

Lighting Requirements for Nighttime Highway Construction

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Abstract: This paper presents the development of a practical framework for identifying the lighting requirements for nighttime highway construction activities. The framework is named Construction Visual Requirements, "CONVISUAL," and is designed to consider and quantify the varying lighting needs for different visual and construction tasks. The framework is developed using an original and interdisciplinary approach that integrates concepts and models from construction engineering and vision science to ensure the provision of adequate lighting conditions on site that enable workers to properly see and perform their tasks safely and with satisfactory quality. CONVISUAL determines the required illuminance level for each construction activity based on its required visual tasks and the visual capacity of construction workers. A prototype of CONVISUAL framework is implemented to illustrate its unique capabilities of (1) providing a deeper understanding of the visual requirements of nighttime construction activities; (2) specifying the required illuminance levels in a scientific and systematic approach; and (3) delivering a rational justification for the specified illuminance levels.

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Introduction

An increasing number of highway construction and maintenance projects are performed during nighttime hours in order to minimize the negative impact of daytime work zones on traffic flows (Bryden and Mace 2002; Cottrell 1999; Ellis et al. 2003; El-Rayes and Hyari 2003). In order to maintain quality and safety in these nighttime construction projects, many state Departments of Transportation (DOTs) have recently started to develop and adopt lighting standards to specify the minimum lighting requirements for nighttime highway construction operations (El-Rayes et al. 2003; El-Rayes and Hyari 2005a,b). Existing state DOT lighting requirements specify a minimum level of average illuminance on site to ensure the availability of adequate lighting conditions for all planned nighttime construction activities. Illuminance represents the intensity of light incident on a surface area in lux (lm/m^2), and it can be measured on site using simple light meters (Taylor 2000).

Lighting requirements for nighttime highway construction need to be carefully specified by state DOTs, as low levels of illuminance on nighttime construction sites can negatively affect the quality and safety of construction work, and excessive levels can lead to unnecessary waste in lighting cost, glare to road users, and light trespass to adjacent property. In order to identify the

current practice of lighting requirements for nighttime highway construction, an extensive literature review and a comprehensive survey were conducted to gather information on available lighting standards from all state DOTs (NCHRP 1996; Bryden and Mace 2002; Ellis et al. 2003; El-Rayes et al. 2003; Hyari 2004). The findings of this survey reveal that (1) existing lighting standards specify varying levels of illuminance that range from 54 to 216 lx for various construction activities, as shown in Table 1; and (2) there is a lack of consensus among state DOTs on the lighting requirements for nighttime highway construction operations (El-Rayes et al. 2003; Hyari 2004). For example, California, Florida, and Maryland DOTs have a single unified minimum lighting level of 54 lx in the entire work area, while the Mississippi and North Carolina DOTs divide lighting level requirements into two categories of 108 lx for moving operations and 216 lx for stationery operations. New York DOT, on the other hand, provides lighting level requirements according to the construction activity being performed and divides lighting level requirements into three categories of 54, 108, and 216 lx.

The aforementioned lack of consensus among existing state DOT standards highlights the need for a scientific-based approach that can be used to objectively determine the required illuminance levels for various nighttime highway construction activities. The need for such lighting standards and specifications has been widely reported by several organizations including (1) the National Institute for Occupational Safety and Health, which highlighted the need for a comprehensive standard for work zone lighting as a preventive measure against worker injuries and deaths (Pratt et al. 2001); and (2) the Federal Highway Administration (FHWA), which indicated the lack of and need for such standards in the U.S. and Europe (Wilken et al. 2001).

Objective

The objective of this paper is to present the development of a scientific framework that can be used to identify the required

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Table 1. Illuminance Requirements in Analyzed State DOTs Standards

