers provided the following comments:

- Light tower:
    - Only problem is with the glare. It's bad for the eyes.
    - Set up and moved by the contractor, not the flagger.

- 12-volt spotlight:
    - Risk of not illuminating the flagger. Flagger moves around and no longer in the light.
    - Nervous to stand under the spotlight.
    - Need someone else to move it; can't leave the traffic.

- 12-volt H.I.D. floodlight:
    - Risk of not illuminating the flagger.
    - Nervous to stand under the floodlight. Not enough light.
    - Need someone else to move it; can't leave the traffic.

5.4.6 Flagger glare from the vehicles

When asked about the glare caused by the oncoming vehicles, one of the flaggers stated that there is glare, but that he is used to it and it does not bother him. Another flagger indicated that it seems like there is more glare from the headlights without the light tower present but with the 12-volt spotlight turned on instead of the light tower.

5.4.7 Other comments

The following are additional comments provided by the flaggers regarding the different types of equipment tested:

- The 12-volt H.I.D. floodlight does not provide much light; sometimes the headlights of the vehicles override the floodlight output.
- Use of some flashing light on top of the spotlight and floodlight would help catch the driver's attention.
- Use of the additional small floodlight on the ground shining up at the flagger makes the flagger more visible, but gives too much glare to the flagger.
- Need to have something to grab the driver's attention.
- More light makes the drivers notice that something is going on and to slow down.
- From ten years of experience, I feel that the spotlight is not good for long term flagging, but may be considered for short term flagging operations.
- Prefers light tower with 4,000-watts output.

5.4.8 Site and flagging operation assessment – OR-212 Road Widening Project

The flagging station was located along a straight section of two-lane roadway. The grade is slightly uphill going westbound, cresting a short distance to the west of the flagging station. There was not much distance between the flagging station and the top of the hill, creating a limited sight distance for traffic traveling eastbound. In addition, the flagging station was adjacent the intersection with SE Regner Terrace Drive. This created a distraction for the flagger when vehicles turned onto or from SE Regner Terrace Drive. It appeared that the flagging station would have been better located to the east a greater distance from the top of the hill and away from the intersection.

The overhead power lines mentioned previously impacted the height to which the light equipment could be raised. No other roadway characteristics were identified that significantly impacted the flagging operation.

The construction operations were taking place not far from the flagging station. The lights on the construction equipment were very bright and, when viewing the flagging station from a distance with the construction operations in the background, the lights on the flagger did not stand out from the construction lights. This may have made it difficult for the drivers to recognize the presence of the flagger. Moving the flagger a greater distance away from the construction operations would have helped improve the contrast between the two sets of lights.

At the eastern flagging station, the flagger was located on the north side of the roadway controlling traffic in the westbound direction. Similar to the other flagging station, a roadway intersected OR-212 from the north at the flagger location. In this location, rather than locating the light tower on the same side of OR-212 as the flagger, the contractor located the light tower on the opposite (south) side of OR-212 and directed the light back across the roadway onto the flagger. Figure 5.4 shows the light on the opposite side of the roadway shining back onto the flagger. This essentially directed the light right into the eyes of the drivers entering OR-212 from the crossroad, creating a significant amount of glare. Numerous drivers entering OR-212 from the crossroad were seen shielding their eyes from the bright light as they entered the intersection. In addition, the relationship of the light to the flagger was such that it created more glare in the flagger's eyes than if it were located on the same side of the road as the flagger. The chosen location for the light created a significant hazard for the drivers and flagger.

Figure 5.4: Location of light tower across the roadway from the flagger

5.4.9 Site and flagging operation assessment – Hwy. 34/Philomath Blvd. Re-surfacing Project

There were no significant roadway features in the vicinity of the flagging station that impacted the operation. Shoulder width was sufficient to locate the light equipment, and there were no obstructions or roadway curves impacting views of the lights. Approximately ¼ mile to the east of the flagger was a stop light at the intersection with SW 35th Street. Traffic stopped at the stop light could easily see the flagger ahead while waiting to proceed, which perhaps assisted in the flagging effort.

On both test projects, the light towers used by the flaggers consisted of four 1,000-watt lamps. When set up by the traffic control personnel at the flagging station, not all of the luminaires were directed towards the flagger location. In some cases, as illustrated in Figures 5.5 and 5.6, single luminaires were directed straight across the roadway while others on the same light tower were aimed up the roadway either at or away from oncoming traffic. The luminaire angles were not adjusted to properly illuminate the flagger. Poor orientation of the luminaires can reduce the effectiveness of illuminating the flagger and increase driver and flagger glare.

Figure 5.5: Orientation of light tower luminaires and illumination of flagger

Figure 5.6: Orientation of light tower luminaires

5.5 DATA ANALYSIS

5.5.1 Illumination of the flagger and flagging area

Although the sample size was limited, Questions 1 and 2 of the motorist survey provided some indication of motorists' perceptions regarding the illumination of the flagger and the flagging area. The responses indicate that the 12-volt spotlight and 12-volt H.I.D. floodlight were satisfactory in illuminating the flagger and the flagging area. Both types of equipment received approximately the same ratings for the same configuration (10 ft. height, 15° offset angle). As shown in Tables 5.3 and 5.6, on average, illumination of the flagger and flagging area were judged as "good."

With the spotlight located at a 0° offset angle, however, illumination of the flagger and flagging area were rated as "average" to "fair," receiving a rating of 3.25 on average. The 0° offset angle does not illuminate the flagger's body on the side facing the oncoming traffic as much as the 15°

offset angle. Therefore, the flagger is more visible using the 15° offset angle. This outcome is consistent with the results of the previous testing done at the airport and parking lot.

At the 0° offset angle the light tower received ratings better than that given to the 12-volt spotlight with respect to illuminating the flagger and flagging area. At the 15° offset angle the light tower received ratings about equal to those of the other equipment. In the illumination of the flagging area, the average rating for the light tower was 2.27 for the 15° offset angle, compared to 2.0 for both the 12-volt spotlight and the 12-volt H.I.D. floodlight. In the illumination of the flagger, the average rating for the light tower was 1.90 for the 15° offset angle, compared to 2.0 for both the 12-volt spotlight and the 12-volt H.I.D. floodlight. Several motorists commented, however, that the 12-volt systems did not provide as much light as the light tower.

With the current flagger illumination practice of using light towers with 4,000-watts output, flaggers are used to the significant amount of light produced by this system. This is perhaps one reason why the flaggers felt so unsafe using the 12-volt systems, even though a limited sample of motorists did not give poor ratings for these systems. The amount of light provided by these smaller systems was significantly different than what the flaggers felt comfortable with.

