ACHIEVING CONSISTENCY IN LIGHTING SCHEMES FOR CONSTRUCTION WORK ZONES THROUGH LIGHTING SIMULATION

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Abstract

Nighttime construction is being adopted by many state DOT's as a way to mitigate the impact of construction operations on the traveling public. Although a number of states have developed standard specifications for nighttime lighting, these standards are usually in the form of generic requirement statements that only specify minimum illuminance levels. The lighting standards do not include specific ways to achieve this illuminance level such as lighting arrangements and configurations for various work zone plans and construction operations. This leaves confusion between the traffic engineers and the contractors and does not guarantee consistency in those plans, thus affecting productivity and safety (lighting conditions account for 18% to 28% of work zone accidents). The main objective of this study is to utilize three dimensional animation and lighting analysis software to study and model lighting conditions of a construction site. This is expected to increase the safety and productivity of construction operations by achieving consistency in work zone lighting schemes. A computerized model was developed, called Nitelite. Various lighting schemes can be studied using the software to provide for typical applications including lighting fixture's locations, luminance, mounting height, tilt angle, and fixture type. The results from the developed software tool were validated through comparisons with previous research conducted using field measurements.

Keywords: Nighttime, Construction, Lighting, Visualization, Rendering, Animations

1. Introduction and Background

Nighttime construction is being adopted by many state DOT's as a way to mitigate the impact of construction operations on the traveling public as an increased amount of highway repair and new construction work is being performed in the off-peak nighttime hours [1,2]. A number of state have therefore developed guidelines and practices for nighttime lighting including New York, Michigan, North Carolina, New Jersey, and Maryland as well as other states [3]. The majority of those guidelines and specifications are based on the details of lighting requirements or standards found in the literature, including roadway lighting design criteria and lighting standards proposed by OSHA (Occupational Safety & Health Administration), ANSI (American National Standards Institute) and IESNA (Illuminating Engineering Society of North America).
Although the existing specifications accurately identify acceptable lighting conditions (such as glare and illuminance), prescriptive information on how to achieve these conditions are still missing [6]. The need for achieving consistency in work zones in general and for lighting schemed specifically is a recognized on both the local and national level [1,2,3]. Recently, the Federal Highway Administration (FHWA) reviewed the state of practice in work zone traffic

management and found that no uniform and objective procedures exists for quantifying the effects of various factors of work zone traffic management plans (which include lighting arrangements) [4]. Furthermore, it has been shown that lighting conditions is one of the main factors affecting the safety of nighttime construction work zones [5]. Detailed prescriptive information on how to achieve acceptable lighting levels would increase the applicability of any lighting specification and therefore help to increase the safety and productivity of construction work zones [6, 7]. Therefore the research proposed here will develop comprehensive specifications for better lighting plans including locations, luminance, angle, and fixture type, for the various work zone configurations.

2. Literature Review

The literature on lighting in work zone is concentrated on developing prescriptive specifications for nighttime lighting [5]. Research has also shown that lighting levels will have an effect on both the workers and the traveling public [6]. Specifically, different lighting fixtures provide varying degrees of visibility, which depends on the lighting levels and spectral distribution of the lamp color and the prevailing lighting conditions on site [7,8]. For example, high-pressure sodium and metal-halide lamps are the most widely used types of lamps in nighttime construction operation. Metal halide lamps provide better visibility in outdoor environment and improved peripheral vision, which has a significant impact on safety since it is primarily responsible for detecting changing road conditions and movements of objects due to the spectrum distribution from lamp

One of the challenges facing the researchers is to identify methods for glare control when developing the typical lighting plans. While illuminance level is easily specified and controlled glare is not [9]. In the research developed here, three measures were utilized to control glare during nighttime construction operations including: selection of lighting sources that minimize glare on site, proper design and arrangement of lighting equipment on site (e.g. aiming angle, mounting height) in order to reduce high glare levels, and utilizing glare control hardware, if needed. Another concern that has been identified is light trespassing to adjacent properties [10]. Specific lighting fixtures and mounting locations will be used to mitigate light trespassing. The research presented here allows the contractor and the DOT officials to verify light trespassing conditions for specific sites.

