Work Zone Illumination Design: Guidance Strategies to Specify Appropriate Work Zone Lighting Plan

Sherine Anani
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WORK ZONE ILLUMINATION DESIGN GUIDANCE

STRATEGIES TO SPECIFY APPROPRIATE WORK ZONE LIGHTING PLAN

by

Sherine Anani

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Engineering at The University of Wisconsin-Milwaukee

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ABSTRACT

WORK ZONE ILLUMINATION DESIGN GUIDANCE
STRATEGIES TO SPECIFY APPROPRIATE WORK ZONE LIGHTING PLAN

by
Sherine Anani

The University of Wisconsin-Milwaukee, 2015
Under the Supervision of Professor Yue Liu

Night construction is frequently used because it can better satisfy the primary traffic control objectives than daytime work. If night construction is used, the design of illumination plans should be analyzed and developed as part of the project development process.

There are fewer crews out working on the road in the winter, partly because of the conditions but also because the days are shorter and there’s not a lot of light by which to work.

In fact, the days can get short enough, especially as you go farther north, that even a normal day involves some “night work.” Construction work zones are also increasingly active at night during the summer to accommodate traffic and tight project schedules. At any time of the year, road construction at night requires proper lighting to ensure quality work and for everyone’s safety.
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Chapter 1

1. Introduction:

1.1. Purpose

Previous research has shown lighting to be one of the most important factors in nighttime construction. Safety in the work zone, quality of work, and morale of workers are all directly related to work zone lighting.

Before allowing or mandating night construction as an option or as a requirement in the, two fundamental conditions should be met in order for night construction to proceed: reduced traffic volumes; and setup and removal of temporary traffic control patterns can be done on a nightly basis.

Night construction is increasingly used on highway construction and maintenance projects. Frequently-mentioned reasons for using night construction include:

- Compressing the project schedule by increasing the number of hours worked each day.
- Reducing traffic delays associated with lane closures by completing the work at a time when traffic volumes are low.
- Minimizing operational disruptions by completing emergency repairs or preventative maintenance at night.
- Minimizing safety risks to road users associated with activities such as overhead demolition, setting girders, or stringing electrical wires across the roadway.
- Improving product quality and increasing worker comfort in hot climates by completing the work when outdoor temperatures are relatively low.

This document has three objectives:

- To provide designers with an overview of the main design considerations related to work zone illumination.
• To assist designers in deciding when to specify the use of night construction techniques.
• To assist designers in determining how to specify appropriate work zone lighting in contractual documents.

As shown in Figure 1, well-designed work zone lighting contributes to worker safety, the safety of drivers and other road users, work quality, productivity, and worker morale. Conversely, poorly-designed work zone lighting can create situations that are hazardous for workers, drivers, and other road users.

As they develop project plans and contractual provisions, designers face a choice of three fundamental options related to night construction:

1. *Requiring* the work to be done at night (for example if night construction is necessary to manage traffic impacts).

2. *Allowing* the work to be done at night at the discretion of the contractor and/or field engineer.
3. Prohibiting the work from being done at night (for example if working at night would have excessive noise/vibration impacts on nearby residents, or if artificial illumination cannot be used without compromising traffic safety).

Many highway designers are unfamiliar with lighting design. Perhaps for this reason, in the past designers often left the selection of work zone illumination systems to the discretion of the contractor or field engineering staff—who may also be unfamiliar with illumination. Too often, this has resulted in work zones with excessive glare that creates a serious safety hazard, as shown in Figure 2. Therefore, illumination should be considered during the design phase whenever night construction will be required or allowed. This requires the following actions during the project design phase:

- *Minimum and maximum* illumination levels should be specified in the contractual documents, along with preferred illumination methods.
- The contractual documents should include provisions for agency approval of the type and location of contractor-supplied lighting. Typically this can be accomplished either by means of shop drawings or through a field demonstration at least 24 hours prior to the start of each new lighting set-up.
- Contractual provisions should be established to require the contractor to modify the lighting system if it presents a safety hazard to workers, drivers, or other road users.

Figure 2. Blinding glare caused by poorly-positioned work zone illumination at a freeway work zone. Source: Lakeside Engineers.
For the purposes of this document it is sufficient to note that night work is increasingly used on highway construction and maintenance projects for various reasons, such as expediting the project schedule by working more hours each day, limiting lane closures to off-peak hours, and improving worker comfort in hot climates.

This document uses the engineering term luminaire to refer to a lighting fixture and the term lamp to refer to the light source within a luminaire. Contractors are more likely to call the former a light and the latter a bulb.

1.2. Case of study

In this thesis I tried to give a practical way to check the light plan provided by the contractor or to engineers, I modeled a work zone and showed the layout of a typical asphalt paving operation by going to WisDot standards and added some traffic control by going back to MUTCD manual book.

I Used the Sketch Up software to model the 3D workzone with the Asphalt truck, paver and rollers. I export this model to Agi32 software to add the lightening plan and do all the calculations needed to analyze the plan.

In order to know how to accept or reject the light plan we have to understand several concepts related to lightening.

We have to study the Human Vision: Brightness, Contrast, and Glare, we have to understand the Lighting Intensity and Uniformity and the difference between illuminance and luminance, we have to know about the Commercially Available Lighting Technologies and Equipment.

In this thesis I am going to identify and talk about all these concepts before starting the analysis process.
Chapter 2

2. Illumination Design

2.1. Glossary:

**Illuminance**: The amount of light falling on a surface, measured in foot-candles (US customary units) or lux (metric units). $1 \text{ fc} = 10.764 \text{ lux}$.

Illuminance may be increased by increasing the intensity of a light source, increasing the number of light sources, or decreasing the distance of the light sources from the surface area.

**Luminance** is a photometric measure of the luminous intensity per unit area of light travelling in a given direction. It describes the amount of light that passes through, is emitted or reflected from a particular area, and falls within a given solid angle.

**Glare**: A condition of vision in which there is discomfort or a reduction in the ability to see details or objects, caused by an unsuitable distribution or range of illuminance, or by extreme contrasts.

**Brightness**: Illuminance, as perceived by the human eye.

**Lamp**: A bulb or other device that produces light.

**Luminaire**: A light fixture.

2.2. Classification of Illumination Requirements by Task

Illumination can be divided into three levels: Level I is required throughout the work zone, while active work areas where equipment is operating require Level II or Level III, depending on the difficulty of the work and how much it depends on worker visual performance.

**Level 1**: This level of illuminance is recommended for:
• the general illumination of all work operations by contractor’s personnel in areas of general construction operations, including layout and measurements ahead of the actual work, excavation, cleaning and sweeping, landscaping, planting, and seeding.
• stockpiles, are illuminated to Level I to enhance safety
• areas where crew movement may take place involving slow-moving equipment, and having large objects to be seen
• Area of lane or road closures continuously throughout the period of closure, including the setup and removal of the closures.