Comments were also provided by the flaggers regarding the need to fully illuminate the flagging area to make the motorists aware of the flagger and flagging operation. There was concern that the smaller light outputs did not sufficiently indicate to the motorists the presence of the flagging station.

In addition, the flaggers felt particularly uncomfortable using the 12-volt spotlight because of the limited area over which the light is projected. As can be seen in the illumination plots generated from Task 3 (presented in Appendix D), the light emitted from the spotlight is spread over a smaller surface area compared to the 12-volt H.I.D. floodlight and light tower. Standard flagging operations involve movement of the flagger across the lane. The flagger will typically move into the lane after the first vehicle stops in order to signal following vehicles. A spotlight concentrates the light in a small area. As the flagger moves out into the lane to control traffic, he/she often steps out of the light when the spotlight is used. Therefore, a spotlight is not appropriate. The floodlight and light tower allow for movement around the flagging station that is required as part of the flagging operation.

5.5.2 Driver glare

Question 3 of the motorist survey addressed the amount of discomfort glare experienced by the motorists. The average ratings for the 12-volt spotlight and 12-volt H.I.D. floodlight were notably less than that of the light tower. This is due to the greater amount of light emitted from the light tower and is consistent with the results of the previous testing at the airport and parking lot. Several motorists commented that the glare produced by the light tower was distracting.

For the light tower, there was significant difference in the ratings for the different offset angles. An offset angle of 0° received an average rating of 3.10, while an average rating of 2.20 was calculated for the 15° offset angle. This is consistent with what would be expected, given that the greater offset angle directs the light away from the oncoming traffic. A greater offset angle, however, also directs the light to a greater extent into the eyes of the flagger and motorists traveling in the opposite direction.

5.5.3 Flagger glare

An assessment of the glare experienced by the flagger due to the light equipment was made based on input from the flaggers. The flaggers commented that the light tower created a significant amount of discomforting glare. They experienced little or no glare from the other light equipment.

The 15-foot height of the light tower, which was limited by the presence of the power lines above, was lower than typical. The light tower luminaires are typically raised to a height of 20 to 25 feet. Placing the luminaires at a lower height put them closer to the flagger's line of sight. Therefore the amount of glare experienced by the flaggers may have been greater than the flaggers were used to in a typical flagging operation.

5.5.4 Operability and maneuverability of the light equipment

Regarding the operability and maintainability of the light equipment, the flaggers felt that all of the systems were easy to set up and operate. No noteworthy issues were raised by the flaggers regarding the use and maintenance of the equipment. One disadvantage of the light tower that was mentioned was the delay experienced waiting for the light tower lamps to warm up. In addition, it was recognized that one advantage of the smaller systems was their portability. The flaggers commented that the smaller systems were more portable and perhaps more suitable to shorter duration flagging operations.

5.5.5 Impact of the site and flagging operations

Several issues related to the project site and flagging operations impact the performance of the light equipment. When locating and setting up the flagging station, consideration needs to be given to the surrounding roadway features. The flagging station should be located on a section of the roadway avoids features which limit placement and orientation of the light equipment, require the flagger to move away from the illuminated flagging area, and obstruct the motorist's view of the flagger.

The flagging station should not be located adjacent to an intersection in which drivers will approach the flagger from different directions. The light equipment illuminates only one side of the flagger. Motorists approaching the flagger on the side that is not illuminated may have difficulty in seeing the flagger. In addition, the motorists may experience additional glare from the light equipment, depending on the direction from which they approach the equipment.

The location of the flagging station relative to the construction operations should also be considered. Construction operations will typically employ a light tower and/or lights on construction equipment to illuminate the work area. These lights are often as bright as or brighter than the lights used to illuminate the flagger. If the flagging station is located too close to the construction operations, it may be difficult for the motorists to distinguish the flagging operation from the construction operations in the background. The illuminated flagger needs to stand out from the other activity in the work zone. Sufficient distance should be provided between the flagging station and construction activity to ensure that the flagger is clearly visible. If sufficient distance cannot be provided due to project site constraints, increasing the output of the lights illuminating the flagger should be considered.

Consideration should be given to the orientation of the luminaires on the light equipment. The luminaires should be aimed downward on the flagging area such that they illuminate the flagger during the entire flagging operation. Luminaires that are mis-directed reduce the illumination of the flagger and flagging area, and may increase the amount of glare to the motorist or flagger.

5.6 CONCLUSIONS FROM PROJECT SITE TESTING

This phase of the study provided valuable input to the use of the light equipment in practice that was not gained from the previous study tasks. The following conclusions can be made from this phase of the study:

- *Flaggers do not feel comfortable using 12-volt spotlight or 12-volt H.I.D. floodlight systems because of the small amount of light they emit compared to the light tower.* Flaggers are used to, and feel more comfortable under the significant amount of light produced by the light towers with all four lamps turned on. While motorists may feel that the 12-volt systems adequately illuminate the flagger and flagging area, the flaggers feel unsafe when using these systems because of the lower level of light emitted.
- *Project sites containing a greater number and intensity of surrounding artificial lights (e.g., urban/suburban environments) require lights with greater output to illuminate the flagger, while sites that have little or no surrounding artificial lights (e.g., rural/suburban areas) do not require lights with as great output to illuminate the flagger.* When the light tower was used, the contrast between the illuminated flagging area and the surrounding environment was greater than that created by the smaller systems for the given (suburban/rural) surroundings. The light output of the 12-volt systems did not create enough contrast with the other lights nearby. In addition, the bright lights used for the construction operations made it more difficult to discern the flagger and flagging area.
- *A 15° offset angle performs better than a 0° offset angle.* The motorists rated the 15° offset angle configurations higher than a 0° offset angle configurations in terms of flagger illumination, flagging area illumination, and glare.
- *The 12-volt spotlight and 12-volt H.I.D. floodlight systems are more portable than the light tower.* The smaller systems can easily be set up and relocated by one person and in a shorter period of time. Also, there is no delay, or not as much delay as the light tower, in the time it takes for the lamps in the smaller systems to power up.
- *The floodlight works better than the spotlight to illuminate the flagger when the flagger moves around the flagging area.* The spotlight concentrates the light in a small area outside of which the flagger may need to move to control traffic. The floodlight allows the flagger to move over a larger area and remain illuminated.
- *Motorist glare is a concern with the light tower, but not with the 12-volt spotlight and 12-volt H.I.D. floodlight.* The amount of light emitted by the light tower with 2,000-watts

output was discomforting to some drivers, while the smaller systems did not produce enough light to cause any glare.