Number	Highway construction activity	Lighting level requirements in lux							
		California	Florida	Maryland	Michigan	Mississippi	New York ^a	North Carolina	Oregon
1	Earthwork: excavation/embankment/backfill	Outdoor active construction areas, concrete placement, excavation, access ways, loading: 54 lx	A minimum of 54 lx for lighting nighttime construction activities	A minimum of 54 h over the construction area		Tower lights: 216 lx over the work area, machine operations: 108 lx on and around the machine	54	Tower lights: 216 lx over the work area, machine operations: 108 lx on and around the machine	
2	Landscaping: seeding/mulch/sodding/planting						54		
3	Erosion control: riprap/ditch lining								
4	Subgrade								
5	Subbase/Base courses								
6	Paving bituminous surfaces				108		108		
7	Rolling bituminous surfaces and pavements								
8	Paving PCC surfaces						108		
9	Finishing PCC pavements								
10	Milling and removal						108		
11	Pavement resurfacing						108		
12	Pavement patching						216		
13	Crack and joint sealing						216		
14	Concrete sawing								
15	Shoulders: earth and aggregate								
16	Shoulders: bituminous and PCC								
17	Bridge construction and maintenance								
18	Culverts and sewers								
19	Drainage structures								
20	Guardrail and fences								
21	Work zone setup, take down, and revision						54		
22	Work zone flagger station								b
23	Work zone access and material handling								
24	Highway signing								
25	Pavement marking: striping and markers								
26	Electrical wiring and cables						216		
27	Electrical poles and posts: lighting/traffic signals						216		

^aGeneral construction operations in N.Y. standards are required to have a minimum of 54 lx.

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

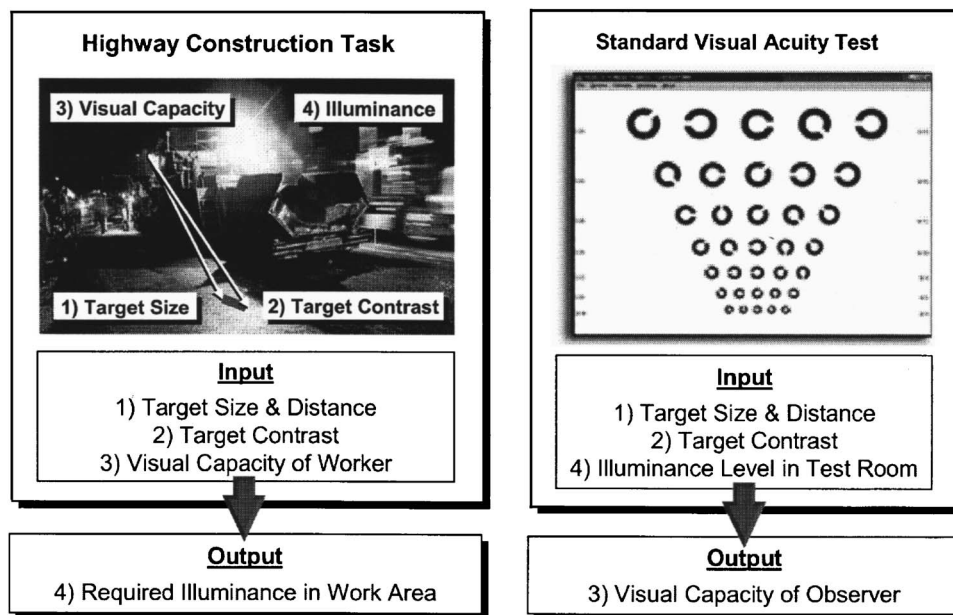


Fig. 1. Analogy between CONVISUAL framework and standard visual acuity tests

illuminance levels that need to be provided on nighttime highway construction sites. The framework integrates interdisciplinary concepts from construction engineering and vision science to ensure that the specified illuminance levels in the work area are adequate and enable construction workers to see all the critical work details needed to perform their tasks safely and productively. The framework is named Construction Visual Requirements, "CONVISUAL," and is developed in two main stages: framework design and prototype implementation, which are described in the following sections of the paper.

CONVISUAL Framework

The present framework is designed to consider and quantify the varying lighting needs on highway construction sites that range from high to low depending on the type of construction work. For example, crack filling activities in pavement surfaces require high levels of lighting to ensure adequate visibility of small work details such as pavement cracks that need to be identified and filled by workers. On the other hand, excavation work needs lower levels of lighting because the equipment operator is not required to identify small work details. Accordingly, the present framework is designed to consider these varying visual and lighting needs in its determination of the minimum lighting requirements for various highway construction activities.

CONVISUAL is designed to ensure the availability of adequate illuminance levels in the work area to enable workers to see and identify the specific work details necessary for their safety and productive work. As shown in Fig. 1, the factors that affect the visibility of such targets in highway construction operations include: (1) the size of the target and distance between worker's eye and the target; (2) the contrast between the target and its immediate background; (3) the visual capacity of the worker; and (4) the illuminance level in the work area. For example, in Fig. 1, the ability of a paving equipment operator to clearly see and properly perform this tasks depends on (1) the size and viewing distance of the guiding marks on the pavement; (2)

the contrast between the guiding marks and the pavement; (3) the visual capacity of the operator; and (4) the provided level of illuminance on site. These factors and the identification of construction targets are analogous to those utilized in standard visual acuity tests. These standard tests are performed to determine the visual capacity/acuity of human subjects by testing their ability to identify standard size targets at a fixed distance and contrast between the target and its background under a specified illuminance level in the test room.

