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16. Abstract Project

Historically, pedestrian signal heads have been internally illuminated using incandescent lamps. However, with the current widespread use of light emitting diodes (LEDs) in pedestrian signal heads, concerns regarding the visibility of LED devices have emerged. Research was needed to develop measurable visibility performance requirements for pedestrian signal heads, as well as test methods to verify compliance with these requirements.

Researchers solicited expert opinions concerning the minimum luminance necessary for the daytime recognition of the walking person and upraised hand indications. The findings indicated that the minimum luminance values proposed by the Institute of Transportation Engineers (ITE) (5300 cd/m^2 and 3750 cd/m^2) should provide an adequate level of brightness for daytime recognition of the walking person and upraised hand indications, respectively.

Through a nighttime discomfort glare study, researchers determined the median glare threshold for the walking person and upraised hand indications to be approximately 3100 cd/m^2 and 2600 cd/m^2, respectively. Since these values are less than the minimum luminance levels proposed by ITE, researchers recommended that pedestrian signals be dimmed at night. In addition, the discomfort glare study findings indicated that the ITE minimum dimmed luminance requirement (i.e., 30 percent of the minimum luminance values) will provide an adequate level of brightness for nighttime recognition of the walking person and upraised hand indications.

Researchers also evaluated two test methods by which to measure the luminance of pedestrian signal indications. The ITE proposed test method measures the luminance of a pedestrian signal indication at nine separate points on the indication's surface, while the full indication method measures the luminance of an entire indication in one measurement. Researchers recommended the use of the full indication test method to verify compliance with the recommended visibility performance requirements.

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VISIBILITY PERFORMANCE REQUIREMENTS AND TESTING PROCEDURES FOR PEDESTRIAN SIGNAL HEADS

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TEXAS TRANSPORTATION INSTITUTE
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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation (TxDOT) or the Federal Highway Administration (FHWA). This report is not intended to constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. The engineer in charge of the project was Melisa D. Finley, P.E. (TX-90937).

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TABLE OF CONTENTS

Page

Page

LIST OF FIGURES

Figure **Page**

LIST OF TABLES

Table **Page**

1. INTRODUCTION

Pedestrian signal heads are traffic control devices that are used to direct pedestrian traffic. Historically, pedestrian signal heads have been internally illuminated using incandescent lamps. Thus, the current Texas Department of Transportation (TxDOT) pedestrian signal lamp specification (*1*) only addresses the use of incandescent optical units. However, with the current widespread use of light emitting diodes (LEDs) in pedestrian signal heads and other traffic control devices, concerns regarding the visibility of LED devices have emerged. Research was needed to develop measurable visibility performance requirements for pedestrian signal heads, as well as test methods to verify compliance with these requirements.

PROJECT OVERVIEW AND REPORT ORGANIZATION

The overall objective of this project was to develop specifications and testing procedures to be used by TxDOT to accept and pre-certify pedestrian signal heads. More specifically, the purpose was to determine the minimum and maximum visibility performance requirements needed to ensure the recognition of pedestrian signal indications.

The Texas Transportation Institute (TTI) conducted the research project described herein from September 1, 2002, to August 31, 2003. Described below are the activities completed, as well as the report organization.

- *Literature Review* – The research team reviewed previous research concerning pedestrian signal head characteristics, pedestrian signal head specifications, as well as the visibility performance requirements of other traffic control devices. Chapter 2 summarizes the research reviewed.
- *Modified LED Pedestrian Signal* – In order to assess the visibility performance requirements of pedestrian signals, the research team modified a LED pedestrian signal so that it was capable of producing the walking person and upraised hand indications at multiple light output levels. Using two measurement methods and regression analysis, researchers determined the range of light output produced by the modified signal's indications. Chapter 3 documents the modifications and procedures used to determine the light output range.
- *Expert Panel* – The researcher team conducted an expert panel to evaluate the minimum luminance necessary for daytime recognition of the walking person and upraised hand indications. Chapter 4 describes the results of the expert panel.
- *Nighttime Discomfort Glare Study* – The research team also conducted a nighttime study to determine the luminance at which discomfort glare occurs. In total, 30 participants 55 years of age or older viewed a range of light output levels for both the walking person and upraised hand indications at two signal heights (7 ft and 10 ft). Chapter 5 presents the experimental design and results from the nighttime study.
- *Recommendations* – Based on the results from the research conducted, the research team developed recommendations regarding the visibility performance requirements of pedestrian signal indications. Chapter 6 documents the recommendations.

2. LITERATURE REVIEW

LEDs are solid-state semiconductor devices that convert electrical energy into visible light. Commercial research into LED technology began in the 1960s and changed rapidly in the 1980s with the emergence of multiple colors, improved reliability, and increased efficiency (*2*). In order to reduce energy consumption, during the 1990s, practitioners began to use LEDs to illuminate traffic control devices. With the proliferation of LED technologies, concerns regarding the brightness of LED devices have surfaced. Just recently, the visibility performance of pedestrian signals has begun to be investigated.

PHOTOMETRY

Photometry is the measurement of light in the visible spectrum (380 nanometers [nm] to 740 nm). A few of the more common photometric terms are described below:

- Brightness is a subjective term that refers to the attribute of light sensation by which a stimulus appears more or less intense or to emit more or less light.
- Luminance (L) is the measure of light reflected from a surface or emitted by a light source, roughly equated to "brightness." It is not affected by distance and is expressed in foot Lamberts (fL) or candelas per meter squared (cd/m^2).
- Luminous intensity (I) is a measure of the strength of a light source. It is derived from luminance by multiplying the luminance by the source area ($I=L*A$). It is expressed in candelas (cd) and is sometimes referred to as a candlepower.
- Illuminance (E) is the amount of light falling upon an object. It is derived from luminous intensity by the "inverse square law" ($E=I/d^2$) where d is distance. It is expressed in foot candles (fc) or lux (lx).

STANDARDS FOR PEDESTRIAN SIGNAL HEADS

Institute of Transportation Engineers

In the United States, the Institute of Transportation Engineers (ITE) is the primary organization that develops equipment and material standards for vehicle signal heads, as well as pedestrian signal heads. For years, ITE's vehicle signal and pedestrian signal standards (*3*) only addressed signals with incandescent lamps, since incandescent lamps were the primary light source used in such devices. However, in July 1998, ITE approved an interim purchase specification for 8-inch and 12-inch LED vehicle signals (*3*) to provide guidance to agencies concerning the use of LED technology as an alternative to incandescent lamps. This interim purchase specification includes sections for physical and mechanical requirements, electrical standards, quality assurance, and warranty provisions, as well as photometric (i.e., visibility) requirements. The photometric requirements section covers the luminous intensity and distribution, chromaticity, and photometric maintenance of red, yellow, and green traffic signal indications.

Currently, the National Cooperative Highway Research Program (NCHRP) is funding project 5-15, *Visibility Performance Requirements for Vehicular Traffic Signals*. The objectives of this project include the development of visibility performance requirements and test methods to verify compliance with the performance requirements. Based on information provided on the NCHRP website (*4*), project 5-15 has been completed, and a research result digest should be available in late 2003.

Just recently, the ITE LED Specification Committee released draft purchase specifications for LED pedestrian signal heads and LED arrow vehicle signal heads for public comment (*5*, *6*). Both of these draft specifications include photometric requirements and test methods. More specifically, the LED pedestrian signal head draft purchase specification provides the following minimum luminance requirements, which are identical to the minimum light output requirements currently being used by California (*7*):

- For a minimum of 60 months, the maintained minimum luminance of the walking person indication shall not be less than 5300 cd/m^2.
- For a minimum of 60 months, the maintained minimum luminance of the upraised hand indication shall not be less than 3750 cd/m^2.

In addition, the LED draft pedestrian signal head purchase specification requires that the average luminance of each indication not exceed twice the maintained minimum luminance requirement of the indication (as defined above).

The draft test method for determining if the minimum luminance requirements are met is similar to the current procedure used by California (*8*). The test method proposed by ITE uses a luminance meter located on the physical axis of the optical unit. The luminance meter is set up at a distance such that the selected aperture samples a half-inch diameter area at the optical unit's surface. A minimum of nine separate points spread across the illuminated indication are measured perpendicular to the surface of the optical unit. Thus, the luminance meter must be moved in the horizontal and vertical planes, so as to sample the entire emitting surface of the optical unit.

Finalization and approval of these new LED specifications will provide practitioners with additional guidance with respect to the visibility performance requirements of pedestrian signal heads as well as vehicle signal heads. However, until the draft LED pedestrian signal head purchase specification is approved, the 1985 pedestrian signal head standard (*3*), which does not address the required minimum light output, will be used.

TxDOT Specifications

The 1993 TxDOT specification book (*9*) only addresses incandescent pedestrian signals and does not include visibility performance requirements. Thus, in 2000 and 2002, TxDOT revised two departmental specifications (TO-7062 and TO-7061, respectively) that describe the minimum acceptable requirements for pedestrian signal heads and LED pedestrian signal optical units (*10*, *1*). The LED optical unit specification (TO-7061) requires that the symbolic indications be solid and a minimum of 11 inches high and 6 inches wide. In addition, the LED optical unit

specification states that outlined indications are not acceptable. The LED optical unit specification also requires the beam intensity and color of each unit to meet or exceed the ITE vehicle signal head standards (*3*). However, as noted in the previous section, the LED vehicle signal head interim purchase specification only addresses the minimum luminous intensity values for red, yellow, and green LED vehicle signals. Thus, the minimum luminous intensity values for pedestrian signal heads, which are white and Portland orange signals, are not addressed in the currently approved ITE vehicle signal head or pedestrian signal head standards.

In addition, TxDOT has a departmental specification (TO-7045) that addresses vehicle signal heads (*11*). This specification contains physical and mechanical requirements, housing requirements, incandescent and LED optical unit requirements (including light output requirements for red, yellow, and green LED optical units), electrical requirements, environmental requirements, as well as requirements for testing, documentation, and warranty.

Manual on Uniform Traffic Control Devices

The Millennium edition of the Manual on Traffic Control Devices (MUTCD) (*12*) and the 2003 Texas MUTCD (*13*) provide standards and guidance for pedestrian signals independent of the type of lamp (i.e., incandescent or LED). In addition, neither MUTCD addresses the visibility of pedestrian signals in terms of photometric performance requirements. Instead, both MUTCDs include the following:

- The bottom of the signal housing shall be mounted no less than 7 ft and no more than 10 ft above the sidewalk level.
- The signal shall be positioned to provide maximum visibility at the beginning of the crosswalk.
- Indications should be conspicuous and recognizable (both day and night) at all distances from the beginning of the crosswalk to a point 10 ft from the end of the crosswalk.
- At crosswalks where the pedestrian enters the crosswalk more than 100 ft from the pedestrian signal, the indications should be at least 9 inches high.

In addition, both MUTCDs require that all new pedestrian signal indications consist of symbolized messages. Both MUTCDs only permit the three symbol indications:

- The steady walking person to signify that a pedestrian may start to cross the roadway with the potential for turning traffic conflicts. (A flashing walking person is considered to have no meaning and thus cannot be used.)
- The flashing upraised hand to indicate that a pedestrian shall not start to cross the roadway, but if already started, shall proceed out of the traveled way.
- The steady upraised hand to indicate that a pedestrian shall not enter the roadway.