3. NiteLite Development and Framework

NiteLite is developed on Autodesk VIZ 2006 (VIZ) which was designed to provide accurate three-dimensional modeling and animation capabilities to a personal computer platform. The capabilities of VIZ can be enhanced are enhanced by its scripting language MaxScript. Furthermore, Nitelite allows users to study the dynamic nature of lighting in construction sites by allowing the animation of expected traffic patterns and studying that impact on the lighting conditions in the job site.

A developed a library of predefined standard construction zone objects, with their materials can be defined and used for easy modeling of construction sites. The first step in the workflow is modeling the construction sites. In this step, the user can define the size and placement of the construction operations objects in the scene. Modification options available in VIZ increased the complexity of the shape. The materials used in the scene are then defined. The Material Editor

allowed the user to add realism to the geometric shapes. "A material describes how an object reflects or transmits light. This description determined the manner in which light affects the scene. The material description can be integrated with the construction operation objects developed in the library.
Standard lights used in the construction site are then placed. Accurate photometric data for the lights are defined to have a specific output and coverage. Cameras were placed to allow a consistent viewing perspective. VIZ created a radiosity solution based on the lighting and camera choices and used that solution in the rendering process. To study the dynamic aspect of lighting a nighttime construction site, animation of objects in the scene can be made. The user can have the ability to define Average Daily Traffic patterns (ADT)s as well as the speed of relevant construction operation which can affect the lighting conditions, e.g. the speed of the "paving train". This workflow can be applied to create a scene that would be similar to the nighttime lighting conditions on a road construction site. This similarity would be used to prove the validity of the research. Figure 1 shows an example of a rendered nighttime construction site.

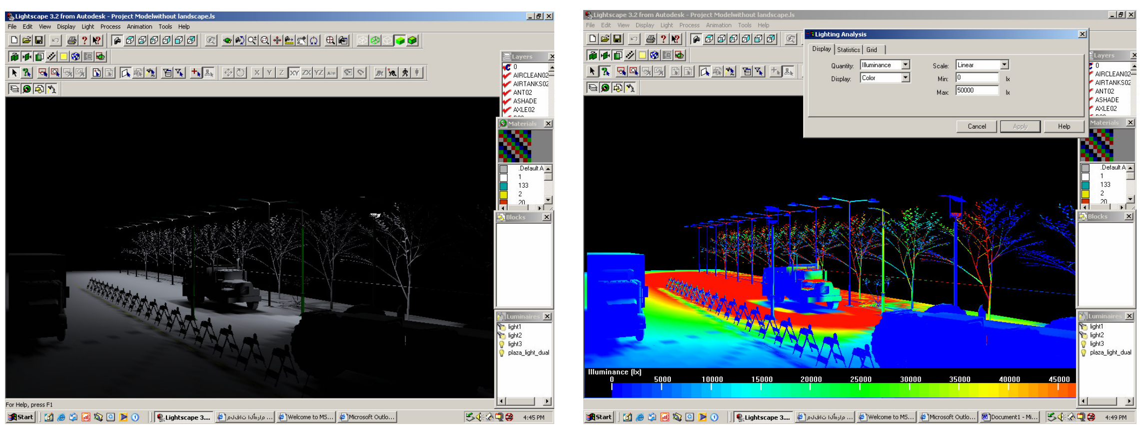

Figure 1, Examples of Isoflux maps of a typical lighting arrangement

4. Typical Prototype Application

The dimensions for the road model resulted from a survey of research available on the internet. From these varied sources shown in Figure 2, a reasonable estimation of the typical road dimensions was created. A cross section of the modeled road section is shown in Figure 2. The road sections were dimensioned and created using basic geometric primitives. The stripes were then created and placed in proper position relative to the position of the road primitive. The road and stripe primitives were grouped together to create the group [road template]. This group represented a section of road 7.31 m wide and 3.05 m long. This group was duplicated to create the 97.56 m road in the scene. The stripe primitives are deeper than a typical paint stripe. This aspect provided better visibility of the stripes at height in the scene. The stripes were elevated to protrude 4.8 mm from the road surface. A 1.2 m shoulder was created on each side of the road. Beyond the shoulder a large, flat field area was created.

The lighting towers and luminaries were created next. The towers were constructed to follow the research conditions described in [15, 16 and 17]. The towers lifted the lights to 7.8 meters above ground level. The horizontal cross bars provided a reference point for the location of the lights. While experimenting with different lighting solutions, the lights were moved relative to their initial position on the crossbar. The final element to be added was the moving light source. Sample objects are shown in Figure 2.