- *Project site features and flagging operations impact the quality of flagger illumination.* Roadway features that obstruct the location or orientation of the light equipment, or the location of the flagging station relative to oncoming traffic, can reduce the effectiveness of the light equipment in illuminating the flagger and flagging area and minimizing motorist glare. In addition, whether site features hamper use of the light equipment or not, the equipment should be set up and used in a manner that provides for optimal illumination.

6.0 RECOMMENDATIONS

Task 5 comprised providing documentation of the research along with recommendations of minimum illumination performance expectations and lighting system guidelines for highway work zone flaggers. Provided below are recommendations for flagger illumination during nighttime construction and maintenance operations.

6.1 LIMITATIONS ON APPLICATION AND EXTENSION OF RESEARCH FINDINGS AND RECOMMENDATIONS

As described previously, the objective of the study was to develop guidelines for the optimal illumination of flaggers during nighttime maintenance and construction operations on highway projects. The scope of the research included field laboratory and project site testing of light equipment under nighttime conditions. The testing was performed under conditions that consisted of clear, crisp weather during nighttime hours after dusk and before dawn. All illumination measurements and observer ratings were taken when ambient light levels were less than 0.01 foot-candles. Testing was postponed when weather conditions impacted the ability of the light meter to make accurate readings, which occurred during light, drizzly weather.

Application of the research findings is limited to flagging operations that are conducted under conditions similar to that in which the testing was performed. Actual flagging operations may need to be conducted under conditions that are different than that which were present during the testing. Examples of other conditions for which the research findings do not apply include, but are not limited to:

- during daytime, dusk, and dawn hours;
- in rainy, snowy, or foggy weather;
- when the flagger is standing in dark shadows during daytime hours;
- when the motorists' view of the flagger is obstructed; and
- when obstructions between the light equipment and flagger create shadows on the flagger and in the flagging area.

The research findings should not be extended to flagging operations conducted under conditions different than those present during the testing. When actual conditions are different, flagger illumination should be modified appropriately to ensure the safety of the flagger, motorists, and maintenance and construction personnel. Special consideration should be given to twilight hours and in other situations with transitional lighting such as heavy shade or inclement weather.

6.2 RECOMMENDED MINIMUM AND OPTIMUM ILLUMINATION PERFORMANCE

A variety of outcome measures were used in the study to assess the performance of the light systems in illuminating flaggers. Safety of the flagger, motorists, and maintenance and construction personnel is the most important concern and is reflected in the illumination, glare, uniformity, and visibility outcome measures. These measures indicate the level and quality of illumination of the flagger and flagging area. Therefore, these measures are used as the basis for the recommended minimum and optimum illumination performance levels for flagging operations.

The following illumination performance levels are recommended based on the information collected in the study. This information includes that collected in the literature review and the data recorded during the light equipment field and project site testing.

- General illumination performance: *Flagger illumination should be sufficient to ensure the safety of the flagger, motorists, and maintenance and construction personnel during flagging operations.*

- *Illumination on the roadway surface should be at least five foot-candles, or at least two times that provided by other light sources without the light equipment used to illuminate the flagger present, whichever is greater.*

  Five foot-candles is classified as Level I, the lowest illumination level, and is recommended only for general illumination in the work zone and for areas where crew movement takes place (*Hanna 1996*). OR-OSHA standards for construction sites also specify five foot-candles for "General construction area lighting", and five foot-candles for "General construction areas, concrete, placement, excavation and waste areas, accessways, active storage areas, loading platforms, refueling, and field maintenance areas" (*OR-OSHA 2002*). The OR-OSHA standards for construction do not specify worksite conditions or processes specific to the illumination of flaggers during nighttime operations.

  The study test data also indicate that five foot-candles is an appropriate minimum level of illumination on the roadway. The observers participating in the flagger visibility assessments conducted in the study gave significantly poorer visibility ratings for the systems that produced less than five foot-candles on the roadway surface than for those that produced more than five foot-candles. In addition, those systems that provided less than five foot-candles were viewed as unsafe by the flaggers because the light was not sufficient to alert the motorists of the flagging station. The flaggers also felt unsafe while flagging when using the light equipment that provided less than five foot-candles.

  The requirement that the illumination must be at least two times that produced by other light sources without the flagging light equipment is to ensure that the flagger and flagging area stand out from the surrounding activities. Permanent roadway lighting, construction operation lighting, or other light sources around the work zone may make it difficult to distinguish the flagger and flagging area if the light equipment used for flagging does not provide enough illumination.

- *The minimum illumination should be provided throughout an area of roadway that extends five feet beyond the designated flagging area in all directions, where the designated flagging area is defined as follows:*
    - *The designated flagging area is the area of roadway over which the flagger will move to control traffic during the flagging operation.*
    - *The designated flagging area should have a radius at least the width of the lane on which traffic is being controlled.*
    - *The center of the designated flagging area should coincide with the initial flagger location at the start of the flagging operation.*

Section 00225.17 – Work Zone Traffic Control, of the ODOT *Standard Specifications* prescribes that temporary illumination equipment provide an illuminated area of at least 12 m (40 feet) diameter at ground level (*ODOT 2002*). As described previously in this report, during flagging operations the flagger commonly walks out into the roadway when controlling traffic. The flagger may also be required to move up or down the roadway to communicate with motorists, control traffic coming from other directions, or move to/from the flagging position. The size of the designated flagging area will vary depending on the flagging operation and site conditions. Therefore, rather than prescribing a specific size for all flagging areas, the required illuminated area should be based on the specific flagging operation and site conditions. A minimum radius equal to the width of the lane is given in order to ensure that the illuminated flagging area is at least large enough to alert motorists of the presence of a flagging station.

The designated flagging area encompasses all of the roadway area over which the flagger will move during the flagging operations, and should be determined before flagging operations begin. Prior to commencing the flagging operations, the flagger should be made aware of the size and location of the designated flagging area. The flagger should stay within the designated flagging area during flagging operations. The minimum allowed illumination is required for a distance of five feet beyond the designated flagging area to ensure that the flagger is sufficiently illuminated at the very edges of the designated flagging area and as a safety precaution in case the flagger steps outside the designated flagging area.

- *The flagger should be illuminated such that the flagger is visible, and is discernable as a flagger, from a distance of 1,000 feet.*

The flagger should be as visible as possible and stand out from the surrounding environment and activities. There are no existing quantitative criteria regarding the minimum illuminance levels on the surface of the flagger's body. Section 6E.02 of the MUTCD prescribes that flaggers must be visible at a minimum distance of 1,000 feet (*FHWA 2000*). This allows the motorist adequate time to slow their rate of speed and react to the flagger's instructions. No data was collected from the study which demonstrated that the minimum distance should be longer or shorter than 1,000 feet.