Each symbol indication shall be at least 6 inches high, independently illuminated, and emit a single color. The walking person indication shall be white, and the upraised hand indication

shall be Portland orange. The permitted symbol designs are set forth in the Standard Highway Signs book (*14*).

In May 2002, the Federal Highway Administration (FHWA) released proposed second revisions to the Millennium edition of the MUTCD. The proposed revisions pertinent to this research include:

- Symbol indications shall be solid.
- Outline style symbol indications shall not be used.
- Upraised hand indications shall be flashed continuously at a rate of at least 50 flashes per minute (fpm) and at most 60 fpm.
- The illuminated period of each upraised hand indication flash shall be at least half and at most two-thirds of the total flash cycle.

PEDESTRIAN SIGNAL HEAD RESEARCH

A large portion of previous pedestrian signal head research has focused on the indications (e.g., symbol versus text) and on accessible pedestrian signals. However, in 1997, Pennak, Mace, and Finkle (*15*) conducted a study to determine performance criteria for acceptable pedestrian signal visibility. This research examined the legibility of 3-inch letters and 6-inch symbols at distances of 60 ft and 96 ft. The supplied voltage to the signal was set at 100, 75, and 50 percent of full power. Test stimuli included several types of commercially available incandescent, fiber optic, and LED pedestrian signals. Signal displays included text (WALK and DON'T WALK) and symbolic (walking person and upraised hand). Also included were two different rectangular signal housings (9-inch and 12-inch) and two 11-inch round red-amber-green signals with symbol masks.

Forty-eight individuals aged 62 and older participated in the signal visibility study. Each participant was asked to identify a specific signal's location in the test stimuli array, name the signal's display configuration, and score the brightness of the signal on a five-point scale. Results indicated that a minimum intensity of 25 cd is adequate under most lighting conditions for any pedestrian signal regardless of technology, distance, signal size, and display configuration. In addition, the data suggested that the 9-inch signal housing provided sufficient visibility with fewer phantom effects. To account for the possibility of overly bright signals, researchers recommended a maximum intensity of 100 cd.

RELATED RESEARCH

Research concerning the visibility performance of other traffic control devices, such as dynamic message signs (DMS) and arrow panels, has also been conducted. In the 1980s and 1990s, several studies (*16*, *17*, *18*, *19*) were performed to determine the effects of luminance on dynamic DMS legibility. Table 1 summarizes the character luminance recommendations from these studies.

Table 1. Summary of Character Luminance Recommendations.

Past Research	Daytime Character Luminance (cd/m^2)	Nighttime Character Luminance (cd/m^2)
Mazoyer & Colomb (*16*)	--	30 to 230
Padmos et al. (*17*)	4000	100
Colomb & Hubert (*18*)	1500 to 4000	Not Conclusive
Garvey & Mace (*19*)	1000	30

-- Did not evaluate

In 2001, TTI completed a research project (*20*) for TxDOT concerning the minimum character luminance requirements of portable DMS. Based on the previous research findings summarized in Table 1 and additional evaluations, TTI researchers recommended a daytime minimum character luminance of 4000 cd/m^2 and a minimum nighttime character luminance of 30 cd/m^2. In addition, TTI researchers recommended a testing procedure to be used to verify compliance with the recommended luminance requirements.

With respect to arrow panels, in the 1990s, NCHRP sponsored research project 5-14 (*21*) to evaluate the factors affecting detection and recognition of arrow panels and to develop a practical test method to verify arrow panel visibility. Table 2 contains the visibility requirements recommended by the researchers.

Table 2. Recommended Luminous Intensity Requirements per Lamp (*21*).

Time of Day	Speed (mph)	Minimum On-Axis (candela/lamp)	Minimum Off-Axis (candela/lamp)	Maximum Hot Spot [a] (candela/lamp)
Day	≥ 45	500	100	NA
Night	≥ 45	150	30	370

[a] Maximum intensity requirement must be met at the lamp "hot spot," which may or may not be on-axis
NA Not applicable

In 2000, TTI conducted a research project (*22*) for TxDOT that examined the visibility requirements of arrow panels. Using the NCHRP 5-14 recommendations in Table 2 and additional evaluations, TTI researchers recommended the minimum and maximum panel luminous intensities in Table 3. In addition, TTI researchers recommended a testing procedure to be used to verify compliance with the recommended intensity requirements.

It is important to note that some of the visibility performance requirements utilize luminance while others use luminous intensity. As part of the NCHRP 5-14 research project, Finkle (*23*) developed a method for estimating source using a luminance meter in cases where the source can be considered a point source and the source is smaller than the aperture of the luminance meter. This luminance-to-intensity method presents the opportunity for the practitioner to evaluate a light source (e.g., a pedestrian signal head) from the point of view of the observer or driver.

Table 3. Recommended Luminous Intensity Requirements for an Entire Arrow Panel (*22*).

Time of Day	Speed (mph)	Minimum On-Axis (cd)	Minimum Off-Axis (cd)	Maximum On-Axis (cd)
Day	≥ 45	4000	800	NA
Night	≥ 45	1200	240	5500

[a] Intensity requirements for the entire panel when displaying a left or right flashing arrow (10 lamps illuminated)
NA Not applicable

Using a "through the lens" luminance meter, an investigator targets a device such that the device fills the aperture and measures the luminance (Figure 1). After the luminance of the device is recorded, the luminous intensity of the panel can be calculated through the use of the following formulas:

$$I = L * A \quad (1)$$

where: I = total intensity (cd)
L = measured luminance (cd/m^2)
A = area of the luminance meter aperture at target distance (m^2)

$$A = [\tan (APsize) * D/2]^2 * \Pi \quad (2)$$

where: APsize = aperture size (radians or degrees)
D = distance between target and luminance meter (m)

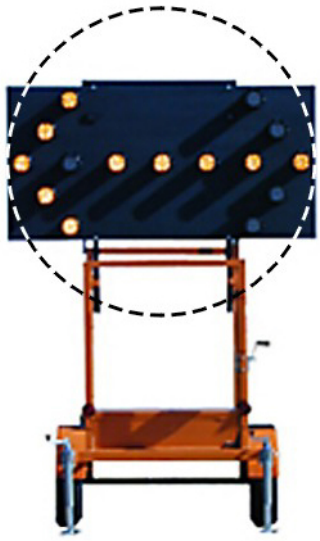


Figure 1. Arrow Panel within Luminance Meter Aperture.

As seen in Figure 1, the aperture is not entirely filled by the arrow panel; thus, ambient or stray light may enter the meter making it necessary to take both a "target on" measurement and a "target off" measurement. The luminance measurement is then the difference between two distinct luminance readings. Once the difference is obtained, it can be entered into equation 1. This on/off measurement technique is necessary when taking readings during the day or in a lighted area.

The luminance-to-intensity measurement is a new estimation technique for luminous intensity estimation of field light sources. However, this measurement process can solely be used to measure the luminance of an entire device, such as a pedestrian signal indication. The luminance-to-intensity measurement technique and calculations have been validated in laboratory experimentation, in the field evaluation of arrow panels (*21*), and in a symbolic traffic signal study sponsored by the FHWA (*23*), which included pedestrian signals.

3. MODIFIED LED PEDESTRIAN SIGNAL

In order to assess the visibility performance requirements of pedestrian signals, the research team modified a LED pedestrian signal so it was capable of producing the walking person and upraised hand indications at multiple light output levels. This chapter documents these modifications, as well as the two test methods used to determine the range of luminance values produced by each indication.

MODIFICATIONS

Researchers obtained and modified a LED pedestrian signal in order to vary the light output (brightness) of the walking person and upraised hand indications. More specifically, to provide a precise and repeatable method of varying the light output of the pedestrian signal, researchers employed a method known as pulse width modulation.

The internal power supply for the indications, which could not be used, was disconnected and replaced with a precision, outboard power supply of the same voltage. This voltage was supplied to the two indications through high-speed electronic switches called power MOSFETs. When the electronic switch was "on," the indication was at its normal (full) brightness. When the electronic switch was "off," the indication would not be illuminated. To control the light output between normal brightness and no illumination, the electronic switch was turned "on" and "off" at a rate of 1000 times per second. The ratio of on-time to off-time controlled the brightness. For example, if the on-time equaled the off-time, the light output of the indication would be approximately 50 percent of the normal brightness. At 1000 hertz (Hz), the human eye does not recognize the on/off cycles but instead perceives a change in brightness.

To control the on/off cycle, a microprocessor was employed that varied the on/off ratio between 0/255 to 255/255. Thus, each increase in the on/off ratio (i.e., 0/255 to 1/255) was equal to a 3.9 increase in the on-time. This microprocessor was then directed by a disk operating system (DOS) program, run from a laptop computer, to illuminate either the walking person or upraised hand indication at the specified on/off ratio.

LUMINANCE TEST METHODS

ITE

Initially, researchers measured the luminance of each indication using the ITE proposed test method. At 20 of the 255 light output levels, researchers measured the luminance of each indication at nine separate points on the indication's surface. Figure 2 shows the nine measurement points for the walking person and upraised hand. For each light output level measured, researchers averaged the nine separate luminance values. Regression analysis was then used to determine the relationship between the independent variable (light output level) and the dependent variable (average luminance). Figure 3 illustrates this relationship for each indication. The luminance level of the walking person indication ranged from approximately 200 cd/m^2 to 13,450 cd/m^2, and the luminance level of the upraised hand indication ranged from approximately 200 cd/m^2 to 11,350 cd/m^2.

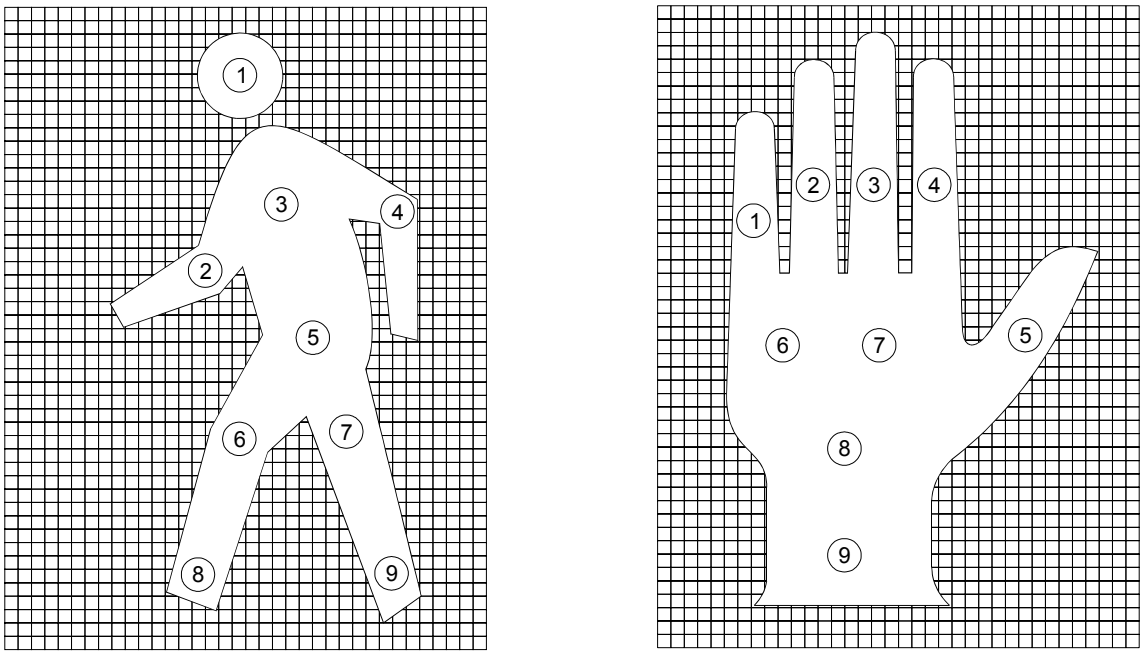
One disadvantage of the ITE proposed test method is that the locations of the nine points are not defined; thus, the luminance may be measured at different points on multiple signals. However, even after defining the points in Figure 2, researchers found it difficult to measure the exact same area twice. In addition, since the measurement area is small (half-inch diameter) compared to the size of the indication (11 inches high by 6 inches wide), slight movements in the location of the measurements can produce large variations in the results as individual LEDs are included or not included in the measurement area.