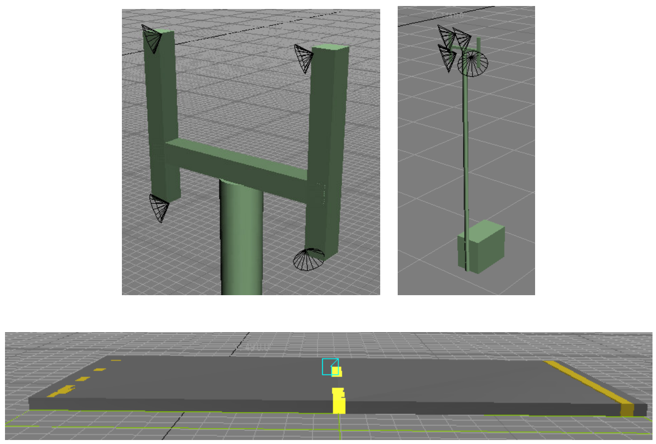

Figure 2 Sample Objects

4.1 Defining the Materials

The Materials Editor available in VIZ allows the user to configure materials used in the model to accurately represent actual attributes. This model relied on the preexisting materials available in the VIZ to create accurate depictions of the nighttime construction environment. The materials editor uses several different methods to compute the reflectance in the scene. Some of the materials utilized may not have selectable material. For these surfaces, materials photometric data can be specified. For example, the stripes on the road were a gloss painted finish and the material selected for the luminaries was a flat paint finish. There can be found in the screen capture in Figure 3.

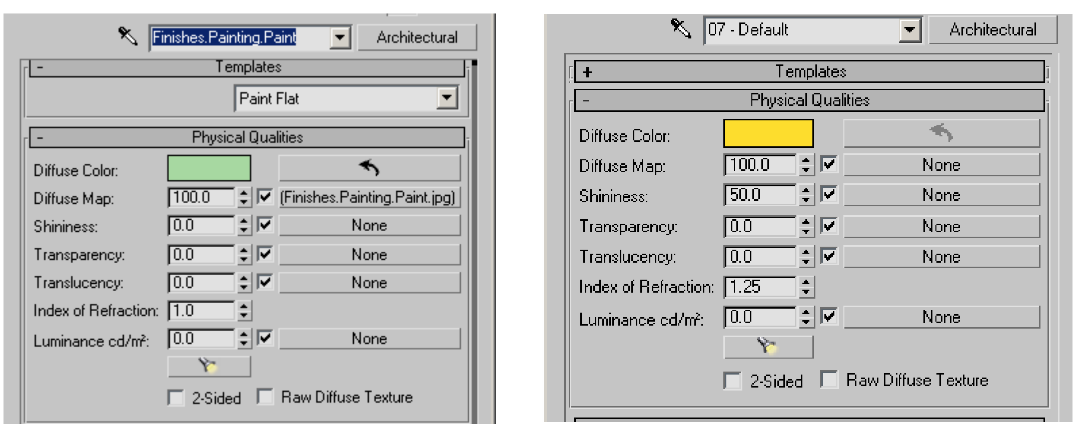

Figure 3 Screen Capture of the Material Editor

4.2 Adding Lights and Cameras

The luminaries were configured to produce an output similar to the output of a typical 1000 watt metal halide bulb. A survey of previous work provided a photometric map for the desired output. Using the modifier menu in VIZ, the output of the modeled lights was adjusted until a similar output pattern was achieved. Some of the setting is shown in **table 1.** Four of these spotlights were assigned to each tower. These lights were pointed at a 45 degree angle into the workzone. Two lights were created to represent the dynamic light source. These lights were positioned on the box primitive in a manner that is similar to their placement on a vehicle.

Table 1, Sample settings for lights used

Parameter	Value
Light type	Point untargeted at 30’1.197”
Distribution	Spotlight
Color	Metal Halide
Resulting Intensity	1500 lx at 25’
Hotspot/Beam	92.0
Falloff/Field	94.0

5. Simulation Results

Calcualtion for the simulation were performed in the virtual scene of the target size of all critical details that need to be viewed during the construction operations. The target size (also called the visual angle) can be calculated for each critical detail by measuring the standard viewing distance between the critical detail and a virtual worker’s eye. [17]

This virtual worker is basically a digital model of a typical construction worker. Similarly, the contrast that is typically encountered on site between the critical detail and its immediate background can be measured virtually in the scene. This contrast is important because it affects the visibility of construction targets, as objects with superior contrast can be seen easier given the same lighting conditions. Contrast can be calculated as a function of the luminance of a target and that of its background [16].