- *The roadway uniformity ratio (the ratio of the average illuminance to the minimum illuminance) over the designated flagging area should be 5:1, with a maximum roadway uniformity ratio of 10:1.*

  Consistency in the illumination of the roadway surface is important to ensure that there are no dark areas in the flagging area. Dark areas in the flagging area could confuse the motorists as to the presence, location, and size of the flagging area. A uniformity ratio not exceeding 10:1, with 5:1 being more reasonable, is recommended for work areas (*Bryden and Mace 2002*). These ratios are also applicable to flagging operations. The light equipment configurations that were found to be optimal, and which were viewed by the flaggers as effectively illuminating the flagging area, had uniformity ratios in this range over the flagging area.

- *The flagger uniformity ratio (the ratio of the average illuminance to the minimum illuminance) over the surface of the flagger's body facing the traffic being stopped should be no greater than 5:1.*

  No guidelines are provided in the literature regarding the recommended maximum flagger uniformity ratio. Flagger uniformity was developed as part of this study to evaluate the consistency with which the flagger is illuminated. Illumination on the surface of the flagger's body facing the oncoming traffic should be consistent and free of dark areas. The light equipment configurations that were rated highly in illuminating the flagger contained flagger uniformity ratios less than or equal to 5:1. Light equipment configurations that produced higher flagger uniformity ratios were given poorer ratings in terms of flagger visibility.

- *The veiling luminance (glare) experienced by motorists when approaching and passing through the flagging area should be as low as possible, and not greater than 0.25 candelas or 1/3 of the average pavement luminance, whichever is less.*

  The Illuminating Engineering Society of North America (IESNA) recommends that veiling luminance be no greater than 1/3 of the average pavement luminance (*IESNA 1993*). For the various light equipment configurations that were judged to be optimal, the calculated veiling luminance ranged from zero up to approximately 0.25 candelas. Higher levels of veiling luminance were associated with light equipment configurations that were rated as producing significant discomforting glare.

  Disabling and discomforting motorist glare is a significant issue. Excessive glare can temporarily blind drivers as they approach the flagging station. In some cases during the project site testing, the workers set up flagging stations that placed more than enough light on the flagger but caused significant glare to the motorists. This was typically the case when a light tower with 4,000-watts output was used, and when the luminaires on the light equipment were not aimed at the flagger. Special consideration should be given to reducing the amount of motorist glare when planning and setting up a flagging operation. Use of a light tower with 4,000-watts output is discouraged, except in cases where there is significant surrounding and background lighting.

6.3 RECOMMENDED LIGHTING SYSTEM GUIDELINES FOR HIGHWAY WORK ZONE FLAGGERS

To safely illuminate a flagger during flagging operations, the light equipment should be selected, configured, located, and oriented to meet the illumination requirements recommended in Section 6.2 of this report. A variety of the different light equipment configurations tested can accomplish this task. However, some of the systems performed better than others in providing the illumination needed to safely illuminate the flagger. The following are recommended guidelines for light equipment to meet the illumination requirements:

- *The light equipment should be located on the same side of the roadway as the flagger.* Locating the light equipment close to the flagger permits maximum illumination of the flagger and assists the motorist in quickly identifying the location of the flagger relative to the source of light. If site conditions prohibit locating the light equipment on the same side of the roadway as the flagger, the light equipment may be located on the other side of the roadway and shine across the roadway at the flagger as long as this does not create glare for traffic approaching the flagging station from other directions.

- *The light equipment should illuminate the flagger from above at a height of approximately 15-25 feet (minimum of 12 feet).* Raising the luminaires high above the flagger decreases the amount of glare experienced by both the motorists and flagger. Lower luminaire heights increase the glare for both the flagger and the motorist.

- *The light equipment should be located on the roadway shoulder approximately 5-10 feet from the edge of the lane.* At this distance, the light equipment will be close enough to provide sufficient illumination over the flagging area, but not too close to the roadway to create a potential roadway obstruction. In addition, the short distance between the edge of the lane and light equipment provides room for the flagger to escape oncoming traffic if needed.

- *The light equipment should be placed at approximately a 15° offset angle to the flagger (minimum offset angle = 0°, maximum offset angle = 30°).* The offset angle is the angle, measured in a horizontal plane, from a line perpendicular to the centerline of the roadway at the flagger location to the line of sight between the flagger and the light. A light placed directly adjacent the flagger would create a 0° offset angle. The offset angle is created by moving the light equipment in the direction of the oncoming traffic. Situating the light equipment in the direction of the oncoming traffic increases the illumination of the flagger, and decreases the flagger uniformity ratio on the side of the flagger visible to the oncoming motorists.

- *The total output of all of the lamps used in the light equipment should be at least 250-watts and not exceed 2,000-watts.* The lower output limit of 250-watts ensures that the flagger and flagging area will be sufficiently illuminated. The upper limit of 2,000-watts keeps the motorist glare from being overly disabling and discomforting.

- *The light equipment output should be increased as the illuminance from, and number of, surrounding and background lights increases.* In order to make the flagger and flagging area stand out from the surroundings, light equipment with higher output should be used in suburban/urban settings in which there are existing surrounding and background lights. In addition, the output should be increased if the lights from construction and maintenance equipment are immediately behind the flagging station. Light equipment with lower output may be used in rural settings in which there is little or no surrounding artificial lighting.

- *Spotlights should not be used.* Luminaires designed as spotlights concentrate the light in a small area. However, flagging operations typically require the flagger to move around the flagging area to control the traffic. When using a spotlight, the flagger may move out of the light and not be readily visible to the motorists. Floodlights, which cast the light over a broad area, should be used.

- *The luminaires on the light equipment should be aimed directly at the flagger when standing in the initial flagging position.* Luminaires that are aimed in other directions may not fully illuminate the flagger and may create additional glare to oncoming motorists.

- *When site conditions constrain the light equipment to be located or oriented such that the motorists experience significant glare, shielding should be provided to reduce the amount of motorist glare.*

6.3.1 Recommendations for flagger illumination operations that require high mobility

For some maintenance and construction work, flagging operations must be mobile. Mobile flagging operations rely upon light equipment that moves along with the operation, either mounted on vehicles or on portable stands that are easily moved to keep pace with the work. Maintenance activities such as lane striping, debris removal, and pavement crack repair often require that the flagger and light equipment be moved frequently. For such operations, a typical light tower that consists of a trailer-mounted generator and large boom with luminaires is not appropriate. Light towers require a significant amount of time to set up, locate in an appropriate position on the shoulder, take down, and transport to the next flagging location. In addition, the lamps on a light tower can take several minutes to warm up and illuminate. Moving light towers at night with the tower in the raised position and the lamps illuminated should be avoided because of the risks involved. Therefore, light towers are not recommended for flagging operations that require high mobility.