Full Indication

At nine of the 255 light output levels, researchers also measured the luminance of each indication using the full indication test method. Figure 4 shows the measurement process for the walking person and upraised hand. For each light output level, researchers measured the luminance of the entire indication twice. These two values were averaged and then regression analysis was used to determine the relationship between the independent variable (light output level) and the dependent variable (average luminance). Figure 5 illustrates this relationship for each indication. The luminance level of the walking person indication ranged from approximately 100 cd/m^2 to 3400 cd/m^2, and the luminance level of the upraised hand indication ranged from approximately 150 cd/m^2 to 4550 cd/m^2.

For the walking person indication, the luminance levels measured using the full indication test method were 25 percent lower than those measured using the ITE proposed test method. For the upraised hand indication, the full indication test method produced luminance levels 40 percent lower than the ITE proposed test method luminance levels. This finding was not unexpected, since in the full indication test method the target aperture is not entirely filled by the illuminated indication and thus includes a portion of the surrounding non-illuminated area in the measurement.

One advantage of the full indication test method is that it yields more consistent results, since the entire indication is included in every measurement. In addition, the full indication test method presents the opportunity for the practitioner to evaluate the brightness of a pedestrian signal indication from the point of view of the observer.



a) Walking Person **b) Upraised Hand**

Figure 2. ITE Test Method Measurement Locations.

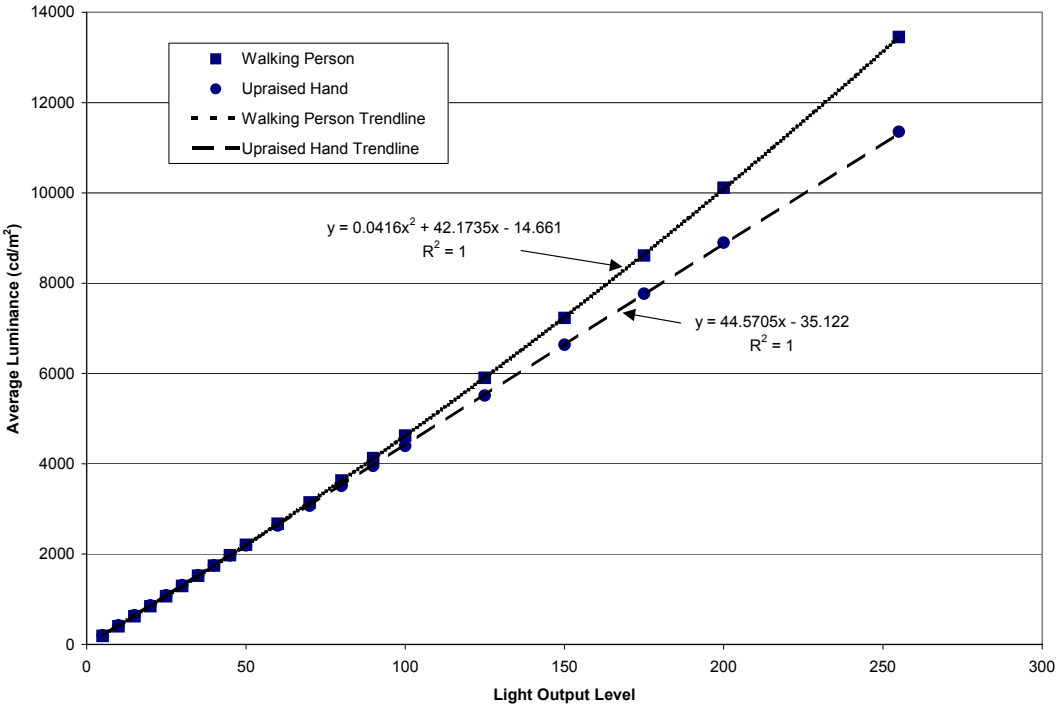
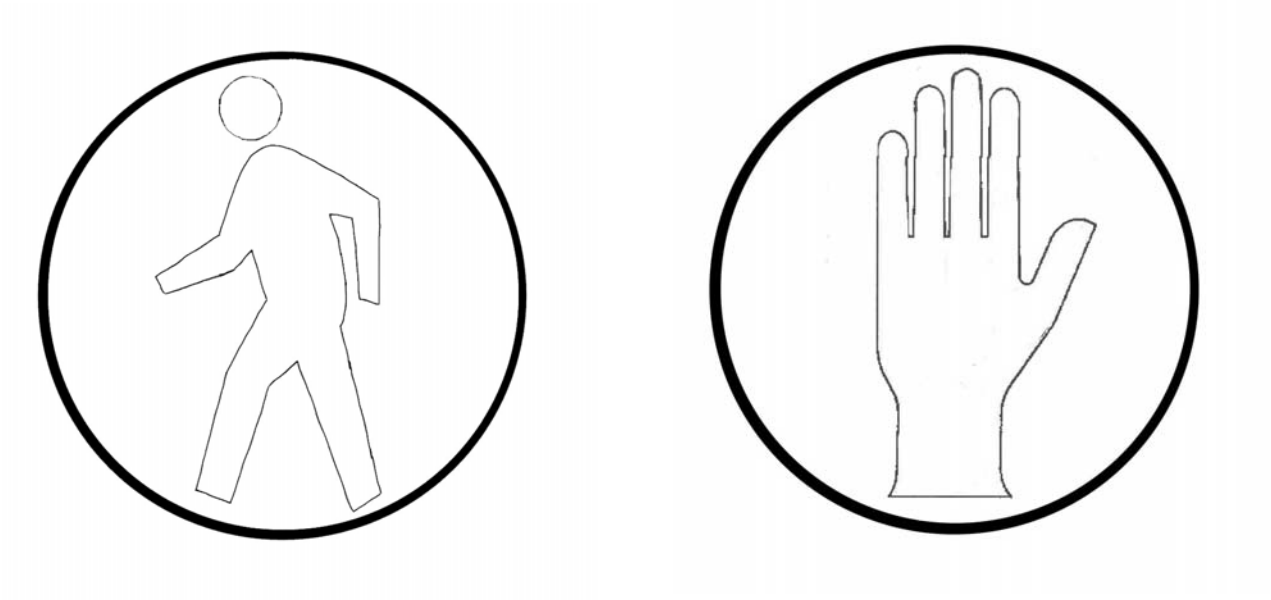


Figure 3. Relationship between Light Output Level and Average Luminance for the ITE Test Method.



a) Walking Person **b) Upraised Hand**

Figure 4. Full Indication Test Method Measurement Location.

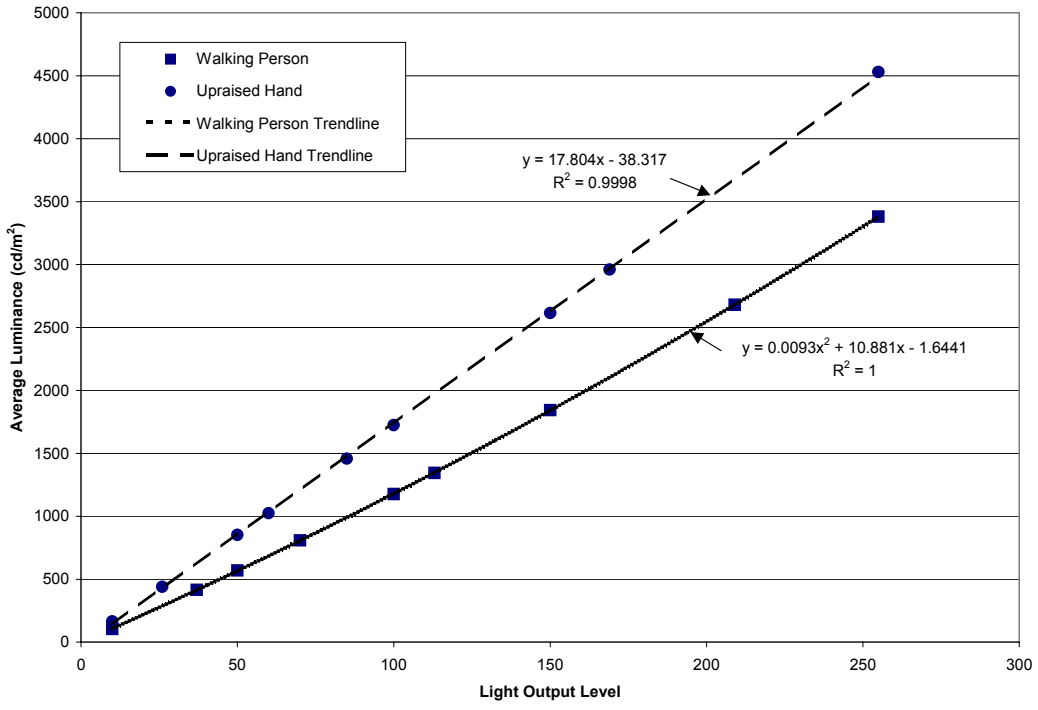


Figure 5. Relationship between Light Output Level and Average Luminance for the Full Indication Test Method.

4. EXPERT PANEL

This chapter documents the results of an expert panel that was convened to examine the daytime minimum visibility requirements of pedestrian signals. Originally, researchers planned to perform a research study using 30 participants 55 years of age or older to determine the minimum luminance requirements of pedestrian signals. However, through pilot studies it became evident that the participants could clearly recognize the indications at low-light output levels (approximately 400 cd/m^2 for both indications). These low thresholds may have been influenced by the limitations of the modified pedestrian signal. The first limitation was that distracter indications could not be used, since the modified pedestrian signal was only capable of displaying two indications (i.e., walking person and upraised hand). A second limitation was that each symbol was a different color. Due to these limitations, researchers were not confident that the resulting minimum luminance values would ensure safe pedestrian operations. Thus, researchers convened an expert panel to provide their opinion with respect to the minimum luminance necessary for daytime recognition of the walking person and upraised hand indications.

PARTICIPANTS

A total of 11 individuals from TTI volunteered to participate in the expert panel. Table 4 summarizes the characteristics of the participants. The majority of the participants were engineers. The expertise of the participants was diverse and included roadside safety, traffic operations, and human factors. The average years of experience in the transportation field was 13 years.