Therefore, the contrast of construction targets can be identified in the scene by measuring the luminance of the construction detail and its background in the scene. Additionally, the reflectance of the construction target can be calculated using the measured luminance of the construction target in the direction of a virtual worker in the scene and the measured illuminance level incident on the construction target [16].

5.1 Animation

The scene at this point in the workflow was static. However, many of the issues in nighttime construction are related to the dynamic movement and interaction of the light sources. These light sources include both the stationary sources and the dynamic sources. The stationary sources include the luminaries and other site specific lighting sources. The dynamic sources are the vehicles traveling in the lanes adjacent to the construction zone. The animation of the light source created a dynamic element that simulated the conditions created by passing traffic. The movement of the dynamic light source was configured to be analogous to that of a moving vehicle. The light source moved in a straight line at a constant velocity of 24.5 m/s or 88 k/h. Figure 4 shows a screen capture of the animation showing the high glare situation created by a moving light source. The left figure shows the vehicle in the beginning frame of the animation. By comparing the colors of the light output to the scale at the bottom of the image, the light output appears to be less than 1660 lx. When the dynamic light source moves into the light field produced by the luminaries, glare maybe created in case construction workers are visually influenced by the light from the moving car.The red spot showing the highest illuminance level was be estimated to be close to 2000 lx and it may cause disability glare to construction workers on the street.

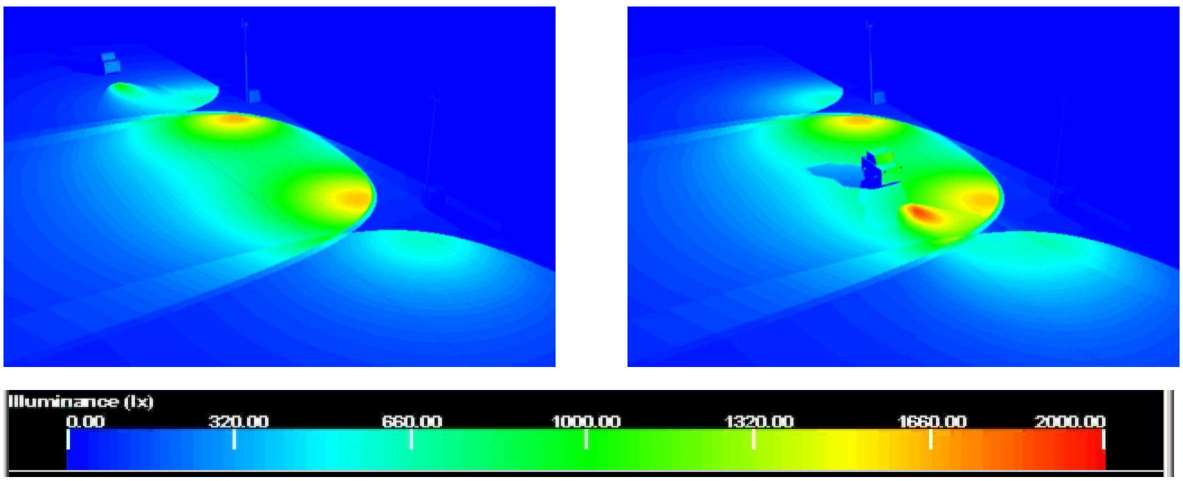

Figure 4, A screen capture of the animation

5.2 Sample Analysis of a Construction Work Zone

One of the rendering options used for this research was the pseudo color exposure control. This setting created a map of the light output with different colors denoting the differing levels of illuminance. An interpretation bar was located at the bottom of each of these renderings. There were two types of renderings created. The first was an animated scene of a dynamic light source passing through the fields of light produced by the luminaries. The second type of rendering manipulated the aiming angle, height, and separation distance of the luminaries.
Figure 5 shows renderings to explore how changing the lighting parameter affects the overall lighting conditions on the site. These renderings compared the light output of the luminaries when the downward angle of the lights was changed. The figure labeled, “0 Degrees,” has a downward angle of zero. The next figure shows the results of a ten degree downward angle. The figures below demonstrate the increase of the “hotspot,” or area of greatest light intensity. The hotspot can be found by locating the area of the rendering with the reddish color indicating the highest light output.
These renderings were created by changing the height of the luminary from the work surface. The first figure shows the light output of a tower located five meters from the ground. The next

shows a tower that has the light 6 meters from the ground. These renderings show the manner in which the hotspot diminishes as the height increases.