When the work to be conducted requires that the flagging station be moved frequently, equipment that is more mobile is suggested. Workers should be able to quickly set up and locate the light equipment in an appropriate position to illuminate the flagger. The equipment should be designed such that it can be quickly taken down and transported to the next location, usually in the back of a truck or small trailer. It should also not be too heavy for one or two people to carry. In addition, there should be little or no delay in the time it takes the lamps to illuminate. Lights that take a long time to illuminate can delay the work, and can create a hazardous situation if not fully illuminated when put into use. The following are examples of types of light equipment that provide high mobility and sufficient flagger illumination:

- A 12-volt light system mounted on a portable light stand and powered by a truck battery nearby (similar to the 12-volt H.I.D. floodlight tested in this study).
- A light system mounted on a portable light stand with wheels and powered by a small, portable generator that is also attached to the light stand (similar to that shown in Figure 3.1a).
- A light system mounted on a truck and powered by the truck's battery (similar to that shown in Figure 3.1b), or by a small, portable generator located in the truck.

Other types of systems may be available that provide sufficient mobility. Regardless of the type of mobile system used, the light equipment must meet the recommended minimum requirements for illuminating the flagger. It should provide the minimum level of illumination on the ground surface and the flagger, and it should be located and oriented to minimize motorist glare and illuminate the flagger for the approaching traffic. The light output should be at least 250-watts in rural conditions where there is no other artificial lighting and should be increased when surrounding lighting exists. The light equipment should be located on the same side of the roadway as the flagger, at an offset angle of approximately 15°, and the luminaires should be elevated at least 12 feet above the ground surface and aimed directly at the flagger. The actual type of equipment, light output, location, and orientation used should be modified to take into account actual work site conditions such as weather impacts, obstructions, and roadway features, and should not impede the path of passing motorists.

A vehicle's headlights should not be used as a means to illuminate a flagger. The use of vehicle headlights to illuminate a flagger is unacceptable because it creates a dangerous glare situation. Of equal concern is when the flagger is placed in a backlighted situation, making it extremely difficult for the driver to observe the flagger's instructions. Flaggers should be lighted from the front to avoid this hazard.

6.3.2 Recommendations for flagger illumination during incident response operations

Certain nighttime operations must be conducted immediately to restore safe roadway operation. Examples include repairing traffic signals, replacing "STOP" signs and other critical signs, removing debris from travel lanes, repairing serious pavement defects, and establishing traffic controls to respond to incidents such as crashes, spills, or natural disasters (*FHWA 2003*). In such instances, flagging operations may be selected to temporarily control traffic. This type of flagging operation is characterized by the need to be set up very quickly by a minimum number of workers, perhaps in a remote location, and stationary for a short period of time until the operation can be completed or additional lighting is provided.

Flagging operations should not be used, even in an emergency situation, unless adequate illumination of the flagger can be provided and the safety of the flagger, motorists, and workers can be ensured. At least 250 watts of light should be used in rural conditions where there is no other artificial lighting. The amount of light output should be increased when surrounding and background lighting exists such that the flagger stands out from the surrounding light. If additional light is not available at the time of the incident, the flagging station should be located away from the surrounding and background lights as far as possible. The light equipment should be located on the same side of the roadway as the flagger, at an offset angle of approximately 15°, and the luminaires should be elevated at least 12 feet above the ground surface and aimed directly at the flagger. Handheld flashlights, portable lights located at the ground level, and vehicle headlights should not be used as the sole means for illuminating the flagger. The actual type of equipment, light output, location, and orientation used should be modified to take into account actual conditions such as weather impacts, obstructions, and roadway features, and should not impede the path of passing motorists.

The light equipment that is recommended for operations which require high mobility, described in the previous section, provides sufficient lighting in emergency situations. It is suggested that ODOT incident response vehicles, and other vehicles that may respond to emergency situations (e.g., ODOT Maintenance vehicles), carry these or similar types of light systems for use in illuminating flaggers.

6.4 RECOMMENDED MODIFICATIONS TO ODOT'S *2002 STANDARD SPECIFICATIONS*

As described previously, Section 00225 – Work Zone Traffic Control, of the ODOT *2002 Standard Specifications* provides direction on flagger operations and illumination (*ODOT 2002*). The findings of this research study provide additional knowledge about flagger illumination that should be incorporated into the *Standard Specifications*. Suggested modifications to the *Standard Specifications* are provided below. Additions to the existing specifications are shown underlined, and strikethrough is used to identify text to delete.

Materials:

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

- <u>Provide flagger illumination sufficient to ensure the safety of the flagger, motorists, and workers during flagging operations.</u>
- <u>Illuminate the roadway surface throughout the designated flagging area, and for a distance of 1.5 m (5 feet) beyond the designated flagging area in all directions, with at least 54 lux (5 foot-candles), or at least two times the amount of illumination provided by other light sources without the light equipment used to illuminate the flagger present, whichever is greater, where the designated flagging area is defined as follows:</u>
    - <u>The designated flagging area is the area of roadway over which the flagger will move to control traffic during the flagging operation.</u>

    - The designated flagging area should have a radius of at least the width of the lane on which traffic is being controlled.
    - The center of the designated flagging area should coincide with the initial flagger location at the start of the flagging operation.
- Illuminate the flagger such that the flagger is visible, and is discernable as a flagger, from a distance of 300 m (1,000 feet).
- The roadway uniformity ratio (the ratio of the average illuminance to the minimum illuminance) over the designated flagging area should be 5:1 and no greater than 10:1.
- The flagger uniformity ratio (the ratio of the average illuminance to the minimum illuminance) over the surface of the flagger's body facing the traffic being stopped should be no greater than 5:1.
- The veiling luminance (glare) experienced by motorists when approaching and passing through the flagging area should be as low as possible, and not greater than 0.25 candelas or 1/3 of the average pavement luminance, whichever is less.
- ~~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 luminaire.~~
- ~~Provide shielding to prevent the illumination from adversely affecting traffic.~~

Equipment:

00225.26 Light Equipment used for Illuminating Flaggers at Night – Use light equipment as follows:

- Use light equipment that sufficiently illuminates the flagger and flagging area, and meets the mobility requirements of the operation.
- Locate the light equipment on the same side of the roadway as the flagger. If the light equipment cannot be safely located on the same side of the roadway as the flagger, it may be located on the opposite side of the roadway.
- Locate the light equipment on the roadway shoulder 5-10 feet from the edge of the travel lane.
- Illuminate the flagger from above at a height of approximately 15-25 feet (minimum of 12 feet).
- Place the light equipment at approximately a 15° offset angle to the flagger (minimum = 0°, maximum = 30°), where the offset angle is the angle, measured in a horizontal plane, from a line perpendicular to the centerline of the roadway at the flagger location to the line of sight between the flagger and the light. The offset angle is created by moving the light equipment in a direction towards the traffic being controlled.
- Aim all of the luminaires directly at the flagger.
- Provide a total output of at least 250-watts. Increase the output above 250-watts as the illuminance from, and number of, surrounding and background lights increases. Do not provide a total output more than 2,000-watts, unless located in an "urban" setting in which the surrounding and background lighting is extensive and more than 2,000-watts is needed to make the flagger stand out from the surrounding and background lighting.