Table 4. Expert Panel Participant Characteristics.

Participant Number	Expertise	Years of Experience
1	Roadside Safety Structures	35
2	Work Zones and DMS	19
3	Traffic Signals and ITS	13
4	Traffic Operations	14
5	ITS and Traffic Control Devices	14
6	Public Transit and Human Factors	9
7	Signs and Markings	1
8	Human Factors	10
9	Mechanical Engineering	3
10	ITS and Data Communications	13
11	Traffic Signals and ITS	14

PROCEDURE

Researchers conducted the expert panel at the TTI proving ground facility, which is a 2000-acre complex of research and training facilities located at the Texas A&M University Riverside Campus (approximately 12 miles northwest of the university's main campus).

The participants were each positioned 100 ft away from the pedestrian signal. Each participant viewed the two indications (i.e., walking person and upraised hand) on-axis at two pedestrian signal heights (7 ft and 10 ft). For each height and indication, the participant would increase the brightness of the indication until they reached a level of brightness they would require as a minimum to ensure that pedestrians could clearly recognize the indication. Figure 6 shows a participant viewing the pedestrian signal.

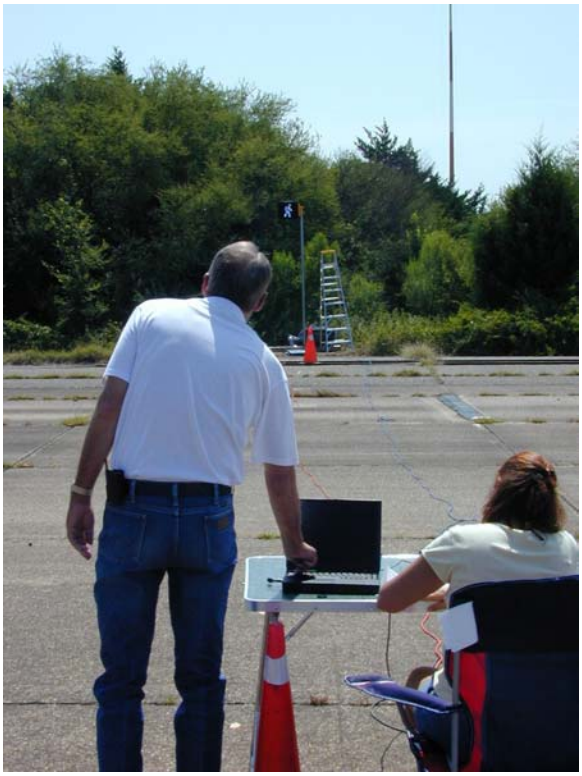


Figure 6. Expert Panel Setup.

DATA REDUCTION

Each participant selected two minimum brightness levels for each indication (i.e., one at each signal height). Using the regression equations derived from the ITE test method, researchers determined the luminance values corresponding to each minimum light output level. For each indication, researchers then combined the luminance data from each height and determined the median minimum luminance.

RESULTS

Figure 7 contains the cumulative distribution of the minimum luminance levels selected by the expert panel for the walking person indication. The median minimum luminance was approximately 3200 cd/m^2, which is 40 percent less than the ITE proposed minimum luminance of 5300 cd/m^2. Figure 8 contains a similar plot for the upraised hand indication. The median minimum luminance was approximately 4000 cd/m^2, which is comparable to the ITE proposed minimum luminance of 3750 cd/m^2. Based on the results of the expert panel, the proposed minimum luminance levels in the ITE draft purchase specification should provide an adequate level of brightness for daytime recognition of the walking person and upraised hand indications.

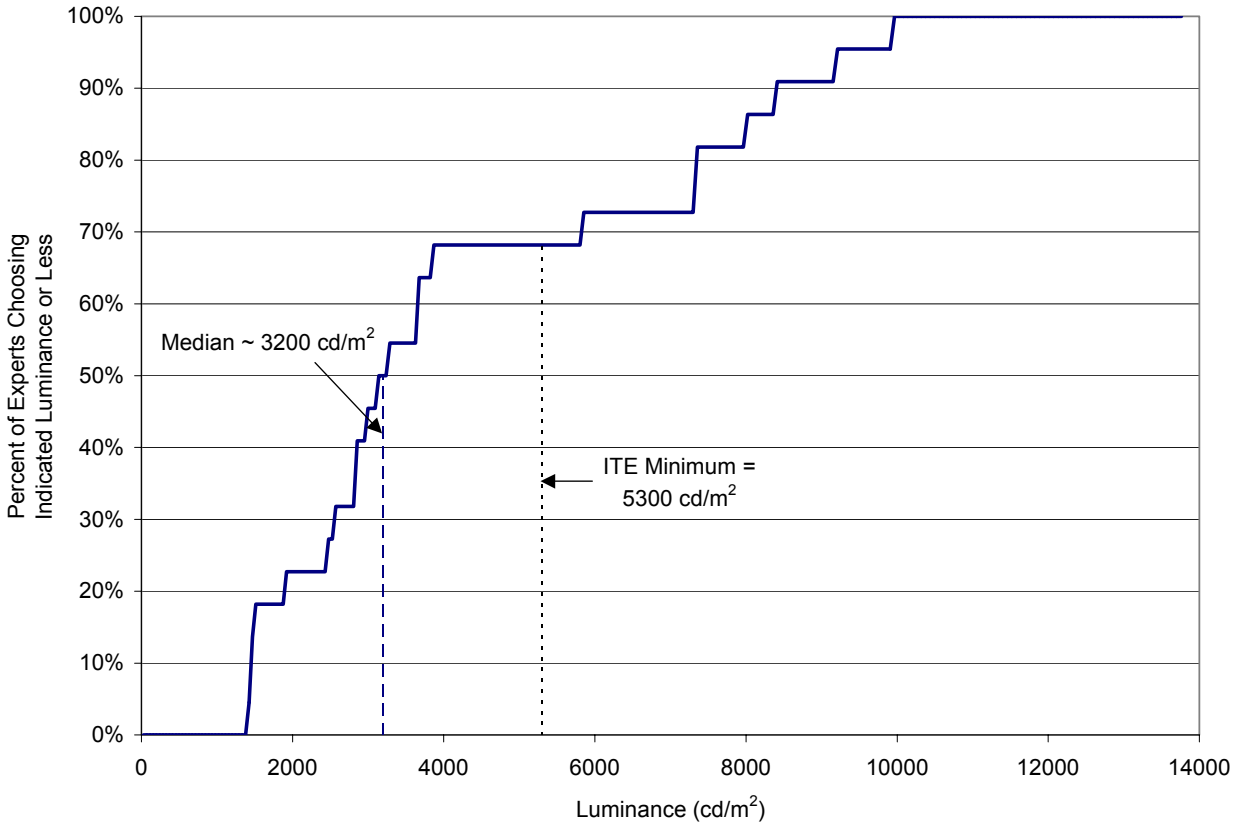


Figure 7. Cumulative Distribution of the Minimum Luminance for the Walking Person.

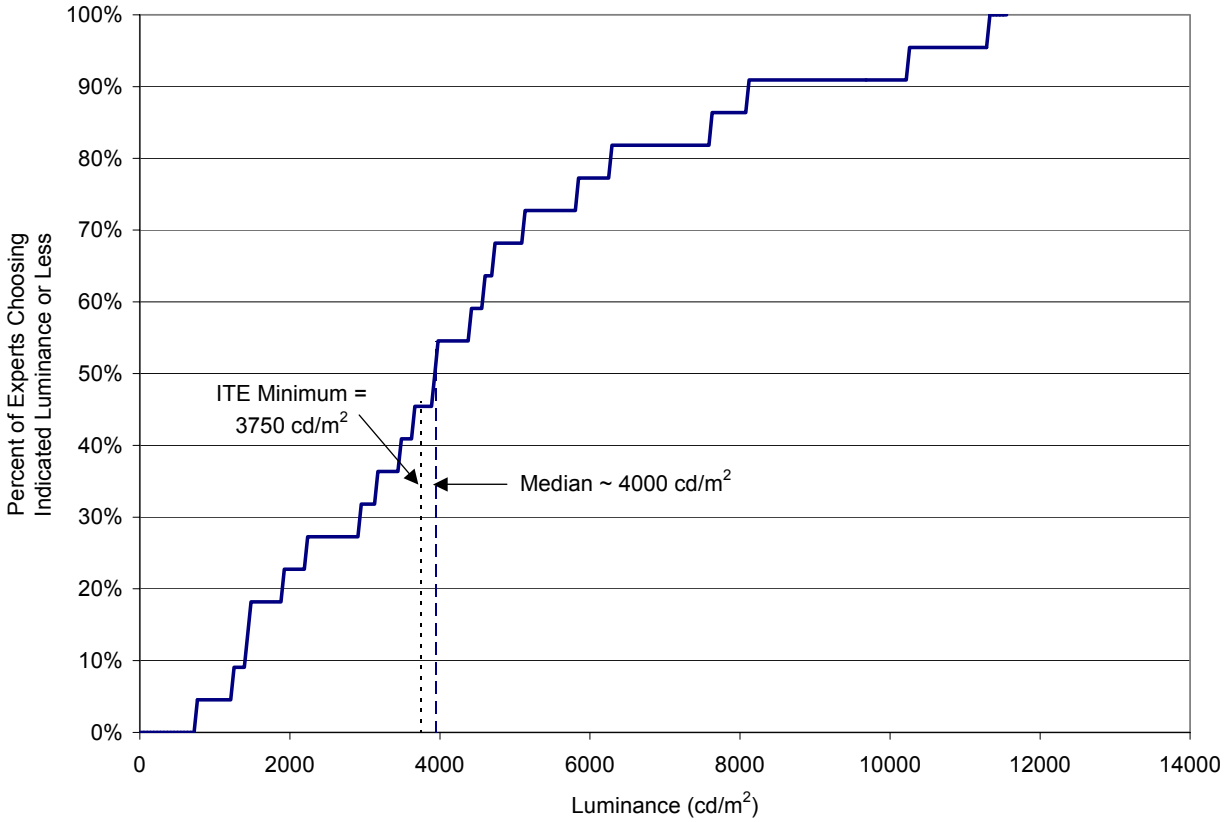


Figure 8. Cumulative Distribution of the Minimum Luminance for the Upraised Hand.

5. NIGHTTIME GLARE STUDY

Discomfort glare is caused by a level of light that is intense enough to result in a measurable level of subjective pain or annoyance to the observer. This chapter documents the results of a nighttime study that was conducted to determine the luminance at which discomfort glare occurs for the walking person and upraised hand indications.

PARTICIPANTS

As a person ages, many aspects of their sensory and cognitive functions deteriorate. With respect to visual capabilities, older adults experience reductions in visual acuity and contrast sensitivity, as well as an increased sensitivity to glare. Therefore, a total of 30 individuals 55 years of age or older were recruited from the Bryan-College Station area to participate in the nighttime discomfort glare study. The average age of the participants was 68 years old and the average visual acuity was 20/29. Half of the participants were male, and half of the participants were female.

PROCEDURE

Participant check-in and briefing took place at the TTI facility at the Texas A&M Riverside Campus. Upon arrival, the participant was provided with an explanation of the study and asked to read and sign an informed consent document. Each participant was then given a standard static visual acuity (Snellen) test.