**Level II**: This level of illuminance is recommended for areas on or around construction equipment
Examples: Asphalt paving, milling, and concrete placement and removal

**Level III**: This level of illuminance is suggested for tasks requiring a higher level of visual performance.
Examples: joint repair, pavement patching and repairs, pavement patching and repairs

This following table will presents a summary of the findings and recommended guidelines for illumination of nighttime highway work, the content of the guidelines includes recommended minimum illumination levels for different nighttime highway work tasks. (RALPH D. ELLIS, 2003)
This table was created from the NCHRP 498 report, where:

<table>
<thead>
<tr>
<th>Category</th>
<th>Minimum illumination</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I</strong></td>
<td>54 lx (5 fc)</td>
</tr>
<tr>
<td><strong>II</strong></td>
<td>108 lx (10 fc)</td>
</tr>
<tr>
<td><strong>III</strong></td>
<td>216 lx (20 fc)</td>
</tr>
<tr>
<td>Category I</td>
<td>Category II</td>
</tr>
<tr>
<td>------------------------------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>Excavation – Regular, Lateral Ditch, Channel</td>
<td>Barrier wall, Traffic Separators</td>
</tr>
<tr>
<td>Embankment, Fill and Compaction</td>
<td>Milling, Removal of Pavement</td>
</tr>
<tr>
<td>Asphalt Pavement Rolling</td>
<td>Asphalt Paving and Resurfacing</td>
</tr>
<tr>
<td>Subgrade, Stabilization, and Construction</td>
<td>Concrete Pavement</td>
</tr>
<tr>
<td>Base Course Rolling</td>
<td>Base Course Grading and Shaping</td>
</tr>
<tr>
<td>Sweeping and Cleaning</td>
<td>Surface Treatment</td>
</tr>
<tr>
<td></td>
<td>Waterproofing and Sealing</td>
</tr>
<tr>
<td></td>
<td>Sidewalk Construction</td>
</tr>
<tr>
<td></td>
<td>Guard Rails and Fencing</td>
</tr>
<tr>
<td></td>
<td>Striping and Pavement Marking</td>
</tr>
<tr>
<td>Landscaping, Sod and Seeding</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Highway Signs</td>
</tr>
<tr>
<td></td>
<td>Bridge Decks</td>
</tr>
<tr>
<td></td>
<td>Drainage Structures and Drainage</td>
</tr>
<tr>
<td></td>
<td>Piping</td>
</tr>
<tr>
<td>Maintenance of Embankments</td>
<td></td>
</tr>
<tr>
<td>Reworking Shoulders</td>
<td></td>
</tr>
</tbody>
</table>
2.3. Glare

Glare is a sensation caused by bright light in one’s field of view. Glare can reduce one’s ability to see, create feelings of discomfort or both.

The eye reacts in two distinct ways to the presence of glare:

- discomfort glare: has no direct effect on vision
- disabling glare: effectively reduces contrast and, therefore, visibility of objects

The pictures in figure 2 earlier showed the glare caused by a light in a work zone in US 10 WB. Glare can lead effects:

- Decreasing visibility distance
- Increasing reaction times
- Increasing recovery time.

The Illuminating Engineering Society (IES) recommends that veiling luminance be no greater than a third of average pavement luminance.
There are a number of strategies for controlling glare. These include: (JAMES E. BRYDEN, July 2002)

- Selecting luminaires that send light in only the direction where it is needed (Figure 3).
- Using multiple luminaires to achieve a more uniform lighting level and reduce shadows.
- Installing diffusers to spread the light from each lamp more uniformly.
- Using luminaire housings and glare screens to cut off the view of undesired light sources.
- Mounting the luminaire very high (around 40 feet) to keep the lamp out of the normal field of view, or mounting it so low that it is well below eye level.

2.3.1. Techniques to control and minimize glare and illumination spillover - Glare control checklist [3]

Suggested requirements for glare control and avoidance are presented in Table 15 in the NCHRP 498 report which tells the following:

- Beam Spread: Select vertical and horizontal beam spreads to minimize light spillage.
- Mounting Height Coordinate minimum mounting height with source lumens
- Location: Luminaire beam axis crosses normal lines of sight between 45° and 90°.
- Aiming
- Supplemental Hardware
Glare is hard to measure because how light is perceived is subjective and depends on several factors (including the age of the person). However, the baseline metric used for assessing glare is luminance within a person's field of view measured at a specific vantage point (cd/m²). This is the amount of light reflecting off of a surface into a viewer’s eye (Autodesk Sustainability Workshop, 2011)

2.3.2. Unified Glare Rating (UGR):

The luminance of a lamp divided by the background of visible luminance from the room is called the Unified Glare Rating, or UGR, and it ranges from 5 to 40. The lower the number, the better. (Candelas, Lumens and Lux)

This is a simple explanation about the Unified Glare Rating (UGR):

![Diagram of Unified Glare Rating (UGR)](image)

The UGR is given by the following model:

\[
UGR = 8 \log \left[ \frac{0.25}{L_b} \sum \left( \frac{L^2}{p^2} \right) \right]
\]

Lb, the background luminance or cd/m²rd, L is the luminance of the luminaire. Looking at L and Lb,
Glare increases with stronger lamps and lower background lighting, whereas it decreases with weaker lamps and more background illumination.

- UGR < 10: Glare is so insignificant it can be ignored.
- UGR > 30: Lots and lots of glare!

The UGR model was developed by the international commission on illumination CIE, for applications of interior lighting.

2.3.3. **Glare Rating (GR)** – this model was developed by the international commission on illumination, CIE, for applications in outdoor lighting [CIE document 112-1994].

Glare rating is calculated based on illuminance on the eye when observing each point in an array of points from a single observer position. (Paper, 2014)

The calculation of Glare Rating includes terms for veiling luminance on the eye (LVL) and veiling luminance by the environment (LVE). Veiling luminance on the eye is a summation across all luminaires of the illuminance perpendicular to the line of sight (EEYEi) and divided by a factor of the angle between the viewer’s line of sight and the direction of the light (qi). Veiling luminance by the environment includes the average horizontal illuminance (EHOR,AV), the reflectance (ρ) and the unity solid angle in steradians (Ω).

Glare rating is given as:

\[
GR = 24 + 27 \log \left( \frac{L_{VL}}{L_{VE}^{0.9}} \right) \\
L_{VL} = 10 \sum_{i=1}^{n} \frac{E_{EYEi}}{(q_i)^2} \\
L_{VE} = 0.035 \times \left[ \frac{E_{HOR,AV} * \rho}{(\pi \times \Omega)} \right]
\]

This results in values ranging from 10 to 90, where 10 and below is unnoticeable and 90 is considered unbearable.
GR calculation is integrated into photometric software packages, so is useful to apply in a planning situation for an outdoor field. It should also be noted that the calculation of this value is done from a single observer’s point within the area being lit, so it’s largely dependent on what points are chosen. Due to the difficulty of separately measuring each luminaire. (Paper, 2014)

In chapter 4 we will introduce AGi32 software that can calculate the GR values using this model

2.4. Vertical and Horizontal Illumination

Imagine a warehouse worker whose job is to select the correct box amongst many products that are stacked on a large array of shelves. This task requires good vertical illumination: ideally each shelf should be lighted in such a way that the fronts of all the boxes are visible and the upper shelves do not shadow the products stacked lower down. The amount of light that falls on the floor is of lesser importance. Luminaires such as the one shown in Figure 4 might be selected.