The development of CONVISUAL framework considers the same four visibility assessment factors shown in Fig. 1; however, it utilizes the actual target size and viewing distance, actual

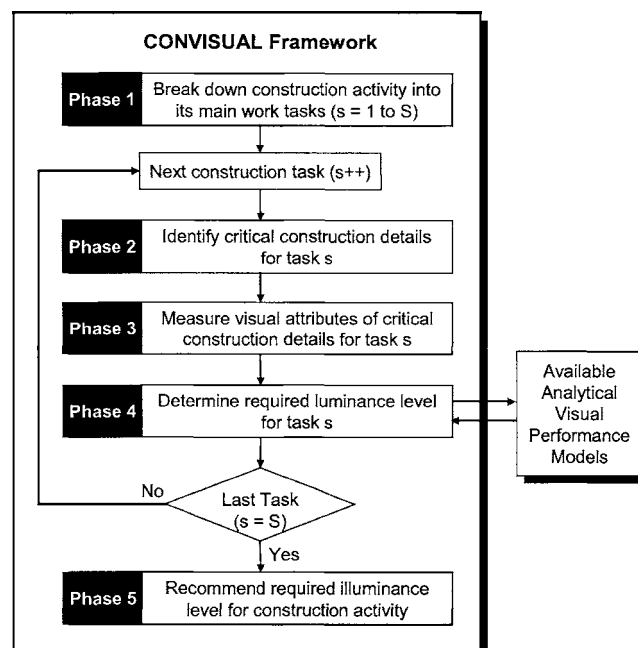


Fig. 2. Construction visual requirements framework

Table 2. Identification of Critical Construction Details for Pavement Marking Tasks

Task	Worker	Critical construction detail
Surface preparation	Sweeping equipment operator	Outline of the pavement surface and therefore there is no critical (i.e., small) construction detail that needs to be seen from a long viewing distance
Spotting	Spotting worker	Spotting string line.
Marking	Marking machine operator	1. Front wheel of the guidance bar (see Fig. 7). 2. Paint spots on the pavement in front of the machine.
	Paint system operator	1. Paint guns and the glass beads dispenser (see Fig. 8). 2. Paint spots on the pavement in front of the paint guns.
Testing	Testing equipment operator	Testing equipment and the pavement marking from a close distance (see Fig. 8), and therefore there is no critical construction detail that needs to be seen from a long viewing distance.

contrast of the construction target, and a visual capacity level representative of all workers in order to determine the required illuminance level in the work zone. CONVISUAL is designed to accomplish this for each highway construction activity in five major phases: (1) construction work breakdown structure; (2) identification of critical construction details; (3) field measurement of visual attributes for construction details; (4) determining the required luminance level; and (5) recommending the required illuminance level, as shown in Fig. 2. The following sections provide a brief explanation of these five major phases.

Phase 1. Construction Work Breakdown Structure

The purpose of this phase is to perform an in-depth operational analysis of the construction activity and break it down to all its constituent *work tasks* ($s=1$ to S). For example, the pavement markings activity can be broken down into four main tasks: surface preparation, spotting, marking, and testing (Migletz and Graham 2002). Similarly, the asphalt paving activity can be subdivided into the main tasks of materials handling, paving, and rolling. This work breakdown is essential to identify the visual and lighting requirements for all the typical tasks involved in each construction activity.

Phase 2. Identification of Critical Construction Details

The objective of this phase is to analyze, at the operational level, the type of work involved in each construction task in order to

identify all the critical details that need to be seen by construction workers. This analysis and information gathering can be performed by reviewing the literature, conducting field studies, and/or interviewing field personnel (e.g., engineers, contractors, equipment operators, superintendents) who have experience in each of the identified work tasks. This structured approach can be used to identify the critical construction details for any set of construction tasks. For example, the critical construction details that need to be clearly seen by equipment operators in a pavement marking task can be identified using this approach to include the front wheel of the guidance bar and the paint spots on the pavement, as shown in Table 2.

Phase 3. Field Measurement of Visual Attributes for Construction Details

In this phase, the three main visual attributes of target size (α), contrast (C), and reflectance factor (R_T) are measured on site for all the identified critical details of construction task s as follows.