During the study, the participant was positioned 100 ft away from the pedestrian signal at a predefined location. From this location, the participant viewed the pedestrian signal on-axis. The topography between the signal and the viewing location was straight and flat.

Each participant evaluated the glare of four treatments at multiple brightness levels. The treatments included two indications (i.e., walking person and upraised hand) and two pedestrian signal heights (7 ft and 10 ft). For each treatment and brightness level, the participant viewed the indication for three seconds and then ranked the glare of the indication using the following scale:

1. Comfortable – where there is little or no glare and the indication is easy to look at,
2. Acceptable – where the glare has become a nuisance but is tolerable, and
3. Irritating – where the glare is at a point that the indication is annoying to look at.

Researchers utilized the method of limits with staircase modification to alter the brightness of the indication. The method of limits (*24*) is a behavioral method that can be utilized to identify an absolute threshold. For each trial, the stimulus is changed gradually until the participant's response changes (e.g., "No, I cannot recognize the symbol" to "Yes, I can recognize the symbol"). The absolute threshold is the luminance of the indication at which the response changes. The threshold can be approached with an ascending series (start with weak stimuli) or a descending series (start with strong stimuli).

The staircase modification (*24*), used in this study, is one variation of the method of limits that offers increased efficiency. For each treatment, the study administrator began with the lowest luminance level and increased the brightness of the stimulus in increments of 10 until the participant ranked the glare of the indication a "three" or "irritating." After the participant ranked three consecutive luminance levels as "irritating," the direction was reversed. Thus, the study administrator would decrease the brightness of the stimulus in increments of 10 until the participant ranked the glare of the indication a "one" or "comfortable." Four reversals in direction were completed per treatment.

The study administrator provided verbal directions to the participant, recorded the participant's responses, and varied the luminance level of the pedestrian signal. In addition, the study administrator recorded the vertical illuminance at the participant and at the pedestrian signal immediately before and after each study.

Half of the subjects viewed the indications at 7 ft first, while the other half viewed the indications at 10 ft first. In addition, the order of the indications was randomized to counter any learning effects that may have been present.

The participants were compensated $25.00, and the study took approximately one hour to complete. Payment was made upon completion of an individual's participation.

DATA REDUCTION

In total, 480 trials were conducted. For each trial, researchers determined the light output level where the participant changed their ranking from a "one" to a "two" (i.e., the acceptable glare threshold) and the light output level where the participant changed their ranking from a "two" to a "three" (i.e., the irritating glare threshold). Due to inconsistencies in ranking or the use of only one or two of the rankings (e.g., the participant did not rank any of the brightness levels a "three"), only 312 acceptable glare threshold data points and 451 irritating glare threshold data points were further analyzed.

Using the regression equations derived from the ITE test method, researchers determined the luminance values corresponding to each light output level. For each indication, researchers then combined the luminance data from each height and determined the median acceptable glare threshold and the median irritating glare threshold. In addition, the remarks made by the participants during the study were reviewed and summarized.

RESULTS

Figure 9 contains a cumulative plot of the acceptable and irritating glare thresholds for the walking person indication. The median irritating glare threshold was approximately 3100 cd/m^2, which is 42 percent less than the ITE proposed minimum luminance of 5300 cd/m^2. As shown in Figure 10, the upraised hand indication results are similar. The median irritating glare threshold was approximately 2600 cd/m^2, which is 31 percent less than the ITE proposed minimum luminance of 3750 cd/m^2. Based on these results, at night a pedestrian signal complying with the

ITE proposed minimum luminance values would cause discomfort glare to approximately 60 percent of the participants.

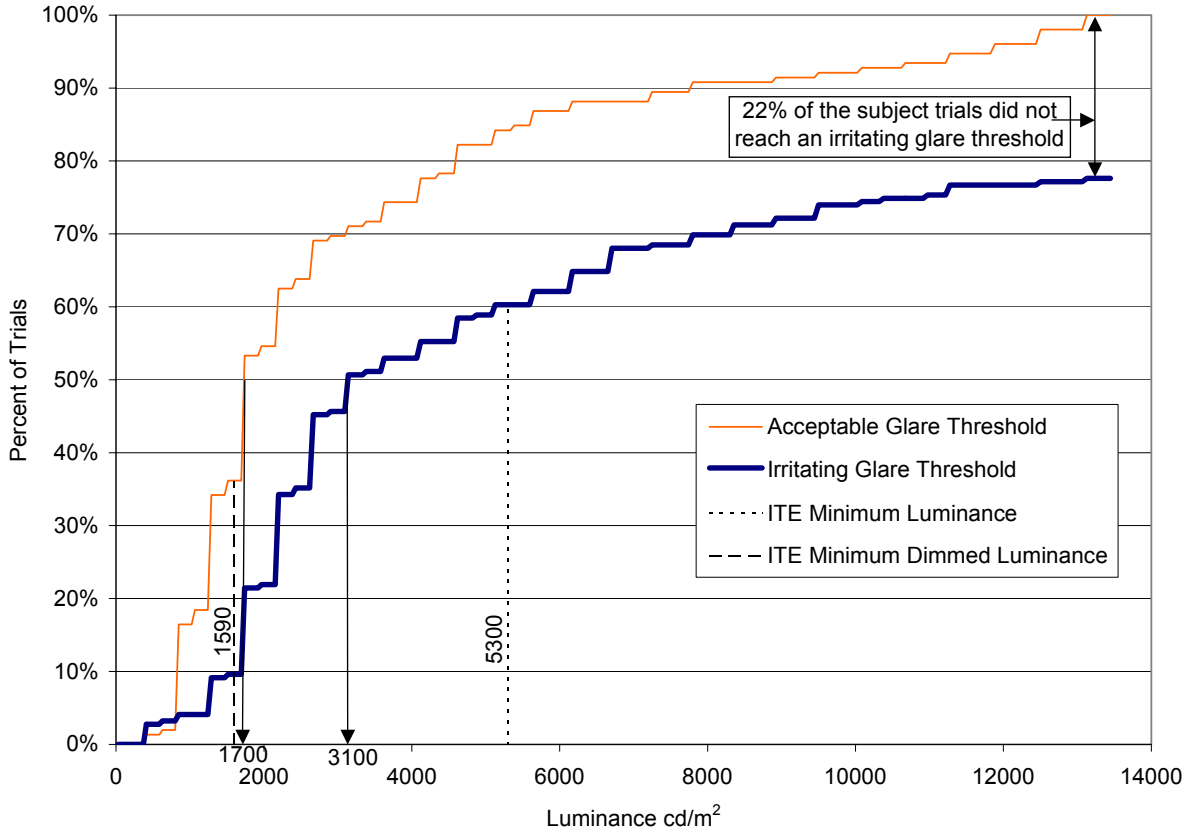


Figure 9. Cumulative Distribution of the Glare Thresholds for the Walking Person.

In order to account for the minimum luminance required for daytime recognition of pedestrian signals, as well as the occurrence of discomfort glare at night, the pedestrian signal indications need to be dimmed relative to the ambient light conditions. Dimming is considered an optional requirement in the ITE LED pedestrian signal head draft purchase specification. When nighttime dimming is required, the minimum dimmed light output cannot be less than 30 percent of the minimum luminance values; however, a maximum dimmed light output is not specified.

The minimum dimmed luminance values from ITE are plotted against the data from the glare threshold study in Figures 9 and 10. The allowance for a 30 percent reduction in the minimum luminance at night was most likely based on previous nighttime vehicle signal research (*25*) that found that a 30 percent reduction in the daytime level did not reduce the visibility of the signal at night. This 30 percent reduction was also used in the development of arrow panel visibility performance requirements (*21*, *22*). In addition, even though the discomfort glare study did not directly evaluate the minimum luminance required to recognize pedestrian signal indications at night, it may be inferred from the acceptable glare threshold data that approximately 65 percent

of the participants could adequately view the indications at the ITE proposed minimum dimmed luminance values.

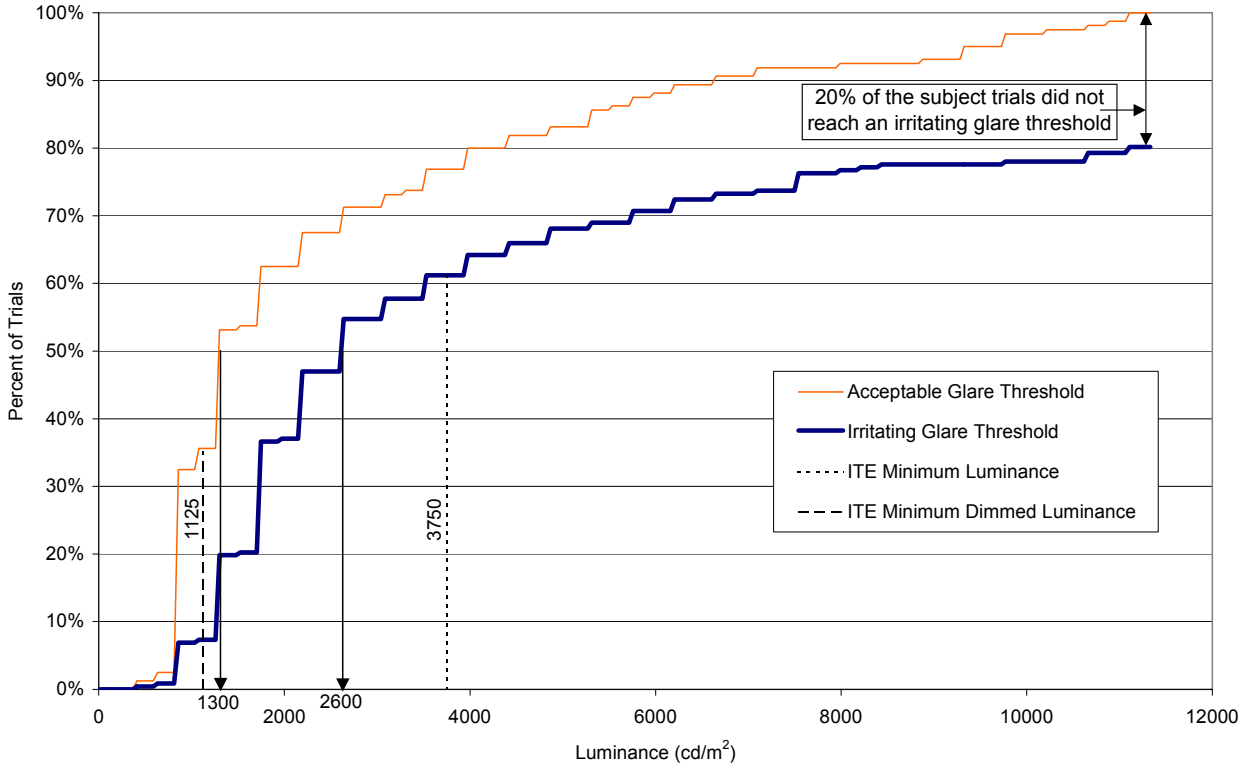


Figure 10. Cumulative Distribution of the Glare Thresholds for the Upraised Hand.