These renderings were created by changing the distance separating the two towers. The first rendering shows the light intensity of a separation distance of 10 meters. The next shows a separation distance of 20 meters. This set of renderings demonstrates the manner in which the compounding of the lights increased the hotspot light output.

Plots of the preceding relationships are shown in **Figure 6.** The first plot shows the relationship between downward aiming angle and maximum scene lighting. The next plot demonstrated the relationship between height and hotspot intensity. The final plot demonstrates the manner in which the separation distance affects the hotspot intensity.

Variations in Aiming Angle (from 0 to 40 degrees using a step of 10 degrees)	Variations in Height (from 5 m to 9 m using a step of 1 m)	Variations in Separation Distance (from 10 m to 40 m using a step of 10 m)

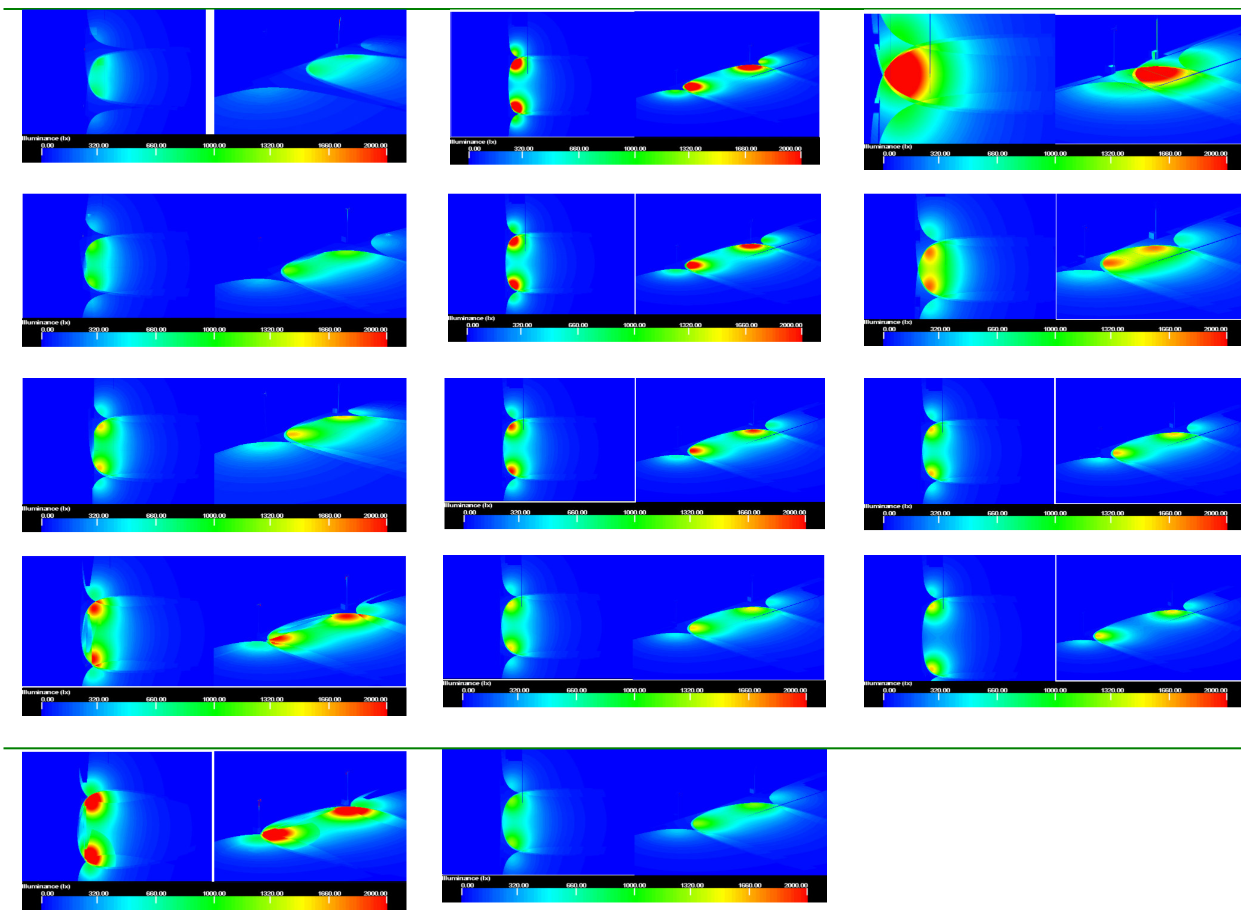

Figure 5, Lighting parameters' effects of lighting conditions

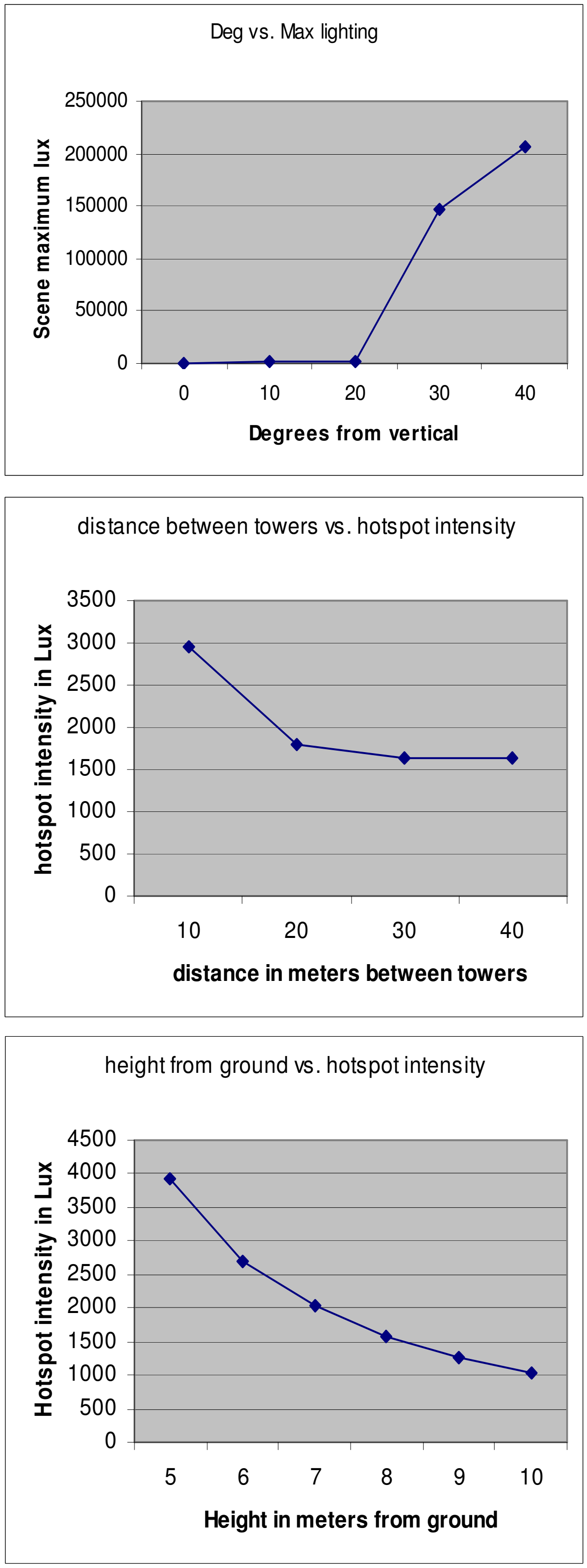

Figure 6, Effect of parameters on the lighting intensity
(top: tilt angle, middle: distance, bottom: height)

6. Conclusions and Limitations

The benefits of developing consistent lighting specifications through state agencies has been recognized by a number of different state DOTs [4, 11]. Standardized lighting arrangements save time and money in developing plans for work zones and ensure a measure of quality control over the plan which in return means added safety and productivity. Furthermore, the ability to quickly generate efficient work zone lighting plans will not only lead to a more efficient construction operation but will also result in reduced road user complaints and improved safety. The number of crashes in work zone attributed to lighting conditions ranges from 18% to 28% [9], while work zone accidents cost a total of $8.66 billion on the national level [12]. If only a small percentage (10%) of those accidents can be avoided, this translates to in savings of $240 million. Furthermore, previous research indicates that the lack of consistent lighting plans is a major concern, which reduces the safety and productivity of the construction operation. Since this study was performed using simulation software that employs specific calculation algorithm further works would be necessary. More detailed study is being performed by the authors.