1. Measure the target size of all critical details that need to be viewed during the construction operations of task s using the target size (α). The target size is also referred to as the visual angle and it can be identified for each critical detail by measuring (1) the typical viewing distance (D) between the critical detail and the worker's eye; and (2) the dimension of the critical detail (A) that needs to be viewed by the worker, as shown in Fig. 3 and Eq. (1) (Grundy 1981)

$$\text{target size}(\alpha) = \tan^{-1}\left(\frac{A}{D}\right) \times 60 \quad (1)$$

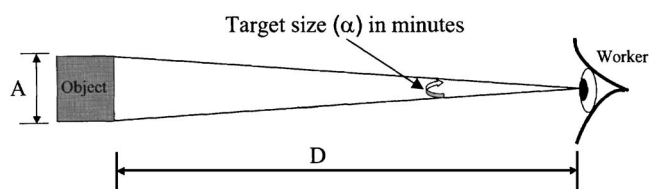
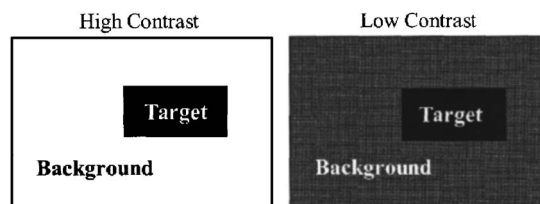
where α =target size in minutes of arc for identified critical detail; A =dimension of the critical detail; and D =distance between worker's eye and the critical detail.

2. Measure the contrast (C) that is typically encountered on site between the critical detail and its immediate background. Contrast affects the visibility of construction targets, as objects with higher contrast are easier to see under the same lighting conditions, as shown in Fig. 4. Contrast can be calculated as a function of the luminance of a target and that of its immediate background as shown in Eq. (2). As such, the contrast of construction targets can be identified on site by measuring the luminance of the construction detail and its immediate background, using a luminance meter

$$\text{target contrast}(C) = \left| \frac{L_T - L_B}{L_B} \right| \quad (2)$$

where L_T =luminance of the critical detail/target in construction task s ; and L_B =luminance of the background.

3. Identify the reflectance factor (R_T) of the construction target which is directed toward the worker using Eq. (3) (Pritchard 1999). The reflectance factor (R_T) can be identified using (1)

**Fig. 3.** Target size of critical detail**Fig. 4.** Target contrast

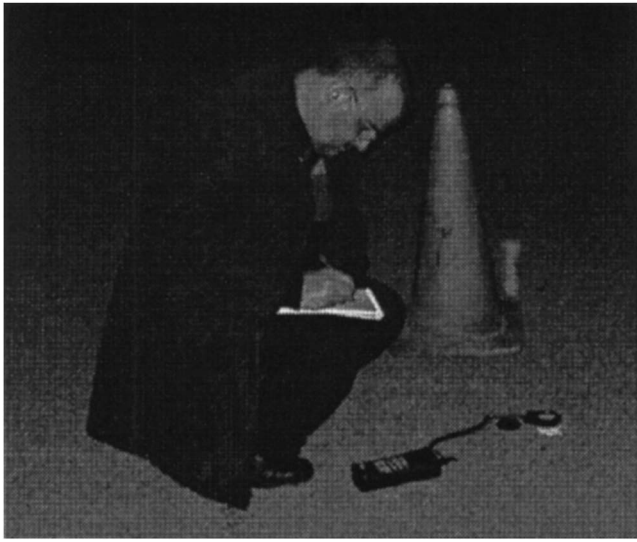


Fig. 5. Measuring illuminance of construction targets

the measured luminance value of the construction target (L_T) toward the worker which was obtained in step 2; and (2) the measured illuminance level incident on the construction target (E_T) which can be easily measured on site using an illuminance meter as shown in Fig. 5

$$\text{reflectance factor } (R_T) = \frac{L_T}{E_T} \quad (3)$$

Phase 4. Determining Required Task Luminance

The purpose of this phase is to determine the required task luminance level (L_s) that provides adequate visibility of all the identified and measured construction details, using available analytical visual performance models (Halonen 1993). This is accomplished in CONVISUAL framework in two main steps:

1. Utilize analytical visual performance models from vision science to identify the required visual acuity level (VA_{required}) for each task based on its visual attributes that were measured in the previous phase. For example, the Werner Adrian visual acuity model can be used to estimate the needed visual acuity (VA_{required}) for an exterior task performed by an average young subject based on the contrast between the critical detail and its immediate background (C), and the background luminance (L_B) as shown in Eq. (4). It should be noted that this visual acuity (VA_{required}) is also defined as the reciprocal of the target size measured in minutes (Halonen 1993), as shown in Eq. (4). This calculated visual acuity (VA_{required}) level represents the minimum visual requirements to view the construction target, and therefore it needs to be adjusted in the next step to enable older workers to view these targets and perform their work comfortably (Grundy 1981)

$$\begin{aligned} \text{required visual acuity}(VA_{\text{required}}) \\ = 0.425 \log_{10}(C \cdot L_B) + 0.866 = \frac{1}{\alpha} \end{aligned} \quad (4)$$

where VA_{required} =visual acuity of the subject; α =measured target size in minutes of arc; C =measured contrast between target and its background; and L_B =background luminance in cd/m^2 .

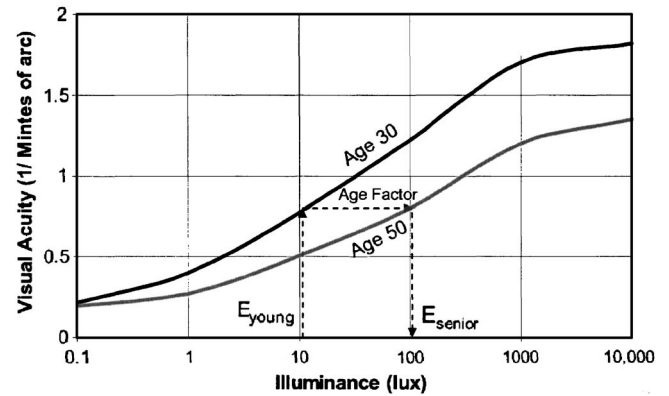


Fig. 6. Impact of age on visual performance (data from Industrial Engineering, Ergonomics and Work Organization 2004)

2. Adjust the minimum required visual acuity value (VA_{required}) obtained in the previous step by a visual comfort factor (CF) to enable workers to perform their visual tasks comfortably and to ensure that their visual systems are not operating at their limits as shown in Eq. (5). To this end, Grundy (1981) recommends a CF value of 2 to ensure that visual tasks can be performed efficiently and with comfort. Accordingly, Eq. (4) can be rewritten to calculate the required luminance (L_s) for a young worker based on (1) the comfort visual acuity (VA_{comfort}) level that ensures a comfortable view of the construction target; and (2) the measured contrast (C) between the target and its immediate background as shown in Eq. (6)

$$VA_{\text{comfort}} = VA_{\text{required}} \times CF = \left(\frac{1}{\alpha} \right) \times CF \quad (5)$$

$$\text{required task luminance}(L_s) = \frac{10^{[(VA_{\text{comfort}} - 0.866)/0.425]}}{C} \quad (6)$$

Phase 5. Recommending Required Activity Illuminance

The purpose of this phase is to transform the required task luminance level (L_s) to a recommended activity illuminance level (E_A) that can be easily measured on construction sites using simple and inexpensive illuminance meters. This is accomplished using the following three main steps:

1. Identify the required activity luminance level for a young worker (L_A) based on all the required luminance levels (L_s) calculated for all tasks ($s=1$ to S) in the previous phase, as shown in Eq. (7)

$$\text{required activity luminance}(L_A) = \max_{s=1}^S [L_s] \quad (7)$$

2. Transform the required activity luminance level (L_A) to an equivalent required activity illuminance level for a young worker (E_{young}) using the reflectance factor (R_T) of the construction target surface, as shown in Eq. (8) (Pritchard 1999)

$$\begin{aligned} \text{required activity illuminance for young workers } (E_{\text{young}}) \\ = \frac{L_A}{R_T} \end{aligned} \quad (8)$$

3. Adjust the required activity illuminance level for a young worker (E_{young}) by an age factor to consider the visual abilities of all construction workers on site, including older