![Figure 5: Low bay luminaire with omnidirectional lighting pattern.](http://www.gelighting.com/LightingWeb/na/solutions/indoor-lighting/vb5-versabeam-luminaire.jsp)

![Figure 6: Low bay luminaire with predominantly downward lighting pattern](http://www.gelighting.com/LightingWeb/na/solutions/outdoor-lighting/um5-unimount-400-luminaire.jsp)

Next consider the case of a group of highway workers whose job is to assure that newly-laid pavement has the correct surface finish. This task requires good horizontal illumination: ideally the entire pavement surface should be lighted in such a way that the workers and their equipment will not shadow the roadway surface they are trying to see. This task requires some light on
vertical surfaces such as the sides of the paving machine, but the pavement surface itself is of greatest importance. Luminaires such as the one shown in Figure 5 might be selected.

As the example above suggests, the selection of work zone lighting systems should take into consideration the tasks that are being performed. Flatwork primarily requires horizontal illumination, while building a tall retaining wall requires vertical illumination. Some tasks require both. In most cases highway construction primarily requires horizontal illumination, so it is generally possible to select lighting equipment that can be mounted overhead to direct predominantly downward. The selection of devices that provide relatively little vertical illumination can help minimize glare for drivers and spillover into areas where no work is being done. (Nchrp_Report_476_JAMES E. BRYDEN) Chapter 2.9.

### 2.5. Measuring Lighting Intensity and Uniformity

Commonly used lighting terms are most easily explained using an example. Imagine an old-style incandescent lamp (or “light bulb”). The lamp consumes a certain amount of electricity (perhaps 60 watts) and produces a certain amount of light (perhaps 800 lumens). More precisely, it emits a luminous flux of 800 lumens, which is the total amount of light going in all directions. Now imagine a 12” x 12” white card that is held a certain distance from the lamp: the amount of light falling on the card is the illuminance. In addition, the amount of light falling on the card depends on the distance between the card and the lamp: as the card is moved closer to the lamp, the illuminance increases. In US customary units illuminance is measured in foot-candles; in the metric system it is measured in lux (one foot-candle is 10.76 lux). Most of the light reflects off the card; this reflected light is called luminance. A person looking directly at the lamp also sees luminance. Luminance is usually measured in candelas per square meter (cd/m2). Human perception of luminance depends partly on the color of the light. If two adjacent parts of a scene have very different luminance levels, it is perceived as glare. As a result, both light intensity and light uniformity are important in the perception and comprehension of a scene.
Luminance and luminous flux are difficult to measure without special equipment, but illuminance can be measured easily in the field using a light meter. Since light meters are relatively inexpensive (around $25 to $250 depending on quality and features) and can be purchased at electrical supply stores or online, the standards for illumination of work zones and other work environments are based on illuminance. Illuminance can be increased by increasing the intensity of a light source, increasing the number of light sources, or decreasing the distance of the light sources from the work surface. Table 2 provides some examples to familiarize the reader with typical illuminance levels.

Table 2: Examples of Illuminance Levels

<table>
<thead>
<tr>
<th>Situation</th>
<th>Illuminance (Foot-Candles)</th>
<th>Illuminance (lux)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Moon on Clear Night</td>
<td>0.025</td>
<td>0.27</td>
</tr>
<tr>
<td>Civil Twilight</td>
<td>0.3</td>
<td>3.4</td>
</tr>
<tr>
<td>Permanent Roadway Lighting</td>
<td>0.25 to 1.5</td>
<td>3 to 16</td>
</tr>
<tr>
<td>Residential Living Room</td>
<td>4.6</td>
<td>50</td>
</tr>
<tr>
<td>60 watt incandescent bulb 20 inches away</td>
<td>9 to 12</td>
<td>100 to 125</td>
</tr>
<tr>
<td>Office Interior</td>
<td>30</td>
<td>320</td>
</tr>
<tr>
<td>Sunrise on Clear Day</td>
<td>37</td>
<td>400</td>
</tr>
<tr>
<td>Hospital Operating Room</td>
<td>1675</td>
<td>18,000</td>
</tr>
<tr>
<td>Direct Sunlight</td>
<td>3,000 to 12,000</td>
<td>32,000 to 130,000</td>
</tr>
</tbody>
</table>

2.6. Human Vision and factors

Contractors and their suppliers often take a “brighter is better” approach toward work zone lighting. This overlooks an important fact: human vision works best when lighting levels are relatively uniform. The Excessive differences in contrast or illumination levels produce the glare. Simply put, when part of a scene is very bright and part is very dark, the human eye struggles to make the entire scene viewable:
• Mild to moderate glare is uncomfortable.
• Severe glare causes people to look away, try to shield their eyes, squint, or close their eyes. These instinctive behaviors clearly are undesirable while driving.
• In extreme glare, the fluid inside the eye scatters the light and the brain is unable to process the incoming visual information: the driver is temporarily blinded.

Older people are more susceptible to glare and take longer to recover from its effects. Even for young drivers, fully adapting to a sudden change in lighting levels requires several minutes. The adjustment process is not symmetrical: the eye adapts more quickly to an increase in brightness than to a decrease. Therefore, avoiding abrupt brightness changes is an important consideration for work zone lighting design.

Contractors tend to think about work zone lighting in terms of workers and their tasks, which usually require a pool of light in the immediate vicinity of each work operation. This perspective is very different from what is seen by drivers moving through the work zone at speed, which often consists of a dynamic series of bright and dark areas. If drivers’ eyes adjust to relatively bright lighting near the main work operation (such as paving), they may not clearly see dimmer secondary work operations downstream (such as saw cutting in advance of the paver). As shown in Figure 4, a related problem is work zone lighting layouts that leave workers silhouetted against a bright background. Therefore, lights need to be aimed carefully and lighting levels throughout the entire activity area need to be relatively uniform to minimize the risk of vehicle-worker collisions.
2.7. Lighting Distractions

The more objects there are in a driving scene, the more mental effort is required for drivers to process incoming visual information and decide which objects are important to the driving task. During night work operations the number of light sources and objects (workers, vehicles, etc.) can sometimes be overwhelming. As a result, drivers (especially those travelling at high speed) will tend to ignore objects in their peripheral vision. Visual overload is particularly likely if there are large variations in lighting intensity in different parts of the scene. Flashing lights on work vehicles are intended to draw attention—but they can be an unnecessary distraction if they encourage the driver to focus on a part of the scene that is not relevant to navigating safely through the site.