6. CONCLUSIONS AND RECOMMENDATIONS

The overall objective of this project was to develop specifications and testing procedures to be used by TxDOT to accept and pre-certify pedestrian signal heads. More specifically, the purpose was to determine the minimum and maximum visibility performance requirements needed to ensure the recognition of pedestrian signal indications, as well as test methods to verify compliance with these requirements.

CONCLUSIONS

Daytime Luminance Levels

Through an expert panel, researchers solicited expert opinions concerning the minimum luminance necessary for the daytime recognition of the walking person and upraised hand indications. Based on the results, the median minimum luminance levels for the walking person and upraised hand indications were approximately 3200 cd/m^2 and 4000 cd/m^2, respectively. Since these results were less than or approximately equal to the minimum luminance values proposed by ITE (5300 cd/m^2 and 3750 cd/m^2, respectively), researchers concluded that the proposed minimum luminance levels in the ITE LED pedestrian signal head draft purchase specification should provide an adequate level of brightness for daytime recognition of the walking person and upraised hand indications.

Nighttime Luminance Levels

Through a discomfort glare study, researchers determined the nighttime maximum allowable luminance of the walking person and upraised hand indications for persons 55 years of age and older. The results of this study indicated that the median irritating glare thresholds for the walking person and upraised hand indications were approximately 3100 cd/m^2 and 2600 cd/m^2, respectively. In addition, at night a pedestrian signal complying with the ITE proposed minimum luminance values would cause discomfort glare to approximately 60 percent of the participants. Based on these results, researchers concluded that pedestrian signal indications should be dimmed at night in order to account for the occurrence of glare.

With respect to nighttime dimming, the ITE draft purchase specification requires that the minimum dimmed light output cannot be less than 30 percent of the minimum luminance values. Based on previous traffic control device research (*21*, *22*, *25*) and the acceptable glare threshold findings, researchers concluded that the proposed ITE minimum dimmed luminance requirements (1590 cd/m^2 and 1125 cd/m^2) provide an adequate level of brightness for nighttime recognition of the walking person and upraised hand indications, respectively.

Testing Methods

Researchers also evaluated two test methods by which to measure the luminance of pedestrian signal indications. The ITE proposed test method measures the luminance of a pedestrian signal indication at nine separate points on the indication's surface, while the full indication test method measures the luminance of an entire indication.

For both indications, the luminance levels measured using the full indication test method were lower than those measured using the ITE proposed test method. This finding was not unexpected, since in the full indication test method the target aperture is not entirely filled by the illuminated indication and thus includes a portion of the surrounding non-illuminated area in the measurement.

There were also differences between the test methods with respect to the consistency of the measurements. With the ITE proposed test method, slight movements in the location of the measurements can produce large variations in the results, since the measurement area is small compared to the size of the indication. In contrast, the full indication test method provides more consistent results, since the entire indication is included in every measurement. In addition, the full indication test method presents the opportunity for the practitioner to evaluate the brightness of a pedestrian signal indication from the point of view of the observer.

RECOMMENDATIONS

Based on the results of this project, researchers recommend that TxDOT utilize the full indication test method to verify compliance with the recommended visibility performance requirements in Table 5. For reference, Table 6 shows the visibility requirements corresponding to the ITE proposed test method.

Table 5. Recommended Luminance Requirements Using the Full Indication Test Method.

Time of Day	Walking Person Indication		Upraised Hand Indication	
	Minimum	Maximum	Minimum	Maximum
Day	1300 cd/m^2	-	1500 cd/m^2	-
Night	400 cd/m^2	800 cd/m^2	400 cd/m^2	1000 cd/m^2

- The daytime maximum brightness level was not studied.

Table 6. Recommended Luminance Requirements Using the ITE Proposed Test Method.

Time of Day	Walking Person Indication		Upraised Hand Indication	
	Minimum	Maximum	Minimum	Maximum
Day	5300 cd/m^2	-	3750 cd/m^2	-
Night	1590 cd/m^2	3100 cd/m^2	1125 cd/m^2	2600 cd/m^2

- The daytime maximum brightness levels were not studied.

These recommendations, as well as other additional revisions, have been incorporated into a draft pedestrian signal head specification that can be used by TxDOT to accept and pre-certify pedestrian signal heads. This draft pedestrian signal head specification is located in Appendix A. Appendix B and Appendix C contain additional information concerning the ITE proposed test method and the full indication test method, respectively.

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APPENDIX A:
DRAFT PEDESTRIAN SIGNAL HEAD SPECIFICATION

ITEM 7062

Pedestrian Signal Heads

7062.1. Description. This Specification governs the materials, composition, quality, sampling, and testing of pedestrian signal heads.

7062.2. Bidders' and Suppliers' Requirements. Only materials with approved product codes or designations from the DMS-7062 pre-qualified products list (QPL) will be accepted for bid, if required and stated in the procurement or Contract. The Signal Operations Section of the Department maintains the QPL. The DMS-7062 QPL may be viewed at the following website: http://www.dot.state.tx.us/purchasing/supps.htm.

7062.3. Pre-qualification.

A. All prospective suppliers shall submit sample pedestrian signal heads including optical units for evaluation to the Department's Traffic Operations Division (TRF), Traffic Management Section. Suppliers shall supply two units of each type being submitted for testing. This is to ensure that the manufacturer has the technical and production capabilities to produce a material in accordance with the requirements of this Specification.

B. TRF tests samples for Specification compliance and updates the QPL to include materials that meet Specification requirements. If materials fail to meet any of the Specification requirements, the producer may not resubmit for pre-qualification until one year from original evaluation date. TRF may waive this time limit if provided with documentation from an independent testing facility stating that materials meet all requirements. TRF will enforce the one-year time limit if, after retesting, the material again fails any of the Specification requirements.

C. All materials submitted for pre-qualification tests will be at no cost to the Department. All materials that pass the pre-qualification testing shall become the property of the Department. If requested within 6 months of testing, materials that fail the pre-qualification testing will be returned to the submitter at their expense. After 6 months, failed materials shall become the Department's property to be disposed of at the Department's discretion.

7062.4. Materials.

A. Definitions.

1. Incandescent Optical Unit. The lens, reflector, lamp, lamp receptacle, and associated supporting parts in a signal section.

2. Light-Emitting Diode (LED) Optical Unit. The LED lens and associated supporting parts in a signal section.

3. Signal Section. One housing case, housing door, visor, and optical unit.

4. Signal Face. One section or an assembly of 2 or more sections facing one direction.

5. Signal Head. A unidirectional face or a multidirectional assembly of faces attached at a common location on a support.

B. General.

1. Provide pedestrian signal heads in accordance with the latest "Chapter 3: Pedestrian Traffic Control Signal Heads" of the Equipment and Material Standards of the Institute of Transportation Engineers (ITE), except as noted herein.

2. Provide either aluminum or polycarbonate pedestrian signal heads in accordance with the procurement or Contract.

3. Provide either incandescent optical units, LED optical units, or neither in accordance with the procurement or Contract.

4. Furnish only new materials manufactured within 60 days of the order date.

5. Furnish signal sections, including optical unit, that operate reliably throughout an ambient operating temperature range of -40EF to 165EF. This range corresponds to the environmental tests required by the National Electrical Manufacturers Association (NEMA) Standards Publication TS-2-1998, "Traffic Controller Assemblies with National Transportation Communications for Intelligent Transportation Systems Protocol (NTCIP) Requirements." The Department may use the environmental testing required by TS-2-1998 while qualifying pedestrian signal heads and their components.

6. Use materials that are accurately formed and free of defects affecting strength and appearance.

7. Use components and mounting attachments of adequate strength for the purpose intended.

8. Use pedestrian signal head components and related mounting hardware constructed of corrosion-rust resistant materials capable of withstanding constant exposure to sunlight and corrosive atmosphere, including salt air.

C. Aluminum.

1. Use cast aluminum parts with a minimum tensile strength of 17,000 psi.

2. Use cast aluminum components that are accurately formed and free from pouring faults, sponginess, cracks, blow holes, or other defects affecting their strength and appearance.

3. Use sheet aluminum parts with a minimum tensile strength of 27,000 psi.

4. Use aluminum materials in accordance with Table 1.

Table 1
Aluminum Materials

Type	ASTM	ALLOY
Die Castings	B85	SG100B, SG100A, SC84B, SC84A, S12B, or SC12A
Permanent Mold Castings	B108	CS72A or S5A
Sheet	B209	M1A

D. Polycarbonate.

1. Use ultraviolet-stabilized polycarbonate material.

2. Use one-piece, construction-molded polycarbonate components. Bonding (chemical, thermal, ultrasonic, etc.) of multiple pieces is not allowed.

3. Use polycarbonate housings that are at least 0.09 in. thick and ribbed so as to produce the strongest possible assembly consistent with light weight.

4. Use polycarbonate material in accordance with Table 2.

Table 2
Polycarbonate Material Physical Property Requirements

Test	Required	ASTM
Specific Gravity	$ 1.17	D792
Vicat Softening Point	305EF – 325EF	D1525
Brittleness Point	< 200EF	D746
Flammability	Self-extinguishing	D635
Tensile Strength (Yield)	$ 8,500 psi	D638
Elongation at Yield	5.5 to 8.5%	D638
Shear Strength (Yield)	$ 5,500 psi	D732
Izod Impact Strength (notched, 1/8 in. thick)	$ 15 ft-lb/in	D256
Fatigue Strength (2.5 mm cycles)	$ 900 psi	D671

E. Hardware.

1. Use galvanized steel, stainless steel, or dichromate sealed aluminum bolts, nuts, washers, lock washers, screws, and other assembly hardware except as noted herein.

2. Use hardware in accordance with Table 3.

Table 3
Hardware Materials

Material	Applicable Specification
Stainless Steel	ASTM A 320, Grade B8F Annealed
Galvanized Steel	ASTM A 307, Galvanized to ASTM A 153, Class C or D, or ASTM B 695, Class 50
Aluminum	Alloy 2024-T4, Dichromate sealed finish according to Mil-A-8625A Type II
Brass	UNS C36000

3. When dissimilar metals are used, ensure the metals are selected or insulated to prevent corrosion.

4. Use fiberglass reinforced polycarbonate non-metallic hardware.

F. Gaskets.

1. Use closed-cell silicone or peroxide-cured ethylene propylene diene terpolymers (EPDM) gaskets that can withstand temperatures up to 250EF without permanent deformation or becoming brittle in the optical unit.

2. Use closed-cell neoprene for other gaskets.

G. Housing, Door, and Visor.

1. General.

a. Furnish the door and housing such that there is no light leakage (i.e., light is emitted only through the lens).

b. Furnish housings that are dust and moisture proof for the optical units, connecting wiring, and terminal block when assembled, together with doors, lenses, and mounting attachments.

2. Housing.

a. Furnish one-piece signal housings constructed of die cast aluminum alloy or molded polycarbonate. Use polycarbonate housing cases that are at least 1/4 in. thick and ribbed for strength. Use polycarbonate housing cases with ultraviolet inhibitors to reduce deterioration due to exposure to light.

b. Provide openings in the top and bottom of the signal section that accommodate a standard 1-1/2 in. bracket arm.

c. Furnish two door mounts on the top of the signal housing and two door mounts on the bottom of the signal housing. Use door mounts that allow for interchangeable door mounting.

d. Provide a signal housing electrical system designed to operate from a 120 volt, single phase, 60 Hz alternating current power.

e. Terminal Block.