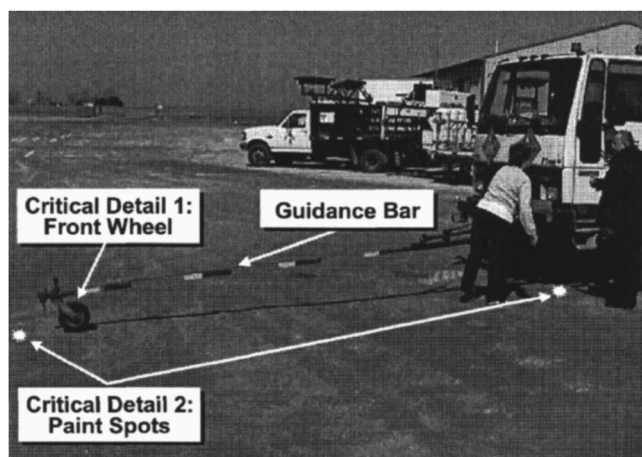


Fig. 7. Critical details for pavement marking machine operator

workers as shown in Eq. (9). The effect of age on visual performance was investigated by many researchers in vision science (Davis and Garza 2002; Halonen 1993; Grundy 1981; Boyce 1973), who concluded that older workers need higher levels of illuminance to maintain an equivalent level of visibility to that of younger workers as shown in Fig. 6. Accordingly, the age factor in the present framework can be identified using formula (10) and it depends on: (1) the required activity illuminance level for a young worker (E_{young}) obtained from step 5.2; and (2) the required illuminance level for a senior worker (E_{senior}) to maintain an equivalent visibility level obtained from Fig. 6

$$\text{recommended activity illuminance}(E_A) = E_{\text{young}} \times \text{AF} \quad (9)$$

$$\text{age factor}(\text{AF}) = \frac{E_{\text{senior}}}{E_{\text{young}}} \quad (10)$$

Prototype Implementation

A prototype of CONVISUAL is implemented to illustrate its use in identifying the required illuminance level for the pavement marking activity, which plays an important role in providing guidance and conveying information to drivers (*Manual* 2000). This particular highway construction activity is selected in this prototype implementation of CONVISUAL due to (1) its typical execution during nighttime hours to minimize daytime traffic delays especially on roads with high volumes of traffic (Migletz and Graham 2002; Cottrell and Hanson 2001); and (2) its importance in highway construction as annual expenditures on this activity were estimated at \$1.55 billion in year 2000 in the United States and Canada (Migletz and Graham 2002). In order to implement a prototype of the present framework for the pavement marking activity, the aforementioned five phases of CONVISUAL (see Fig. 2) are executed in the following sections.

Pavement Marking Work Breakdown Structure

In order to enable the breakdown of the pavement marking activity to its main constituent construction tasks at the operational level, a literature review and a number of field studies were

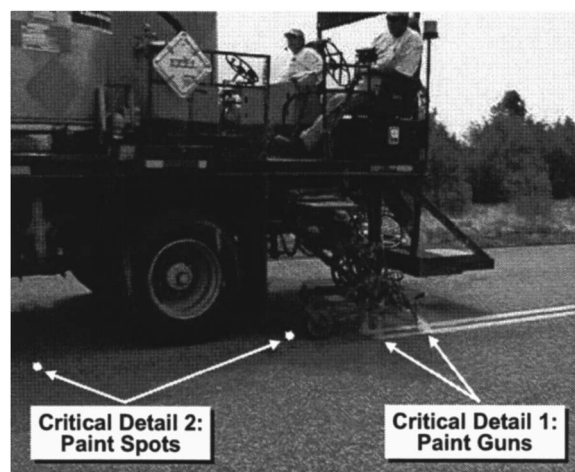


Fig. 8. Critical details for paint system operator

conducted as shown in Fig. 7. The findings of the literature review and the field studies indicate that the pavement marking activity consists of four construction tasks: (1) surface preparation; (2) spotting; (3) marking; and (4) testing (Migletz and Graham 2002). The following sections provide a brief description of the type of construction work involved in each of these tasks and its operational requirements.

Surface Preparation

This task is performed to ensure that the pavement surface is dry and free of oil, dirt, and debris at the time of application in order to improve the service life of the markings (Migletz and Graham 2002). Pavement surface, therefore, needs to be sand or shot blasted, swept, and air blasted before the application of pavement markings. Sweeping and air blasting tasks are usually performed using truck-mounted equipment.