- <u>Use high-intensity discharge (H.I.D.) lamps, such as high pressure sodium or metal halide, or halogen lamps. Other types of lamps shall be pre-approved by ODOT.</u>
- <u>Do not use spotlights that concentrate the light in a small area.</u>
- <u>When site conditions constrain the light equipment to be located or oriented such that motorists experience significant glare, provide shielding to reduce the amount of motorist glare.</u>

00225.27 Flaggers – Equip flaggers as follows:

- Clothing to cover the complete body except head, neck, and arms below the point of the shoulders.
- An orange, yellow, strong yellow-green, or fluorescent versions of these colors, retroreflective vest. The retroreflective material shall be orange, yellow, white, silver, strong yellow-green, or a fluorescent version of one of these colors, and shall be visible at a minimum distance of 300 m (1,000 feet). The vest shall be designed to identify the wearer as a person and be visible through the full range of body motions.
- A fluorescent yellow-green, orange, yellow, or bright white hardhat or baseball-style cap. Wear hardhats when there is danger of falling or flying objects or electrical shock or burns.
- Highly visibly “STOP/SLOW” sign paddles conforming to the MUTCD and fabricated using encapsulated lens reflective sheet or brighter.
- For flaggers farthest from the work site, as indicated in 00225.47, a minimum 610 mm (24 inch) square red flag made of tightly woven fabric or plastic attached to a 914 mm (36 inch) long staff or highly visible “STOP/SLOW” sign paddles. The free edge shall be weighted.
- Portable, self-contained two-way radio with a range suitable for the Project.
- Illuminated stand area of high visibility at night.

Construction:

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

00225.47 Flaggers – Locate flaggers far enough in advance of the work area to permit adequate time for the motorist to respond to the flagger’s instructions. When two flaggers are used for one direction of traffic in advance of a worksite, the flagger farthest from the site may use either a red flag or “STOP/SLOW” sign paddle. The flagger nearest the worksite shall use only the “STOP/SLOW” sign paddle.

When one flagger is used in advance of a worksite, that flagger shall use only the “STOP/SLOW” sign paddle.

Position flaggers, as directed, at locations where traffic can enter the highway within the limits of the work zone. Direct vehicles entering the highway to follow the pilot car line.

Flagging stations shall be staffed continuously or until the Engineer determines flagging is no longer required.

Provide continuous illumination as required for nighttime flagging or until the Engineer determines the illumination is no longer required.

Maintenance:

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 luminaire system.
- Repair equipment and parts recommended by the manufacturer or have an acceptable backup temporary luminaire.

6.5 RECOMMENDED MODIFICATIONS TO ODOT'S TRAFFIC CONTROL ON STATE HIGHWAYS FOR SHORT TERM WORK ZONES MANUAL

As described previously, ODOT's *Traffic Control on State Highways for Short Term Work Zones* manual provides a quick reference for controlling traffic through short term work zones on state highways (*ODOT 1998*). The manual is based on the principles set forth in Section 6 of the *Manual on Uniform Traffic Control Devices*, published by the Federal Highway Administration (FHWA), and the *1996 Short Term Traffic Control Handbook*. The ODOT guidelines are intended to be used for emergency or incident traffic control if practical. Suggested modifications to the manual are provided below. Additions to the existing manual are shown underlined, and strikethrough is used to identify text to delete.

Night Operations

All signs, cones and barricades intended for use during hours of darkness shall be reflectorized.

When flaggers are used, flagger stations should be illuminated with a floodlight <u>that provides a minimum of 250-watts output. The light output should be increased above 250-watts as the illuminance from, and number of, surrounding and background lights increases. More than 2,000-watts of output should not be provided unless located in an "urban" setting in which the surrounding and background lighting is extensive and more than 2,000-watts is needed to make the flagger stand out from the surrounding and background lighting.</u>

<u>The illuminated area on the roadway surface should have a radius of at least the width of the lane plus 5 feet, and be centered on the flagger in the initial flagging position. The size of the illuminated area should be increased to account for flagger movements required to control traffic.</u>

The light should not create ~~a~~ glare for motorists. When site conditions constrain the light equipment to be located or oriented such that motorists experience significant glare, shielding or other measures should be taken to reduce the amount of motorist glare.

The light equipment should be located on the roadway shoulder 5-10 feet from the edge of the travel lane on the same side of the roadway as the flagger. If the light equipment cannot be safely located on the same side of the roadway as the flagger, locate it on the opposite side of the roadway. If located on the opposite side of the roadway, ensure that it does not create excessive glare for motorists approaching in all directions.

The flagger should be illuminated from above at a height of approximately 15-25 feet (minimum of 12 feet). In addition, the light equipment should be placed at approximately a 15° offset angle to the flagger (minimum = 0°, maximum = 30°) with all luminaires aimed directly at the flagger. The offset angle is the angle, measured in a horizontal plane, from a line perpendicular to the centerline of the roadway at the flagger location to the line of sight between the flagger and the light. The offset angle is created by moving the light equipment in a direction towards the traffic being controlled.

The flagger should be illuminated such that the flagger is visible, and is discernable as a flagger, from a distance of 300 m (1,000 feet).

Floodlights should be used instead of spotlights.

When the flagging operation is required to move along with the work, consideration should be given to the mobility of the light equipment. Portable light stands and vehicle-mounted lights provide greater mobility than light towers.

When one or more lanes of a multi-lane state highway are closed at night, an arrow panel should be used for each lane being closed.

Overnight traffic control should be checked at least once during the night.

6.6 FLAGGER ILLUMINATION CHECKLIST

The checklist in Figure 5.7 provides guidance for: 1) assessing the flagger illumination requirements on a work site; 2) selecting the appropriate light equipment to use; and 3) determining the appropriate location and set-up of the equipment. It is important to note that since projects may differ in many ways, the checklist does not address all of the conditions that may exist related to flagger illumination on a work site. Therefore, the checklist should be used for guidance only, and should not be relied upon as a comprehensive list of items to check. Consideration should be given to site-specific features and flagging requirements. Those planning and conducting nighttime flagging operations should also use their own experience and knowledge of flagging operations for guidance on what to examine and look for to ensure the safety of the flagger, motorists, and workers.