(1) Provide in the signal housing one 4 point terminal with the two common points wired together by the supplier.

(2) Use a terminal block that consists of permanently identified electrical sections, each section consisting of two 8/32 in. by 5/16 in. binding screws and a conducting metal strip between the screws.

(3) Use a terminal block that accommodates American Wire Gauge (AWG) 12 field wires.

(4) Use a terminal block rated for a minimum of 20 ampere, 250 volt service, and section to section breakdown voltage shall be a minimum of 1600 volts AC RMS.

(5) Use a terminal block body constructed of one-piece weatherproof molded construction using phenolic materials.

(6) Securely mount or integrally mold the terminal block into the interior of the housing in an accessible position.

(7) Use nickel plated brass for all metal parts except for the binding screws. Use nickel plated brass or stainless steel binding screws.

3. Door.

a. Use the same material as the housing for the door.

b. Use aluminum doors that are one-piece corrosion resistant, aluminum alloy casting with two hinged lugs cast at the bottom and two latch slots cast at the top of each door.

c. Use one-piece polycarbonate doors that are at least 1/4 in. thick with two hinged lugs at the bottom and two latch slots at the top of each door. Use polycarbonate doors with ultraviolet inhibitors to reduce deterioration due to exposure to light.

d. Install two stainless steel wing screws or wing nuts on the door or the housing to provide for opening and closing the door. Use wing screws or wing nuts with a flat-bearing surface or stainless steel flat washers to prevent gouging of the housing door. When the door is open, ensure the wing screws or wing nuts remain captive. When latching or unlatching the door, ensure that the use of tools is not required.

4. Visor.

a. Provide an easily detachable “egg-crate” type visor with diagonal and horizontal louvers with each signal section.

b. Use the same material as the housing and door for the visor.

c. Attach the visor to the door in a manner that will prevent the leakage of light and moisture throughout the periphery of attachment.

H. Exterior Finish.

1. Unless stated otherwise in the procurement or Contract, paint the exterior finish of the completed signal section Federal Yellow No. 13538 of Federal Standard 595 with the exception of the visor, which shall be flat black.

2. Aluminum.

a. Electrostatically apply powder-coat paint or apply 2 separately baked-on coats of high-grade enamel to all exposed metal surfaces.

b. Apply 2 coats of high grade flat black finish paint to the visor.

3. Polycarbonate.

a. Completely impregnate the federal yellow colorant in the polycarbonate material.

b. Apply 2 coats of high grade flat black finish paint to the visor.

I. Mounting Assembly.

1. Use hinged mounting (i.e., clamshell) attachments unless otherwise specified in the procurement or Contract.

2. Use mounting hardware that is a two piece cast aluminum alloy assembly. Join the mounting hardware assembly in the final assembly by stainless steel hinge pins on the back of the unit and a tamper proof bolt on the front of the unit.

3. For the pole half of the assembly, provide two spring pins which act as a hinge for the assembly and are capable of being banded on a steel or wood strain pole, lag screwed into a wood pole, or bolted directly to a 4 in. steel pole.

4. For the signal section half of the assembly, provide a terminal compartment and hinged ears for mating with the pole half of the assembly. Supply provisions for mounting the signal section half of the assembly to the side of the pedestrian signal section with all necessary wiring and with a weatherproof and dustproof seal. Use a terminal block that accommodates AWG 12 field wires.

5. When pedestrian signal sections and hinged mounting assemblies are ordered together, attach and wire the mounting assembly to the signal section on the left side (when viewed from the front). When top and bottom holes exist on the signal section, plug the holes to prevent the entry of foreign material (e.g., dust, insects, and moisture) into the signal section.

6. Use a gasket on the mating surfaces of the two halves to provide a weatherproof and dustproof assembly.

7. Supply provisions to minimize the chance of vandalism to the assembly.

J. Wiring.

1. Bring each wire lead to a separate terminal in the terminal compartment (except for the commons) from one housing. Bring the commons from one housing to the same terminal in the terminal compartment.

2. Maintain the color coding on leads from the individual optical units from the lamp receptacle or back of LED module to the individual terminals in the signal housing terminal compartment (except for the commons). Group the commons from each housing and carry to one terminal. Use the following color coding: orange for “upraised hand” indication, blue for “walking person” indication, and white for common.

3. Wire the indications so that any one indication can be individually illuminated through connections to terminals in the terminal compartment.

4. Provide separate terminals for the interior wires and the field wires. In addition to interior wires required in Section 7062.4.G.2.e.(1), provide and install all other leads necessary to connect the terminal block of the signal section to the terminal block in the terminal compartment.

5. Any variations from the above requirements shall be covered in the procurement or Contract.

K. Optical Unit.

1. General.

a. Furnish a single, self-contained optical unit, not requiring on-site assembly for installation or retrofit into existing traffic signal housings.

b. Ensure that installation does not require special tools.

c. Use a nominal message bearing surface of 16 in. x 18 in.

d. Furnish an optical unit that will withstand without adverse effects mechanical shock and vibration due to high winds, transportation, shipping, and other foreseeable sources.

e. When proper orientation of the optical unit is required for optimum performance, provide prominent and permanent directional marking(s) on the unit, that is an "UP arrow," for correct indexing and orientation.

f. Permanently mark on the backside of the optical unit the manufacturer's name, model number, serial number, manufactured date (month and date), and other necessary identification. Place a label on the unit certifying compliance to ITE standards.

2. Indications.

a. Use signal indications in accordance with the latest revision to the Texas Manual on Uniform Traffic Control Devices except as noted herein.

b. Furnish optical units that are capable of displaying both the "walking person" and "upraised hand" indications.

c. Furnish optical units that display the "upraised hand" indication on the left side of the optical unit and the "walking person" indication on the right side of the optical unit. When the procurement or Contract specifies the use of countdown signals, the "walking person" and "upraised hand" indications may be overlaid.

d. Furnish optical units with "upraised hand" indications that flash continuously at a rate of at least 50 flashes per minute (fpm) and at most 60 fpm.

e. Furnish optical units with "upraised hand" indications that have an illumination period of each flash at least 1/2 and at most 2/3 of the total flash cycle.

f. Use only solid indications. Outline style indications are not allowed.

g. Use indications that are at least 11 in. high and 7 in. wide.

h. Ensure that the illumination of one indication does not result in the illumination of the other indication.

3. Optical and Light Output Requirements.

a. Luminance Requirements.

(1) Furnish an optical unit that provides luminance values in accordance with Table 4 for the testing procedure defined in Section 7062.4.K.3.b.(2) under the operating conditions defined in Section 7062.4.B.5 and Section 7062.4.K.6.a. These values may decrease up to 50% of the table values beyond 15° from the perpendicular to either the left or right on a horizontal plane.

Table 4
Luminance Requirements for the Test Procedure Defined in Section 7062.4.K.3.b.(2)

Time of Day	Walking Person Indication		Upraised Hand Indication	
	Minimum	Maximum	Minimum	Maximum
Day	5,300 cd/m^2	10,600 cd/m^2	3,750 cd/m^2	7,500 cd/m^2
Night	1,590 cd/m^2	3,100 cd/m^2	1,125 cd/m^2	2,600 cd/m^2

(2) Furnish an optical unit that provides luminance values in accordance with Table 5 for the testing procedure defined in Section 7062.4.K.3.b.(3) under the operating conditions defined in Section 7062.4.B.5 and Section 7062.4.K.6.a.

Table 5
Luminance Requirements for the Test Procedure Defined in Section 7062.4.K.3.b.(3)

Time of Day	Walking Person Indication		Upraised Hand Indication	
	Minimum	Maximum	Minimum	Maximum
Day	1,300 cd/m^2	2,700 cd/m^2	1,500 cd/m^2	3,000 cd/m^2
Night	400 cd/m^2	800 cd/m^2	400 cd/m^2	1,000 cd/m^2

(3) Furnish an optical unit that meets the minimum luminance requirements in Section 7062.4.K.3.a.(1) and Section 7062.4.K.3.a.(2) for a minimum period of 60 months.

b. Luminance Testing Procedures.

(1) General.

(a) When testing or submitting for testing, furnish optical units that are representative of typical production units.

(b) Perform optical testing with optical units mounted in a pedestrian signal housing with door, but without a visor attached to the housing or door.

(2) Test Procedure 1. After burn-in, test "walking person" and "upraised hand" indications for rated initial average luminance in accordance with the provisions in Section 7062.4.K.3.a.(1) and Section 7062.4.K.3.a.(3). Before measurement, energize the "walking person" and "upraised hand" indications at rated voltage with 100% on-time duty cycle for a period of 30 minutes. Locate the measuring device on the physical axis of the optical unit at a distance such that the selected aperture samples an area 0.5 in. in diameter at the optical unit's surface. Ensure that the aperture is within the area of the lighted indication. Measure the rated initial luminance of the "walking person" indication and the "upraised hand" indication perpendicular to the surface of the optical unit at the 9 separate points spread across the icon. Calculate the rated initial average luminance for each indication by averaging the 9 separate luminance measurements taken for each indication. Record the current, voltage, total harmonic distortion, and power factor associated with each measurement.

(3) Testing Procedure 2. After burn-in, test "walking person" and "upraised hand" indications for rated initial luminance in accordance with the provisions in Section 7062.4.K.3.a.(2) and Section 7062.4.K.3.a.(3). Before measurement, energize the "walking person" and "upraised hand" indications at rated voltage with 100% on-time duty cycle for a period of 30 minutes. Locate the measuring device on the physical axis of the optical unit at a distance such that the selected aperture samples the entire indication. Measure the rated initial luminance of the "walking person" indication and the "upraised hand" indication perpendicular to the surface of the optical unit at one point that encompasses the entire indication. Record the current, voltage, total harmonic distortion, and power factor associated with each measurement.

c. Chromaticity. Furnish an optical unit in accordance with the chromaticity (color) requirements in the latest "Chapter 3: Pedestrian Traffic Control Signal Heads" of

Equipment and Material Standards of the Institute of Transportation Engineers for a minimum period of 60 months over an operating temperature range of -40EF to 165EF.

4. Incandescent Optical Unit.

a. General.

(1) Provide incandescent optical units only when required in the procurement or Contract.

(2) Each incandescent optical unit consists of a lens, a reflector, and a lamp receptacle with leads to the terminal block (which is to be furnished in each complete pedestrian signal section) together with all bolts, nuts, screws, clips, hinges, lugs, and incidentals necessary for mounting and sealing the various parts of the optical assembly.

(3) Ensure that the lens, reflector, and lamp receptacle form a dust and moisture proof unit. Use a closed-cell silicone gasket to seal the lens to the reflector. Perform moisture resistance testing on incandescent signal sections in accordance with the requirements in the latest NEMA Standard 250 for Type 4 enclosures. Evidence of internal moisture after testing shall be cause for rejection.

b. Lens.

(1) In polycarbonate housings, use lenses injection-molded of a polycarbonate material. In aluminum housings, use either polycarbonate or glass lenses.

(2) Use glass lenses with a high transmission value, a specific gravity of at least 2.50, and in compliance with all ITE specifications.