Spotting

This task involves applying paint spots on the pavement surface, where longitudinal striping is intended to be installed. These paint spots are applied at appropriate spacing (10 m or less) in order to

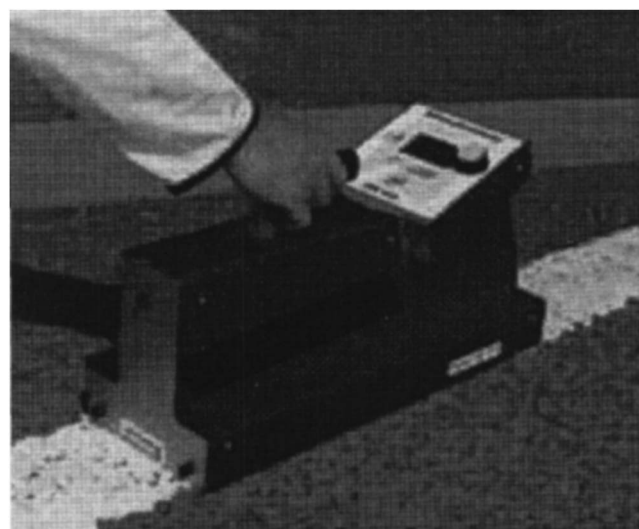


Fig. 9. Pavement marking retroreflectivity inspection

Table 3. Field Measurement of Visibility Attributes for Pavement Markings Activity

Task	Worker	Critical detail	Measured attributes					Calculated attributes		
			Dimension of detail A (cm)	Viewing distance D (m)	Target luminance L_T (cd/m ²)	Background luminance L_B (cd/m ²)	Target illuminance E_T (lx)	Visual angle α (min)	Target contrast C	Reflectance factor R_T (cd/lx/m ²)
Spotting	Spotting workers	Spotting string line	0.6	3.0	2.5	1.88	32	6.87	0.248	0.078
Marking	Marking machine operator	Front wheel of guidance bar	3.0	6.0	2.39	1.71	34	17.30	0.284	0.070
		Paint spots on pavement	2.5	40.0	5.43	1.79	29	2.15	0.670	0.187
	Paint system operator	Nozzles of paint guns	0.5	3.0	3.14	1.90	30	5.73	0.395	0.105
		Paint spots on pavement	2.5	20.0	5.63	1.80	30	4.30	0.670	0.187

provide guidance for the marking equipment and to ensure that the start, finish, and orientation of longitudinal striping is defined as shown in Figs. 7 and 8.

Marking

In this task, the marking material (paint and glass beads) is applied to the pavement surface according to the required dimensions, shapes, and thickness. For longitudinal striping, this task should be performed using a truck-mounted marking machine as shown in Figs. 7 and 8. The machine should be equipped with spray guns capable of applying the material under pressure at a controlled temperature through nozzles equipped with a remotely controlled cutoff mechanism. All guns on the spray carriage shall be in full view of the operators during the spraying operation. For application of broken lines, the spray unit shall include an automatic feed control device capable of being set to produce the specified stripe-to-gap ratio (Migletz and Graham 2002). Pavement marking machines move at about 9 mph while installing markings and it takes two people to operate the marking machine. One drives the truck and keeps it moving in a straight line, while the second operates the painting system. The operators use special headphones in order to communicate with each other and to coordinate the application of the paint.

Testing

This task is performed to inspect the completed pavement markings in order to ensure their compliance with the required specifications. In this task, two main tests are conducted to inspect (1) the retroreflectivity of pavement marking using a portable retroreflector on site as shown in Fig. 9; and (2) the thickness of the applied marking by placing a plate on the road surface, striping over it, and then removing the plate from the road surface to enable the measurement of the thickness.

Identification of Critical Construction Details

During the conducted field studies, the type of work performed by construction crews in each of the aforementioned four pavement marking tasks was carefully studied. This led to the identification of a number of critical construction details that need to be seen by construction workers during the execution of these four tasks as shown in Table 2.

Field Measurements of Visual Attributes for Pavement Markings

After identifying the critical details that need to be seen by construction workers in the previous phase, field measurements were conducted to identify the visual attributes of each critical detail. First, the dimension (A) of each critical detail and its viewing distance (D) were measured on site (see Table 3). Second, a luminance meter was set up in the location from which the worker would normally view each critical detail to measure the luminance of the critical detail (L_T) and that of its background (L_B) as shown in Table 3. Third, the illuminance of the target (E_T) was measured on site using an illuminance meter as shown in Fig. 5 and Table 3. These measured visual attributes were then used to calculate for each critical detail its visual angle (α), target contrast (C), and reflectance factor (R_T), using Eqs. (1)–(3), respectively, as shown in Table 3.

Determining Required Luminance Level for Pavement Marking Tasks

This phase of implementation identifies the level of task luminance (L_s) required by a young worker to view the critical details in each task based on the visual angle (α) and target contrast (C) which were measured on site in the previous phase (see Table 3).