Due to their almost vertical position, vehicle headlights are not good sources for production lighting. They can also be a major distraction to oncoming vehicles, especially if the work operation involves counter-directional travel on a divided highway. Contract specifications should prohibit the use of headlights while work vehicles are stationary in a lighted work area. Counter-directional travel should be avoided; when absolutely necessary it should be done at low speed with headlights off.
2.8. Commercially Available Lighting Technologies and Equipment

Five main types of electric lamps (light sources) are currently available for work zone lighting in the United States:

- **LED**: Light Emitting Diodes (LEDs) offer a number of advantages over older lighting technologies, including low power consumption, light weight, long life, and resistance to vibration and physical damage. The light produced by each individual LED module is highly directional, so most LED luminaries contain several modules aimed in different directions and a diffuser to spread the light. LEDs require no warm-up time and do not generate much heat. The color and Color Rendering Index (CRI) of LED lighting sources varies depending on the product. The most advanced products generate pure white light with a Color Rendering Index (CRI) of up to 100 (thus, the color of objects viewed under LED light can be very similar to their appearance in sunlight).

- **Incandescent**: Incandescent lamps use electric current to pass through a wire filament, often tungsten, to a high temperature, that produces a glow, as well as high temperatures. The bulb is filled with an inert gas or vacuum to prevent filament oxidation. The lamps have poorer efficacy than other lamp types since they produce a great deal of heat. Their low manufacturing cost and very good color rendering index makes the lamps a good choice for task oriented tasks and where control of light direct is critical. Due to their inefficient use of electricity, future use of the lamps are restricted by government regulations.

- **Halogen**: Halogen lamps contain a tungsten filament surrounded and a halogen gas fill (typically iodine or bromine). They require no warm-up time. Although the up-front cost is low, they are not energy-efficient and generate a considerable amount of heat. Halogen lamps have a relatively short life and the filament can break if the lamp is bumped or dropped. They produce a full spectrum with a color rendering index of 100.
- **Metal Halide**: Metal halide lamps use an electric arc through a gaseous mixture of vaporized mercury and metal halides (compounds of metals with bromine or iodine). They are similar to mercury vapor lamps, but contain additional metal halide compounds in the quartz arc tube, which improve the efficacy and color rendition of the light. The most common metal halide compound used is sodium iodide. Metal-halide lamps have high luminous efficacy of around 75 - 100 lumens per watt, which is about twice that of mercury vapor lights and 3 to 5 times that of incandescent lights. Lamp life is 6,000 to 15,000 hours. They are one of the most efficient sources of high CRI white light. Metal halide lamps can be used on poles with a variety of mounting heights, and are good for lighting medium sized areas.

- **Mercury Vapor**: Mercury vapor lamps use an electric arc through vaporized mercury to produce light. They are more energy efficient than incandescent or fluorescent lights, have a relatively long bulb life, and produce a high intensity clear white light output. However, they have a rather poor CRI of 17. Mercury vapor lamps require a warm-up period of 4 to 7 minutes to reach full light output. Mercury vapor lamps are not a recommended source for nighttime highway work [NCHRP Research Results Digest 216]

- **High Pressure Sodium**: High Pressure Sodium (HPS) lamp are an energy-efficient illumination source that produces pinkish-orange light. It is frequently used for permanent roadway lighting. A warm-up time of approximately 5 minutes is required before the lamps reach full intensity. The lamps have a long life, can operate in any position or pole mounting height, and are effective for lighting large areas. Because of the low CRI (about 25) HPS lighting may be unsuitable for certain work operations such as electrical wiring that require accurate color recognition (for example, yellow and orange objects look almost the same under high pressure sodium light). However, where good color rendition is not important, HPS lamps are not a problem. Because of the relatively long warm-up and cool-down times, HPS lamps are also inappropriate for situations where the lights must be turned on and off frequently.
• **Fluorescent**: Fluorescent lamps are a low pressure mercury vapor gas discharge lamp that uses fluorescence to produce visible light. An electric current in the gas excites mercury vapor to produce short-wave ultraviolet light that causes a phosphor coating on the inside of the bulb to glow. While fluorescent lamps are more energy efficient than incandescent lamps, the higher initial cost, a requirement that a ballast be used to provide the initial striking voltage to start the initial arc of ultraviolet light, and substantial shorten bulb life when frequent on and off switching is required. CRI values can range from 50 to 99, with lower values caused by phosphors that emit too little red light. A CRI value of 82 to 100 is common in modern lamps that use a newer halo phosphate coating mixture. Fluorescent lamps are not a recommended source for nighttime highway work [NCHRP Research Results Digest 216]

The New York State Department of Transportation (NYSDOT) initiated Project C-08-14, Nighttime Highway Construction Illumination.

According to a studies done in this project and to a survey was administered in February and March 2011, About 91% of respondents believed that nighttime construction lighting was “very important,”

The biggest concern was the ability of drivers to see the workers, followed by traffic safety and by the ability of workers to see their tasks.

Participants were also asked about the equipment they used for nighttime construction Illumination. For such illumination, survey respondents have used the following technologies: trailer mounted light towers (91%), portable flashlights and clip-on lights (52%), vehicle headlights (46%), semi-permanent mast lighting (26%), balloon lighting (13%), and 21% reported using other sources including equipment-mounted lights, vehicle mounted lights, and
existing street lighting. (John D. Bullough, August 2014)

![Bar Chart: Types of Lighting Currently Used for Nighttime Highway Construction](source: Nighttime Highway Construction Illumination/ NYSDOT Report No: C-08-14)

**The Recommended Lighting Technologies**
2.9. Situations Where Night Work is Not Advisable

The following are some examples of situations where night construction may be inappropriate:

- Noise or vibration caused by night construction would cause excessive disturbance to nearby residences.
- Nightly setup and removal of temporary traffic control devices is impractical based on the nature of the work, traffic volumes, or site conditions.
- Traffic volumes at night are quite high, such that road users would not benefit significantly from adjusting the hours of work.
- The work requires extended closure duration, e.g. for concrete curing.
- Night construction would adversely impact the quality of the work product.
• Night construction is not cost-effective due to its effect on productivity.
• New technologies for lighting and traffic control, such as balloon lights, light emitting
Chapter 3

3. Literature review

3.1. Overview

This chapter summarizes published literature that has been done on work zone lightening issues. Many literature and researches have been done to assist in planning the work zone, choose some of them to help in this research and to start from them. The federal highway administration has been funded many research across the country that related to work zone lighting plans. Some of these researches has been summarized in this thesis.

3.2. Nighttime Lighting Guidelines for Work Zones (April 2013)

This is a guide for developing a lighting plan for nighttime work zones that has been published in April 2013, this material has been done by the American Traffic Safety Services Association ATSSA Supported by the Federal Highway Administration under grant agreement.

Many State Departments of Transportation (DOT) use some form of nighttime work zone to conduct construction and maintenance activities on or near the travel portion of the road system.

Roadway lighting eases the task of driving at night by illuminating the pavement to help drivers see the general direction of the roadway, aiding them in seeing structures alongside the roadway more clearly, and enabling them to see areas of the roadway where headlights do not provide adequate light. There is a similar need to provide adequate lighting in nighttime work zones. (ATTSA Nighttime Lighting Guidelines for Work Zones, April 2013)

However, limited guidance is currently available to address lighting needs relative to the many different tasks that are conducted in a work zone. The Manual on Uniform Traffic Control
Devices (MUTCD) and other existing guidance documents provide minimum specifications for certain general categories of work zone tasks, but they do not provide information regarding the appropriate type, quantity, or configuration of lighting systems to use for specific work zone activities. (ATTSA Nighttime Lighting Guidelines for Work Zones, April 2013)

In this paper they suggested steps for developing a lighting plan, the steps are:

1. Determine Work Activities and Lighting Levels
2. Determine the Work Zone Area to be illuminated
3. Select Type of Lighting System and Source
4. Select Fixture Locations.
5. Check Design for Adequacy including: Field Check the Design / Finalize the Lighting Layout

This document is a 20 pages long, which is make it easy to use be engineers, designers and contractors without the need to be an expert in illumination.