FLAGGER ILLUMINATION CHECKLIST

Project Name: ____________________________________ Project No: ______________

Location: ____ Date: ___________________

Description of Maintenance/Construction Work: ____

____

Checked by: Name: ____

Company/Agency: ____

NO.	CHECKLIST ITEM	YES	NO
1.	Flagger illumination is sufficient to ensure the safety of the flagger, motorists, and maintenance and construction personnel during the flagging operations.	❐	❐
2.	Light equipment meets mobility and duration of use requirements for the flagging operation.	❐	❐
3.	Flagging station is located away from roadway and maintenance/construction work zone features that obstruct the motorist's view of the flagger or control of the traffic by the flagger.	❐	❐
4.	Flagging station is located away from intersecting roadways, ramps, or driveways.	❐	❐
5.	When located near intersecting roadways, ramps, or driveways, light equipment is positioned such that it illuminates the flagger for all oncoming traffic, and does not create excessive glare for all oncoming traffic.	❐	❐
6.	Designated flagging area has been identified and meets the following requirements:		
	• Designated flagging area extends over the entire area throughout which the flagger will move during the flagging operation.	❐	❐
	• Designated flagging area has a radius of at least the width of the lane on which traffic is being controlled.	❐	❐
	• Center of designated flagging area coincides with the initial flagger location at the start of the flagging operation.	❐	❐
7.	The size and location of the designated flagging area have been communicated to the flagger.	❐	❐
8.	The roadway is illuminated uniformly throughout the designated flagging area (i.e., no dark areas are present, and the difference between areas of low illumination and areas of high illumination is not significant).	❐	❐
9.	The minimum illumination required is provided throughout an area of roadway that extends five feet beyond the designated flagging area in all directions.	❐	❐
10.	The flagger is illuminated such that the flagger is visible, and is discernable as a flagger, from a distance of 1,000 feet.	❐	❐
11.	The flagger is illuminated uniformly on the side of the flagger's body and on the "STOP/SLOW" paddle that face the approaching traffic (i.e., no dark areas are present, and the difference between areas of low illumination and areas of high illumination is not significant).	❐	❐
12.	The glare experienced by the approaching motorists is not disabling or discomforting.	❐	❐
13.	The glare experienced by the flagger is not disabling or discomforting.	❐	❐

Figure 5.7: Flagger illumination checklist

14.	The light equipment is located on the same side of the roadway as the flagger or, if on the other side of the roadway, it does not create excessive glare for all approaching traffic.	❒	❒
15.	The light equipment illuminates the flagger from above at a height of approximately 15-25 feet (minimum of 12 feet).	❒	❒
16.	The light equipment is located on the roadway shoulder between 5 and 10 feet from the edge of the travel lane.	❒	❒
17.	The light equipment is placed at approximately a 15° offset angle to the flagger (minimum offset angle = 0°, maximum offset angle = 30°). (Note: The offset angle is the angle, measured in a horizontal plane, from a line perpendicular to the centerline of the roadway at the flagger location to the line of sight between the flagger and light. The offset angle is created by moving the light equipment in a direction towards the traffic being controlled and rotating it so that it shines back on the flagger.)	❒	❒
18.	The total output of all of the lamps used in the light equipment is at least 250-watts and does not exceed 2,000-watts.	❒	❒
19.	The light equipment output is increased as the illuminance from, and number of, surrounding lights increases such that the flagger and flagging area stand out from the surrounding and background lights, including the lights used to illuminate the maintenance or construction work.	❒	❒
20.	All of the luminaires on the light are aimed directly at the flagger in the flagger's initial flagging position.	❒	❒
21.	Spotlights are not used.	❒	❒
		❒	❒
		❒	❒

Other Considerations/Comments: ______________________________

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Figure 5.7 (continued): Flagger illumination checklist

6.7 FLAGGER ILLUMINATION ASSESSMENT FLOWCHART

The type of equipment, its location and orientation, and the appropriate amount of light output to use for a flagging operation will depend on how the equipment will be used and the conditions under which it will be used. How the flagger will be illuminated should be considered prior to conducting the flagging operations in order to ensure proper illumination and the safety of the flagger, motorists, and workers.

When considering how to illuminate a flagger many different questions should be asked related to the required mobility of the equipment and duration of its use, amount of surrounding light, overall roadway features, and conditions at the selected flagging location. Provided below is a simplified flowchart designed to assist in the identification of the appropriate type of lighting equipment to use for an operation and how it should be located and set up. The flowchart consists of three parts: Part 1 – Light Equipment Selection; Part 2 – Flagging Station Location Assessment and Selection; and Part 3 – Light Equipment Set-up and Configuration. All parts of the flowchart should be considered and followed in the order presented.

The flowchart should be used before the flagging operation begins to help plan the operation, and by someone who has experience with nighttime flagging operations and training in setting up flagging operations. An assessment of the existing site conditions should be made prior to using the flowchart and commencing the flagging operations. When existing site conditions are unknown, the site conditions should be evaluated at a time similar to when the flagging operations will take place (i.e., at night, under similar traffic, weather, and background lighting conditions). When conditions exist that are not addressed in the flowchart, other references should be considered to determine how to effectively and safety illuminate the flaggers.

The following are definitions and descriptions of some of the terms used in the flowchart:

- Flagging operation mobility and duration:
  - *Stationary, long-term*: Flagging operations that will be located in the same place for an extended period of time, e.g., for several days or weeks, such as for construction or maintenance operations in a fixed location.
  - *Stationary, short-term or incident response*: Flagging operations that will be located in the same place for a short period of time, e.g., for one day or less, or in incident response operations.
  - *Periodic*: Flagging operations that are required to be mobile and which will be re-located several times during a single work shift.
  - *Frequent*: Flagging operations that require high mobility and will be moved often during a single work shift.