Table 4. Required Luminance for Pavement Markings Activity

Task	Worker	Critical detail	Required visual acuity	Comfort visual acuity	Required task luminance
			$VA_{required}$	$VA_{comfort}$	L_s (cd/m ²)
Spotting	Spotting workers	Spotting string line	0.145	0.291	0.18
Marking	Marking machine operator	Front wheel of guidance bar	0.058	0.116	0.06
		Paint spots on pavement	0.465	0.930	2.11 ^a
	Paint system operator	Nozzles of paint guns	0.174	0.349	0.15
		Paint spots on pavement	0.233	0.465	0.17

^aRequired activity luminance (L_A)=2.11 cd/m².

For each task s , this is achieved in three main steps to calculate (1) the required visual acuity (VA_{required}); (2) the comfort visual acuity level (VA_{comfort}) that ensures a comfortable view of the construction target; and (3) the required task luminance (L_s) for a young subject, using Eqs. (4)–(6), respectively, as shown in Table 4. The results in Tables 3 and 4 highlight the fact that the required luminance level for each task is dependant on the utilized construction method and the visual attributes of all the critical construction details including their size, contrast, and reflectance characteristics.

Recommending Required Illuminance Level for Pavement Marking Activity

The results of the previous implementation phase (see Table 4) indicate that the ability of the pavement machine operator to see the series of paint spots on the pavement surface is the most demanding visual task that requires the highest required luminance (L_s) of 2.11 cd/m^2 . This luminance level is required to enable a young pavement machine operator to see the paint spots ahead of the machine for an adequate distance so the operator can properly maneuver the machine to ensure that the guidance bar will always coincide with the imaginary line connecting these paint spots as shown in Fig. 7. Accordingly, the required activity luminance (L_A) for a young worker in this pavement marking activity is identified to be 2.11 cd/m^2 , and its equivalent required activity illuminance level (E_{young}) for a young worker is determined to be 11 lx based on Eq. (8). This required illuminance level (E_{young}) for a young worker is then adjusted by an age factor of 10 to accommodate the visual capacity of older workers, as shown in Fig. 6 and Eqs. (9) and (10). As such, the present prototype implementation recommends an illuminance level (E_A) of 110 lx for the pavement marking activity in order to ensure the provision of adequate lighting levels for both young and senior workers.

It should be noted that the selected age factor of 10 and recommended illuminance level of 110 lx in this prototype implementation assume that the age of the marking machine operator can reach up to 50 years. This recommended illuminance level of 110 lx is consistent with those recommended by state DOTs for the pavement marking activity as shown in Table 1. Furthermore, this level of illuminance can be easily satisfied on site using commercially available lighting equipment that was found in a number of field tests to be capable of producing average illuminance levels of up to 540 lx (El-Rayes and Hyari 2002). This prototype implementation illustrates the use of the developed framework and highlights its scientific and rational approach for identifying the required illuminance levels for the pavement marking activity. Similarly, illuminance requirements for other highway construction activities can be objectively and practically determined using the earlier described five main phases of CONVISUAL framework. This implementation of CONVISUAL framework can play an important role in resolving the current lack of consensus among state DOTs on lighting requirements which was highlighted earlier in Table 1.

Summary and Conclusion

A framework was developed to identify the required illuminance levels that are needed on nighttime highway construction sites. The framework is named Construction Visual Requirements Framework, CONVISUAL, and its development integrates

interdisciplinary concepts from construction engineering and vision science to ensure that the specified illuminance levels on site are sufficient for all construction workers to see all the critical work details needed to perform their tasks safely and productively. CONVISUAL framework provides a scientific and rational approach for determining the required illuminance level for each highway construction activity based on the size and contrast of the construction detail that needs to be seen by workers and their visual capacity. To accomplish this for each activity, the developed framework can be implemented in five major phases: (1) construction work breakdown structure; (2) identification of critical construction details; (3) field measurement of visual attributes for all construction details; (4) determining the required illuminance level using analytical visual performance models from vision science; and (5) recommending the required illuminance level for the activity that considers the age and visual capacity of all workers on site. A prototype of CONVISUAL framework was implemented for the pavement marking activity to illustrate the practicality of the developed framework and to highlight its unique capability of identifying the required illuminance level in a scientific and rational approach. This should prove useful to state DOTs and highway contractors alike, and should contribute to the development and implementation of more reliable and practical lighting standards that represent the actual lighting needs on nighttime highway construction projects.

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