These guidelines may also help in developing specifications and standards for work zone lighting for use by owner agency as well as contractor personnel to ensure consistency, effectiveness, and safety. (ATTSA Nighttime Lighting Guidelines for Work Zones, April 2013)

3.3. STUDIES TO ASSESS THE IMPACT OF NIGHTTIME WORK ZONE LIGHTING ON MOTORISTS (Melisa D. Finley, 2013)

This project has been done in cooperation with Texas Department Of Transportation and the Federal Highway Administration

This report describes the methodology and results of analyses performed to assess the impact of work zone lighting on motorists.

Field studies were conducted to provide insight into how drivers’ eyes react to typical temporary work zone lighting configurations in Texas compared to standard lighting situations (i.e., no lighting and standard fixed lighting). Researchers also conducted closed-course studies to evaluate the impact
of various work zone lighting scenarios upon the ability of drivers to detect low-contrast objects (e.g., debris) and workers.

The findings from these studies, as well as information from a literature review and review of other state agency specifications, were used to develop work zone lighting guidelines for nighttime operations that considered both worker and motorist needs. (Melisa D. Finley, 2013)


Performing Organization: Rensselaer Polytechnic Institute
Sponsors: New York State Department of Transportation (NYSDOT)
University Transportation Research Center - Region 2

This report was funded in part through grant(s) from the Federal Highway Administration, United States Department of Transportation, under the State Planning and Research Program.

Through the National Cooperative Highway Research Program (NCHRP), Bryden and Mace (2002b) have developed sample plans for nighttime operation lighting and traffic control that can be used by transportation agencies and contractors to assist with this planning process.

While these recommendations are focused primarily on the visual performance requirements of the construction workers, it is also important that illumination be provided to make the workers themselves and their backgrounds visible to drivers in and around the work location (John D. Bullough, August 2014)

Demonstration of Work Zone Illumination

I will shortly summarize a demonstration, done in this document, of various illumination systems including light emitting diode (LED) tower lights, balloon lights using various sources, and novel configurations of portable bollard lights, work lights and floodlights. The demonstration
was attended by individuals from NYSDOT, from the Federal Highway Administration (FHWA), from roadway construction contractors and from equipment rental companies

The demonstration was held on the night of April 18, 2012, Ages ranged from 22 to 70 years old, with an average age of 48 years old. The location for the demonstration was along Temple Lane in the Town of East Greenbush, a two-lane town roadway.

The lighting systems were divided into three zones:

**Zone1**: MH light tower

**Zone2**: LED and balloon lighting systems

**Zone3**: consisting of the experimental and prototype concepts.

The rating scale for the quality, light level and usability judgments was as follows:

1: bad
3: inadequate
5: fair
7: good
9: excellent

The rating scale for the discomfort glare judgments was:

1: unbearable
3: disturbing
5: just permissible
7: satisfactory
9: unnoticeable glare

For both scales, higher numerical ratings correspond to higher quality
In the previous figure are the measured light levels. These measurements show that the conventional light tower was among the systems that provided the highest horizontal light levels on the ground and the highest vertical light levels on the visual task chart.
The previous figure shows the average rating values for quality, light level usability and discomfort glare under each of the lighting systems that were demonstrated.

- The conventional trailer-mounted light tower had the highest illuminance ratings for this system all near a value of 7 (good). Discomfort glare rating value of 5 was lower, (just permissible).
- LED systems and all of the balloon lighting systems had discomfort ratings close to a value of 7 (satisfactory).
- quality and light level ratings were also high for several of the alternative lighting systems in Zone 2.
• An LED light tower rated fairly positively for quality (average rating value around 7),
  light level (average rating values around 6), and discomfort glare (average rating value
  around 7).
• In general the prototype and experimental systems in Zone 3 were not rated as highly as
  the conventional light tower

3.5. NCHRP 476 Guidelines for Design and Operation of
Nighttime Traffic Control for Highway Maintenance and
Construction (July 2002)

This report presents guidelines to assist highway agencies in developing and implementing a
plan for night work that will provide for public and worker safety and satisfy the community
while minimizing waste and other problems associated with the supply of materials and capable
workers. The guidelines also contain a number of innovative procedures suggested by state
DOTs to respond to special nighttime problems, such as control of glare, visibility of workers,
and the need to improve conspicuity of traffic control devices. (Charles W. Niessner, Staff Officer
Transportation Research Board)

Because of the large details and information included in this report I tried to focus on the
chapters that cover the Design Requirements and safety features, so I reviewed chapter 2 and
focused on part 2.9 that talked about Lighting Requirements, and the Classification of
Illumination Requirements by Task.
Chapter 2 section 2.9 also defined the Uniformity, and talked about Glare and Methods to
Minimize Glare, which I mentioned earlier in the Glare discussion.
They also have some lighting design process examples.

3.6. NCHRP 498 Illumination Guidelines for Nighttime Highway
Work—Guidelines for Work Zone Illumination Design
(August 2003)
The purpose of this research was to develop guidelines for the illumination of nighttime highway work including both construction and maintenance activities. Additionally, the research developed guidelines for highway work area lighting design and investigated the use of temporary roadway lighting in connection with highway construction. The conclusion of this study is that nighttime highway work can be performed safely and with economy and quality comparable to that performed in the daytime. The essential critical factor is proper illumination. (RALPH D. ELLIS, 2003).

I reviewed chapter 4, RECOMMENDED ILLUMINATION GUIDELINES from this report and used the information in table 14 (Recommended target illumination levels and lighting guidelines) to talk about the illumination levels, and table 15 to talk about the Glare control checklist.
Chapter 4

4. Methodology

4.1. Developing a lighting plan:

4.1.1. Determine the Work Activities and Lighting Levels:

First we have to identify the work activity that will be performed, whether it is construction or maintenance then based on that we can determine the illuminance level by going back to Table 1. There are the locations in the work area that require closer interaction between workers and equipment. The speed of the equipment or the complexity of the work may necessitate an increase in illumination (see Table1). To increase the illumination to 10 fc, additional fixtures may be added directly to equipment.

4.1.2. Determine the Work Zone Area to be illuminated

The general steps in determining the lighting area of a work zone according to the ATTSA Night Lighting Guide are as follows:

- Use a scale layout of the roadway to determine the area of need.

- Draw the project area on the layout. This should show types of work, with location of workers and equipment. This may need to be done to match the construction stages of the work and should include any other incidental work and workers such as material testing inspectors (pavement coring after the paving operation), installation of lighting or signing structures attached to a bridge, or any other work after the major work has been completed.
• Sketch locations of key items from the traffic control plan and other site characteristics on the layout such as lane drop details, on-site obstructions, existing street lighting, and lane shifts.