7. References

[1] **Amos, S. (1994).** "Development of Guidelines for Systematic Planning, Design, Operation and Maintenance of Nighttime Linear Construction Illumination Systems" PhD Dissertation, University of Florida, Gainesville, Florida.

[2] **Bryden, J. and Mace, D. (2002).** "Guidelines for Design and Operation of Nighttime Traffic Control for Highway Maintenance and Construction" NCHRP Report 476. National Cooperative Highway Research Program, Transportation, Research Board, National Research Council. Washington, D.C.

[3] **Bullough, J., Fu, Z., and Derlofske, V. (2002).** "Discomfort and Disability Glare from Halogen and HID Headlamp Systems". Technical Report 2002-01-0010. Transportation Lighting Group, Lighting Research Center, Rensselaer Polytechnic Institute.

[4] **Ellis, R.D., Jr., Herbsman, Z., Kumar, A., and Amos, S.J., (1995).** "Illumination Guidelines for Nighttime Highway Work", Final Report NCHRP 5-13, National Cooperative Highway Research Program, Transportation Research Board, National Research Council, July 1995.

[5] **Caltrans (2000).** "Caltrans Using Hollywood Lights in Construction Zone" News Release, California Department of Transportation, District 11, San Diego & Imperial Counties.

[6] **Greenquist, J. (2001).** "Lighting the Way to Job-Site Safety" Grading and excavation Contractor Journal, 2001

[7] **Greenquist, J. (1999).** "Lighting: Shedding Light on Portable Light Tower Selection" Rental Equipment Register, Oct 1, 1999

[8] **Flannagan, M., Sivak, M., and Traube, E. (1994).** " Discomfort Glare and Brightness as Functions of Wavelength". Technical report UMTRI-94-29. Transportation Research Center, The University of Michigan. Ann Arbor, Michigan, October, 1994.

[9] **IESNA (1998).** IESNA Guide for Choosing Light Sources for General Lighting. Report DG-10-98. Illumination Engineering Society of North America, New York

[10] **IESNA (1993).** "Design Guide for Roadway Lighting Maintenance". Illuminating Engineering Society of North America DG-4-1993. USA International Dark-Sky Association

[11] **Nassar, K and A. Al-Kaisy (2003).** "Nighttime Construction: Evaluation of Construction Operations" in the 2003 Transportation Research Board Meeting, Washington DC
[12] **Satish B. Mohan and Padma Gautam (2002).** "Cost of Highway Work Zone Injuries", Practice Periodical on Structural Design and Construction, Vol. 7, No. 2.
[13] **Autodesk (2006) .** VIZ 2006 User's Reference
[14] **El-Rayes, K., and Hyari, K. (2002).** "Automated DSS for lighting design of nighttime operations in highway construction projects." 19th International Symposium on Automation and Robotics in Construction, ISARC 2002, National Institute of Standards and Technology, Gaithersburg, MD.
[15] **El-Rayes, K., and Hyari, K. (2003).** "Lighting design requirements for highway nighttime construction." Proc., Construction Research Congress, American Society of Civil Engineers, New York.
[16] **El-Rayes, K., and Hyari, K. (2005).** "CONLIGHT: A lighting design model for nighttime highway construction." J. Constr. Eng. Manage., 467–477.
[17] **El-Rayes, K., and Hyari, K. (2005**). "Optimal lighting arrangements for nighttime highway construction projects." J. Constr. Eng. Manage., 467–476.
[18] **El-Rayes, K., Liu, L., Soibelman, L., and Hyari, K. (2003**). "Nighttime construction: Evaluation of lighting for highway construction operations in Illinois." Technical Rep. No. ITRC FR 00/01-2, Illinois Transportation Research Center, Illinois Dept. of Transportation.