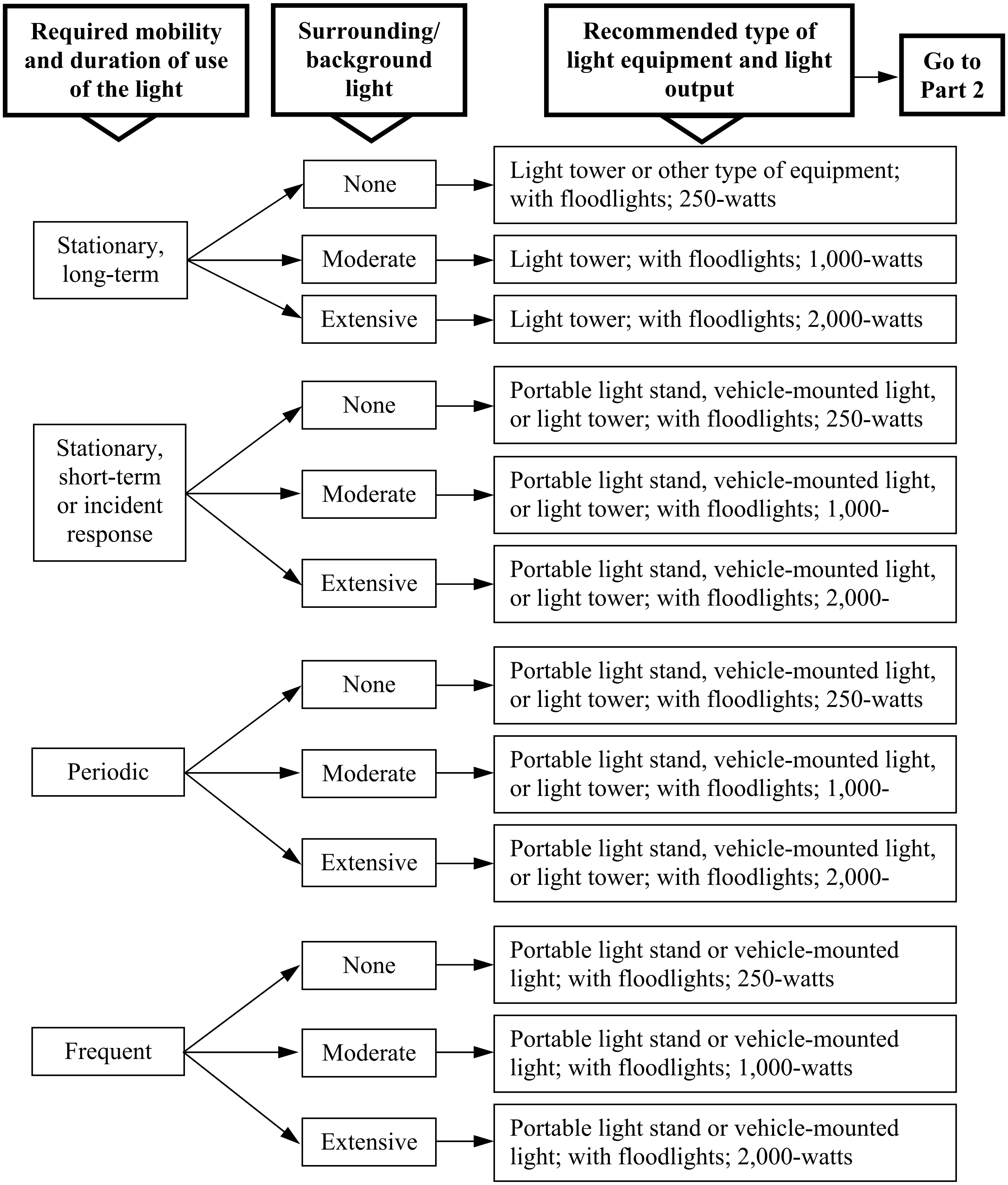
- Surrounding light levels:
  - *None*: There is no natural light, except for moonlight, and no artificial lighting in the vicinity of the flagger. This condition is represented by a "rural" setting.
  - *Moderate*: There is no natural light, except for moonlight, and a moderate amount of artificial lighting and number of artificial lights in the vicinity of the flagger.

This condition is represented by a “suburban” setting in which low output street lights and residential lights are scattered throughout the area.

- *Extensive*: There is no natural light, except for moonlight, and a substantial amount of artificial lighting and number of artificial lights in the vicinity of the flagger. This condition is represented by an “urban” setting in which low, medium, and/or high output street lights, residential lights, and commercial business lights are densely located throughout the area.

FLAGGER ILLUMINATION ASSESSMENT AND SELECTION FLOWCHART

Part 1 – Light Equipment Selection[7]



[7] The light output levels shown for Moderate and Extensive surrounding light conditions are estimates. The amount of light output provided should be determined based on the actual output and number of surrounding and background lights existing at the flagging station such that the flagger stands out from the surrounding and background lights.

Part 2 – Flagging Station Location Assessment and Selection

Presence of roadway and/or maintenance/construction work features that could impact the motorist's view of the flagger or control of traffic by the flagger	**Location of flagging station**
None	Any safe location along the roadway.
Horizontal or vertical curves; bridges, walls, or other structural features; or other roadway or work zone features that limit motorist and/or flagger sight distance	Any safe location along the roadway that provides approaching motorists an unobstructed view of the flagger from at least 1,000 feet.
Intersecting roadways, ramps, or driveways	As far away from the features as possible. Ensure that the light equipment is located such that it illuminates the flagger for all approaching traffic, and that the light emitted does not create excessive glare for all approaching traffic.
Lights used for the maintenance or construction work	At a safe distance away from the lights such that the amount of light provided by the light equipment makes the flagger stand out from the lights used for the maintenance or construction work.
	If the flagging station cannot be moved away from the maintenance or construction work, increase the light output such that it makes the flagger stand out from the lights used for the maintenance or construction work.

Go to Part 3

Part 3 – Light Equipment Set-up and Configuration

Existing conditions at selected flagging station location	Recommended set-up and configuration of light equipment → End
No impacts to set-up and configuration of light equipment.	Light equipment 5-10 feet from edge of lane on same side of roadway as flagger; 15^{o} offset angle (0^{o} min./30^{o} max.); luminaires at 15-25 feet high (12 feet min.) and aimed at flagger; and roadway illuminated with 5 Fc for at least 5 feet beyond the designated flagging area in all directions.
Overhead obstructions, such as power lines, trees, or elevated structures, at the flagging station.	Move flagging station to a different location that does not have the obstructions, and use the same set-up and configuration as that recommended when no impacts are present.
	If no other unobstructed location exists, use the same set-up and configuration as that recommended when no impacts are present, and lower the luminaires to no less than 12 feet high.
No shoulder or right-of-way area on which to locate the light equipment.	Move flagging station to a different location that has sufficient shoulder or right-of-way area, and use the same set-up and configuration as that recommended when no impacts are present.
	If sufficient shoulder or right-of-way area is present on the other side of the roadway, move light equipment to the other side of the roadway, and use the same set-up and configuration as that recommended when no impacts are present. Ensure that the light equipment does not create excessive glare for all approaching traffic.
Obstructions preventing the light from illuminating all of the flagger or the entire designated flagging area.	Move flagging station to a different location that does not have the obstructions, and use the same set-up and configuration as that recommended when no impacts are present.
	Use the same set-up and configuration as that recommended when no impacts are present, and add one or more additional lights to illuminate the shaded areas on the flagger and/or roadway.

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