• Locate any flagger or spotter stations on the layout and provide for lighting their station.

To draw, sketch and model the work zone I used SketchUp and modeled the freeway situation with paving in the right lane, I used the typical paving operation shown in figure 12.

Figure 12: Paving Operation Showing a Steel Wheel Breakdown Roller and a Pneumatic Tire Intermediate Roller
http://www.pavementinteractive.org/article/constructioncompaction/
4.1.3. Select Type of Lighting System and Source

Once the work activities have been identified, it is necessary to determine the type of lighting source to use. Based on the planned work activities and whether the work is mobile, stationary, or long duration, a lighting source using balloon luminaires, portable light plant towers, or roadway luminaires should be chosen. (ATTSA Nighttime Lighting Guidelines for Work Zones, April 2013). See Section 2.7 above.

In this case I choose the MILQPS400 (pulse start metal halide) lamp and tried to modeled this as a balloon luminaire, the one most likely to be used in applications like the night work zone constructions using AGi32 software, similar to Figure 1. Once the Luminaire selected an IES files should be given, where the American Electric Lighting’ provides IESNA-formatted photometric data as an aid to lighting professionals who use lighting design software as part of their lighting specification process.
4.1.4. Select Fixture Locations

When placing lighting sources on the design the location needs to be one that is accessible and adequate for transporting and placing the light source.

To ensure that we choose the good location of the luminaire we need to know where the lighting Levels fall on the roadway, in order to know that we need to use the Iso-footcandel diagrams.

Iso-footcandle diagrams are lines that show you the light level at any given point, each line goes through all point of surface that has the same illumination. The dimension of this diagram is based on the mounting height of the light.

Much of this information is contained in most roadway lighting software, one of the simplest is Footprint software.

Footprint Example

Different input should be given to this program in order to calculate the iso-footcandel diagrams.

First we need to select the IES file, I will be using the IES files chart from an industrial luminaire “Phillips”, available on this link:

http://www.lightingproducts.philips.com/our-brands/daybrite/milseries.html#!f=%2b%40Category%3aIndustrial%2b%40SubCategory%3aLow+Bay
After importing these file to the footprint we have to identify our input, where lumen per lamp is imported from the IES charts,

The Optical Height field enter the vertical distance from the horizontal calculation plane to the luminous center. The luminous center is taken as the center of the lens for cutoff-type luminaires in this case is 14’5”.

The arm length: horizontal distance from the center of the pole to the optical center 12 ft between the lights while I choose the arrangement to be three lights at 120 degree.

The light loss factor this is probably the most complicated input value of all because it depends on a multitude of variables including often unknowable site conditions. The lighting industry generally defaults to 0.75 for pulse start metal halide; 0.80 for high pressure sodium and induction lamps; 0.85 for fluorescent and LED sources.

For the scale I choose 10 (means 1”=10’), the Isoline Preference field. The default value is "Factors of 2". This means curves will be shown at the Target Min (minimum) value.

I will enter the isolines preference manually, while I will choose to have 7 isolines with maximum target of 20 fc, then 15 fc, 10fc, 5fc, 3fc, 2fc, 1fc.
Figure 15: footprint input

After defining all the inputs we hit calculate button and we can see the isolines:

Figure 16: footprint output_iso-footcandel
As we can see in the figure above, each color represents all the points on the grid that have the same luminance value.

The easiness of this software allows you to change the parameters easily and see the luminance value you will get each time, when you can change the arm length or the lights arrangements.

This software, Footprints™, gives you a powerful feature of the ability to overlay one template over another, providing a means of on-screen comparison between competing optical systems if you go. Click on the Form 2 (Optional) tab, you will see a new input form in which you can specify a second IES file.

![Footprints™ Template Specification](image)

*Figure 17: footprint comparison layout*
But these templates are useful when designing to a minimum horizontal illuminance criterion. If you need to meet an average horizontal illuminance requirement you MUST run a point-by-point calculation, templates cannot be used to determine average levels.

**Point Calculation Method**

Point calculation methods are used to determine the illuminance at a specific point on a work plane or surface. Point calculations are often done to determine the uniformity of illumination ratios or the illuminance on vertical surfaces such as a building facade. For our case which is the Exterior point calculations include only a direct contribution from the source. Indirect contributions from reflected surfaces are usually insignificant. (thornlighting, handbook)

Maximum uniformity ratios are specified by IES. Uniformity of illumination is important for visual perception especially in high-speed performance tasks. Poor uniformity can distort both the speed and position of objects. IES provides recommendations for the average to minimum uniformity ratio depending on the road classifications.
Inverse Square Law

\[ \text{Illuminance} = \frac{\text{Intensity}}{(\text{Distance})^2} \]

In Units:

\[ \text{Footcandles} = \frac{\text{Candelas}}{\text{Ft}^2} \]

The most common method used to determine the direct component of illuminance at a point is the Inverse Square Law. *This law states that the illuminance at a point perpendicular to the source is the intensity of the source in candelas divided by the square of the distance in feet from the point to the source.* A light loss factor should also be included to find the maintained illuminance at the point. (thornlighting, handbook).

Point calculations are done by hand only for simple situations, most commonly for small areas or vertical illuminance. Computer programs use this calculation method to check uniformity of illuminance to check the quality of a lighting design.

In this case I am going to use the AGi32 software to do the point calculations.

### 4.2. Performing a Lighting Plan Review

Illumination engineering has several sub-specialties. Building interiors, building exteriors, parking lots, highways, sports venues, airfields, and vehicle interiors all require specific types of lighting equipment and lighting design procedures. Lighting engineers who are experienced in
highway lighting design are not always experts in the design of work zone lighting, which is more similar to designing the lighting for an exterior industrial operation such as a quarry, railroad switching yard, or refinery. A key difference is that many work zones are industrial operations that move continuously. In addition, glare control in industrial operations is often accomplished by mounting the luminaries very high or screening the site with walls or opaque fences; these options are seldom practical in work zones.

Exterior lighting analysis can be done by hand, but the process is tedious because it is necessary to add up all of the light coming from each lighting device at multiple angles. More often, the lighting analysis process is automated using specialty software. While 2D lighting analysis packages can provide insight about the lighting levels available to workers, only 3D rendering packages such as AGi32, Dialux, and Radiance are suitable for determining the way the lighting layout will look to drivers.

Luminaire data files are an essential element of the computer-based design process. These files are usually supplied by lighting equipment manufacturers. They provide detailed machine-readable information about how much light is produced by a lighting device, how concentrated or diffused the light is, and the directional pattern of the light. These characteristics depend on the design of the luminaire itself, such as the type of the lamp and the shape of the reflector and diffuser. In the United States the IES file format is the most frequently used, though most software packages also accept the European ELUMDAT format.

This section will describe how to review a lighting installation in the field and the lighting plan in the office to determine whether it meets acceptance criteria for maximum and minimum illumination levels, uniformity, and glare.

4.2.1. Office Check Design

This step has been proposed by this thesis and after doing extensive research I didn’t find any other Dot or municipality that applied the office check design before going to the field.
The proposing of using AGi32 software to check the design from office has been selected from WisDot to be part of their guidance after a discussion between us and the researcher and professional engineer who’s the supervisor of this project.

Once we get the full plan, including the area that will be illuminated, the type of the luminaire and the fixture locations, IES charts for the selected luminaire should be given. After that full analysis process for the plan should be applied.

In this thesis I suggested AGi32 software to analyze the lighting plan, applying the point calculation method to calculate the illuminance within specified grid, and calculate the glare rates produced by this plan.

**What is AGi32?**

AGi32 is a Calculation tool for accurate photometric predictions: A technical tool that can compute illuminance in any situation, assist in luminaire placement and aiming, and validate adherence to any number of lighting criterion.

Visualization is extremely important to comprehend changes in luminance for different materials and surface properties and predict the effect of various luminaire designs in real-world, light and surface interaction.

With the ability to see results clearly for an entire project, AGi32 can create a virtual model of a proposed design. (AGi32 overview, [http://www.agi32.com/index.php?id=11](http://www.agi32.com/index.php?id=11))

1. After modeling our scenario using SketchUp, Figure13, we can download the free plugin for SketchUp that will export the content from SketchUp to file format that can be imported into AGi32.

2. After importing the model into AGi32, we will define the luminaire that will be going to use, by importing the IES file for the selected luminaire, AGi32 gives
you the option to choose and edit all the properties of the luminaire such as the
aiming angle, the orientation, the pole height and whether it’s a static or dynamic
length, the arrangement of the luminaire and the symbol. In our case I choose the
balloon lights which is very similar to the Circle Down symbol in AGi32
Figure 20, and the single arrangement fixture Figure 19.

Figure 19: Luminaire Arrangements AGi32
After importing the IES file for the selected luminaire a detail description about it will be given including lumens per lamp and Lamp loss factor and the photometric file.
The photometric file shows the polar diagram (Figure 22), the polar diagram illustrates the distribution of luminous intensity, in candelas.

After defining the luminaire, we can go back to our model and select the luminaire locations based on the plan we have. Our location has been selected based on the typical asphalt paving showed in figure12.
As I mentioned earlier that Visualization is extremely important to comprehend changes in luminance for different materials and surface properties and predict the effect of various luminaire designs, AGi32 gives the ability to see the photometric diagrams as a web for each luminaire, and that can give you the chance to compare between the results from different aiming angles and heights and choose the angles or heights that give the best results.
After creating our model, calculation can be done, by hitting the calculations button in the model toolkit list.

To reduce the runtime of the calculations and avoid crashes, I represent the paver and asphalt rollers by rectangular boxes.

**Calculation Methods**

AGi32 allows you to select from two calculation techniques when simulating a lighting application: Direct Calculation Method and Full Radiosity Method. It is easy to move from one to the other and simply repeat the calculation.

**Direct Calculation Method**

Direct Calculation Method is a simplified calculation technique. This method lends itself particularly well to exterior lighting applications such as site lighting, roadway and sports applications. Direct method is represent the point calculation method that we discussed earlier.
To start we have to specify a grid of calculation points, the points could be within a line or polygon.

I have selected the points to be located on the center line of each lane on the roadway, (the red points on figure__)

![Figure 25: Direct Only Calculations Points AGi32](image)

**CIE Glare Rating (GR)**

As mentioned earlier in (section 2.3.3) the CIE has developed a glare evaluation method for outdoor area and sports lighting applications (CIE document 112-1994). This system is available for checking the Glare Rating situation of existing installations and for predicting glare rating at the design stage in new installations. AGi32 is the first North American software to calculate Glare Rating according to CIE standards. (AGi32 Overview , n.d.)

The Glare Rating calculation grid provides an indication of glare restriction at each point in the grid. Glare Rating is restricted to horizontal grids of points below eye level. A lower Glare Rating value (GR) indicates better glare restriction.
I have selected a grid so I can measure the glare occurred at the work zone for workers and on the roadway for drivers.

Figure 26 shows a top view for our model including the calculations grid, while the red color represents the illuminance calculation points and the orange points represent the glare points, after simplifying the instruments into rectangular boxes.

Showing the calculations on the model directly can really help us predict the effect of various luminaire designs by see the values at each point on the model layout.

**IsoLines Calculations:**

As mentioned earlier IsoLine tells about the points that have the same illuminance value within the model. In this case I choose the green color to be the value of the target illuminance (10 Fc) and the red color for (20 fc) and the yellow color means below the target for (5 fc).
Figure 27: IsoLine Values _ AGi32

Figure 28: IsoLine created by AGi32
Full Radiosity Method

The Full Radiosity Method enables all the features found in AGi32 for the accurate computation of interreflected light. (AGi32 Overview, n.d.).

Rendering is used to generate fast and accurate color images of the behavior of light within an environment.

I believe that the rendering option give us a realistic visualize about the lighting plan and the effect of the lights in all direction of the zone.

Figure 29: rendering of an asphalt paving scene_South East view. To reduce runtime the paver and asphalt rollers were represented by rectangular boxes.
Figure 30: Render image_South West view

Figure 31: Render Image_North West view
Start with the "Basic Rendering" slide, which is rendering in its rawest form, light and surface, then evaluate the absolute illuminance levels using Pseudo color. This is infinitely more powerful than individual points of calculated illuminance, where you can actually see the incident light throughout the entire model. It is a very informative tool.

A pseudocolor image (sometimes styled pseudo-color or pseudo color) is derived from a grayscale image by mapping each intensity value to a color according to a table or function. Pseudo color is typically used when a single channel of data is available, in contrast to false color which is commonly used to display three channels of data. (wikipedia).

Pseudocolor image showing the illuminance levels of a work zone scene similar to the true-color scene in Figure 29. Note that the light is brightest near the middle of the scene due to the combined effect of several luminaires. Figure 32 shows the same scene viewed by an approaching driver. Notably, ever when the illuminance is the same, reflections off light-colored objects (such as the white parts of the traffic control drums) produce greater luminance than reflections off dark-colored objects (such as the orange parts of the drums).
Figure 32: pseudocolor image illustrating the Illuminance level (Fc) of the work zone scene. Top view, created using AGi32 software.
Figure 33: Luminance level within the work zone, viewed by approaching driver
After applying all the calculations needed and producing rendered images and pseudocolor images for the work zone, we can have a detail report about our analysis process.

First page of the report the showing the luminaire details, the arrangement the orientation and the location of each luminaire.
## Luminaire Schedule

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<th>Symbol</th>
<th>Qty</th>
<th>Label</th>
<th>Description</th>
<th>Arrangement</th>
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## Luminaire Location Summary

<table>
<thead>
<tr>
<th>SeqNo</th>
<th>Label</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>Cisset</th>
<th>Tilt</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MILM-400</td>
<td>15</td>
<td>1</td>
<td>14</td>
<td>90</td>
<td>0</td>
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<td>0</td>
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<tr>
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<td>72</td>
<td>14</td>
<td>90</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>MILM-400</td>
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<td>72</td>
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<td>90</td>
<td>0</td>
</tr>
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<td>14</td>
<td>90</td>
<td>0</td>
</tr>
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<td>14</td>
<td>90</td>
<td>0</td>
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<td>189</td>
<td>14</td>
<td>270</td>
<td>0</td>
</tr>
</tbody>
</table>

---

**Figure 35:** Page (1) of the report showing the luminaire details
In the second page I choose the numeric summary table which includes the calculations grids that we choose earlier (illumination grid within the workzone, illumination grid on the traffic lane, glare rating grid).

The summary shows the average, maximum and minimum values within the grid.

You can also choose a statistical area, a Statistical Area allows you to analyze calculation points within your model, Statistical areas consider the points within and on the polygon boundary and the results are shown in the Statistical Summary window.

In this case I choose two statistical areas, the first one for glare and it shows that the max glare rate we got was 37 and the min 20 and the second one for the illuminance shows the ave was 16.74 fc.

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**Figure 36: Page(2), Calculations Summary**

<table>
<thead>
<tr>
<th>Numeric Summary</th>
<th>CalcType</th>
<th>Units</th>
<th>Avg</th>
<th>Max</th>
<th>Min</th>
<th>Avg/Min</th>
<th>Max/Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illumination grid</td>
<td>Illuminance</td>
<td>Fc</td>
<td>6.10</td>
<td>12.7</td>
<td>0.0</td>
<td>N.A.</td>
<td>N.A.</td>
</tr>
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<td>Illumination grid_workla</td>
<td>Illuminance</td>
<td>Fc</td>
<td>12.71</td>
<td>49.7</td>
<td>0.0</td>
<td>N.A.</td>
<td>N.A.</td>
</tr>
<tr>
<td>GR_1</td>
<td>Illuminance</td>
<td>Fc</td>
<td>5.58</td>
<td>51.6</td>
<td>0.0</td>
<td>N.A.</td>
<td>N.A.</td>
</tr>
<tr>
<td>GR_1</td>
<td>Glare Rating</td>
<td>N.A.</td>
<td>33.34</td>
<td>37.9</td>
<td>20.7</td>
<td>1.61</td>
<td>1.83</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Statistical Area Summary</th>
<th>Avg</th>
<th>Max</th>
<th>Min</th>
<th>Avg/Min</th>
<th>Max/Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>StatArea_Gaze</td>
<td>32.65</td>
<td>37.0</td>
<td>26.7</td>
<td>1.58</td>
<td>1.79</td>
</tr>
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<td>Workzone Illuminance</td>
<td>15.74</td>
<td>49.7</td>
<td>0.1</td>
<td>107.40</td>
<td>497.00</td>
</tr>
</tbody>
</table>
At page 3 the full model as it appears in AGi32 model page can be displayed.

*Figure 37: Page (3) shows a top view of the final model*
In the page 4, I choose the render image to be displayed

Figure 38: Page (4), rendered image

Pages and tables can be added to the report using the page builder tool.
As currently rendered, the middle of the scene is around 50 fc, and it’s far exceeding the illuminance target values. Some recommendations will be discussed later.

The analysis we did so far can really help the engineer to decide either to accept or reject the light plan, can help specify the problem and then the plan can be easily adjusted by changing the location of the fixtures or the height or the aiming angle of the luminaire and compare the results.

4.2.2. Field Check the Design

Once the lighting plan is installed and activated, field observations of the work zone lighting should be performed by driving and walking through the work zone. The field check should be conducted from the vantage point of the motorist and workers to ensure that glare is controlled and the lighting is adequate for the work being done. Agencies may indicate that field observations are adequate to ensure the lighting plan is appropriate. Measurements can be taken to verify that the necessary lighting levels in the work area are met. Once the field check is complete and the work area has been reviewed, any necessary modifications or adjustments should be implemented and the work zone plan or inspection report should show that deficiencies were identified and remediated. As with any modification or adjustment to a plan that puts the work zone in greater compliance with standards and policies, complete and thorough records must be kept.
Chapter 5

5. Conclusion and recommendations

5.1. Conclusion

The objectives of this thesis were: 1) to provide designers with an overview of the main design considerations related to work zone illumination, 2) To assist designers in determining how to specify appropriate work zone lighting in contractual documents.

To do this we review several reports and documents related to work zone illumination and the specifications for nighttime work zone created by several states DOT, these review was then used to develop work zone guidelines for nighttime operations that considered both worker and motorist needs.

We add on the top of all DOT’s guidance the office check design and we introduced the AGi32 software as a very helpful tool to do all the analysis needed to check the lighting plan.

Isolines with the affordable and simple software that can produce the Isolines is also a very important tool to specify the illumination within the work zone.

I suggest if agencies that perform road work at night can train the people who’s responsible for setting or checking the lighting plan and let them familiar with the minimum lighting requirements and needs for the specific work activity.

The glossary created in this thesis could be very helpful and simple enough even for people that are not familiar with illumination process.
5.2. Recommendations

The following points are recommended to be included in any night time construction project:

1. **Development of a Nighttime Work Plan:**
   The night plan provided by the contractor or the engineer should include the lighting plan and any other traffic control or any other safety item. The lighting plan should have a description about the area will be illuminated, in this thesis we used SketchUp to sketch the work zone including the paving equipment.
   The type of the luminaire and the location of the fixture should be given, an IES charts for the selected luminaire should also be included in the light plan. Field and office checking for the illumination levels should be included. It’s recommended that the field check be done by a professional engineer with experience in the lighting applications.
   Table 1 is recommended as a guideline for horizontal illuminance on a nighttime Construction projects.

2. **Measurement of Illuminance**
   Illuminance should be measured in the field and also in the office using the Isolines templates, engineers should be trained to understand these templates and the photometric (polar) diagrams also.

3. **Glare Checks**
   It is important that the location and direction of luminaries on a nighttime work site be checked periodically so as to avoid any problems with glare. Traveling through the temporary traffic control zone at night is essential to check for the presence of glare to motorists, using for the Glare rating calculation tool the recommended earlier in AGi32 software will be very useful and after doing a deep research about methods to calculate the glare, this one was almost the only outdoor calculation method since that solving the model manually is very complicated.
   Adjusting the luminaire height or location or aiming angles will be easy using the software and comparing the results to have the minimum glare rates is possible.

4. **Documentation**
   According to the “LIGHTING SPECIFICATIONS FOR NIGHTTIME CONSTRUCTION WORK ZONES ON ACTIVE HIGHWAYS” contractor should be required to submit in
writing reports of measured illumination levels. For stationary work sites, at least once every five working days is recommended. For moving work sites, daily readings should be submitted to the Project. (Robert L. Vecellio, December 2006)
References

1. ATTSA Nighttime Lighting Guidelines for Work Zones. (April 2013)


10. Robert L. Vecellio, P. J. (December 2006). LIGHTING SPECIFICATIONS FOR NIGHTTIME CONSTRUCTION WORK ZONES ON ACTIVE HIGHWAYS.