(3) Use lenses and optical systems capable of withstanding continuous illumination of a 69 watt lamp without distortion of the lenses.

c. Reflector.

(1) Use reflectors approximately parabolic in section.

(2) Use silvered glass, aluminum with anodic coating, or metalized plastic reflectors.

(3) Provide a reflecting surface totally free of flaws, scratches, defacements, or mechanical distortion.

(4) Provide the reflector with hinges or lugs so spaced as to give clearance to the hinges or lugs for the door and rigidly hold the reflector in place. Rigidly fasten the reflector holder in place by hinges or lugs for easy removal of the assembly. Ensure that it is not necessary to remove the assembly from its supports for relamping or cleaning the reflector.

(5) The following two additional requirements apply to glass reflectors (in addition to ITE requirements):

(a) Ensure that the silver application method prevents the inclusion of foreign substances between the silver and glass.

(b) Provide a heat-resisting backing of high-grade enamel over the copper coating.

d. Lamp Receptacle.

(1) Use weatherproof molded construction capable of withstanding without deterioration the high temperatures within the optical unit during operation for the lamp receptacle.

(2) Use brass for the lamp receptacle contact and threads. Ensure that the threads provide a uniform and sufficient contact with the lamp base.

(3) Provide a lamp grip to prevent the lamp from loosening due to vibration.

(4) Ensure that the lamp receptacle is rotatable for proper lamp orientation.

(5) Ensure that the lamp receptacle is set so as to place the filament of a standard 69 watt traffic signal lamp (A21 bulb with a medium base and a 2.5 in. light center length) in the proper focal position with respect to the reflector.

(6) Securely fasten receptacle leads to the lamp socket and connect the receptacle leads to the terminal block mounted in the signal section housing at the optical unit by means of solderless wire connector or binding screws and spade lugs.

(7) Rigidly fasten the lamp receptacle holder in place by hinges or lugs for easy removal of the assembly.

e. Lamps.

(1) Furnish lamps only if indicated in the procurement or Contract.

5. LED Optical Unit.

a. General.

(1) Provide LED optical units only when required in the procurement or Contract.

(2) Ensure that LED optical units are interchangeable with incandescent optical units and require no modifications to the signal housing or door.

(3) Use LEDs manufactured using aluminum-indium-gallium-phosphide (AlInGaP) technology or other LEDs with lower susceptibility to temperature degradation than aluminum-gallium-arsenic (AlGaS) technology. AlGaS LEDs are not allowed.

(4) Ensure that the LEDs are uniformly distributed across the indications.

(5) Each LED optical unit consists of an ultraviolet (UV) stabilized polymeric outer shell, multiple LED light sources, and a regulated power supply. Mount LEDs on a polycarbonate positioning plate or conformally coated PC board.

(6) When a lens is used, supply a polycarbonate lens unless stated otherwise in the procurement or Contract. Use a lens material that accurately matches the dominant wavelength of the supplied LED.

(7) Ensure that the LED optical unit is dust and moisture proof to protect all internal LED and electrical components. Provide a housing for each LED optical unit that is sealed watertight enclosure that eliminates dirt contamination and allows for safe handling in all weather conditions. Perform moisture resistance testing on LED signal sections in accordance with the requirements in the latest NEMA Standard 250 for Type 4 enclosures. Evidence of internal moisture after testing shall be cause for rejection.

b. Electrical.

(1) Incorporate a regulated power supply engineered to electrically protect the LEDs and maintain a safe and reliable operation in each LED optical unit. Use a power supply that provides capacitor filtered direct current (DC) regulated current to the LEDs per the LED manufacturer specification. Design the power supply such that the failure of an individual component or any combination of components cannot cause the signal to be illuminated after alternating current (AC) power is removed. Any deviation without prior testing and approval from the Department shall be grounds for automatic removal from the QPL for an undetermined time.

(2) Arrange LEDs in equally loaded circuits.

(3) If any one LED circuit should fail, it should be easily identifiable by visual inspection and replaced or repaired per the warranty.

(4) Use LEDs rated for 100,000 or more hours of operation at the specified amperage and operating temperature.

(5) Ensure that the optical unit operates with a minimum 0.90 power factor.

(6) Ensure that the total harmonic distortion (current and voltage) induced into an AC power line by a signal section does not exceed 20%.

(7) Ensure that the signal modules and associated on-board circuitry are in accordance with the requirements in Federal Communications Commission (FCC) Title 47, SubPart B, Section 15 regulations concerning the emission of electronic noise.

6. Electrical.

a. Furnish an optical unit that operates on a 60 Hz AC line over a voltage range from 80 volts root-mean-square (RMS) to 135 volts RMS. Provide circuitry that prevents flickering over this voltage range. Use a nominal rated voltage of 120 volts RMS for all measurements.

b. Ensure that the optical unit is operationally compatible with TS1, TS2, 170 and 2070 controllers, conflict monitors with plus features, and malfunction management units currently used by the Department and any other Texas governmental entities. In the case of conflicts between Specifications, the latest Department Specifications will control.

c. Provide two, captive, color coded, 600 V, 18 AWG minimum jacketed wires, 3 ft. long, in accordance with the National Electric Code, rated for service at 221EF, for an electrical connection.

d. Provide optical units with circuitry that allows for a reduction in light output in response to diminished ambient light levels. Use light output levels established to match threshold ambient light conditions. Dim the light output in stepped increments or as a continuous variable.

7062.5. Sampling and Testing.

A. General.

1. Specific tests are normally indicated in conjunction with specific Specification requirements. However, the Department reserves the right to conduct whatever tests are deemed necessary to identify component materials and verify results of specific tests indicated in conjunction with Specification requirements.

2. Cost of sampling and testing are normally borne by the Department. However, the costs of sampling and testing materials failing to conform to the requirements of this Specification shall be borne by the Contractor or supplier. Cost of sampling and testing of failing material shall be assessed at the rate established by the Director of TRF in effect at the time of testing. Amounts due the Department for conducting such tests shall be deducted from monthly or final estimates on Contracts or from partial or final payments on direct purchases by the State.

3. Any deviation to product design after testing and approval from the Department shall consist of a new model and must be resubmitted for acceptance. Failure to adhere to this requirement shall be grounds for automatic removal from the QPL for an undetermined time. Random testing of average production modules will be tested to ensure compliance with the Specification.

B. Production Testing.

1. Energize each new optical unit for a minimum of 24 hours at operating voltage and at a temperature of 140EF to cause any electronic infant mortality to occur, and to ensure electronic component reliability before shipment.

2. After the burn-in procedure is completed, test each optical unit for rated initial luminance at rated operating voltage according to Sections 7062.4.K.3.a.(1) – 7062.4.K.3.a.(3).

3. Conduct testing to determine if the LEDs are operating at a forward drive current greater than recommended by the manufacturer.

C. Quality Assurance Testing (Random Sample Testing).

1. The State will perform random sample testing on shipments. Random sample testing may be conducted at any time during the product warranty period.

2. The number of units tested shall be determined by the quantity of each model in the shipment. The sample size shall conform to American National Standards Institute (ANSI)/American Society for Quality Control (ASQC) Z1.4. The TRF shall determine the sampling parameters to be used for the random sample testing. All parameters of the Specification may be tested on the modules. Acceptance or rejection of the shipment shall conform to ANSI/ASQC Z1.4 for random sampled shipments.

7062.6. Documentation Requirements. Provide the following documentation with each optical unit:

A. Complete and accurate installation wiring guide.

B. One schematic diagram for each optical unit, along with any necessary installation instructions.

C. Schematics for all electronics, if required in the procurement or Contract.

D. Contact name, address, telephone number, and fax number for the representative, manufacturer, or distributor for warranty repair.

E. Copy of a test report certified by an independent laboratory that the pedestrian signal model submitted meets ITE Standards for light distribution, chromaticity, and power (consumption, power factor, and harmonic distortion). For LED optical units, the independent lab report shall specify the drive current being supplied to individual LEDs within the unit. Designs that require LEDs to be operated at currents greater than the LED manufacturer's recommended drive current will not be allowed.

F. A mean time between failure analysis report which encompasses the complete optical unit and its individual assemblies. The report shall describe in detail the methodology used.

G. For each LED optical unit submitted, the manufacturer's name, brand and model number of LEDs used shall be provided, along with the LED manufacturer's recommended drive current and degradation curves.

7062.7. Shipment and Delivery. Deliver each pedestrian signal section completely assembled. Ensure that each pedestrian signal section is ready for immediate installation. Individually package each pedestrian signal section. Tag the signal section and LED optical unit showing manufacturer, model number, serial number, and manufacture date. Also display the requisition and purchase order on which the item was delivered on the signal section.

7062.8. Warranty.

A. Provide a warranty for each pedestrian signal section against failure due to workmanship or material defects within the first 60 months of field operation.

B. Provide a warranty for each optical unit against any failure due to workmanship, material defects, or intensity within the first 60 months of field operation. Ensure that the optical unit meets the minimum and maximum luminance values specified in Section 7062.4.K.3.a.(1) and Section 7062.4.K.3.a.(2) during the first 60 months of field operation over the temperature range of -40EF to 165EF. Provide replacement optical units within 5 days after receipt of failed optical unit at no cost to the State, except the cost of shipping the failed units.

C. Ensure that the optical unit meets or exceeds 85% of the standard light output values specified in Section 7062.4.K.3.a.(1) and Section 7062.4.K.3.a.(2) after 60 months of continuous use in a pedestrian signal operation over the temperature range of -40EF to 165EF.

D. Ensure that the measured chromaticity coordinates of the optical unit are in accordance with the requirements for chromaticity in the latest "Chapter 3: Pedestrian Traffic Control Signal Heads" of Equipment and Material Standards of the Institute of Transportation Engineers for a minimum of 60 months over an operating temperature range of -40EF to 165EF.

7062.9. Measurement. This DMS will be measured by each complete pedestrian signal section.

7062.10. Payment.

A. Procurement by the State. Payment for materials under this Specification shall be in accordance with the conditions prescribed in the Contract awarded by the State.

B. Contracts. Payment for materials by this Specification used in Contract projects will not be measured or paid for directly, but will be subsidiary to bid items of the Contract.

APPENDIX B:
ITE PROPOSED TEST METHOD

The procedure and form contained in this Appendix can be followed to measure the luminance of a pedestrian signal head indication at nine separate points and determine if the luminance values meet the minimum and maximum visibility performance requirements. The procedure should be conducted in an area with no ambient lighting (e.g., a completely dark room).

Step 1: Setup of the Pedestrian Signal and Luminance Meter

The pedestrian signal should be positioned on a flat surface and leveled. In order to obtain repeatable measurements, use a tripod to stabilize the luminance meter. Attach the luminance meter to a tripod and set up the tripod so that the luminance meter is stationed 24 ft away from the pedestrian signal. Using a 6-minute aperture at this distance, the aperture samples a half inch diameter area at the optical unit's surface. Luminance meters with other aperture sizes may be used; however, this will affect the distance at which the luminance meter is located away from the pedestrian signal.

Position the luminance meter on the physical axis of the optical unit and ensure that the aperture will be within the area of the illuminated indication. After the luminance meter is positioned, it should be leveled.

Step 2: Measuring the Luminance of the Indication at Nine Points

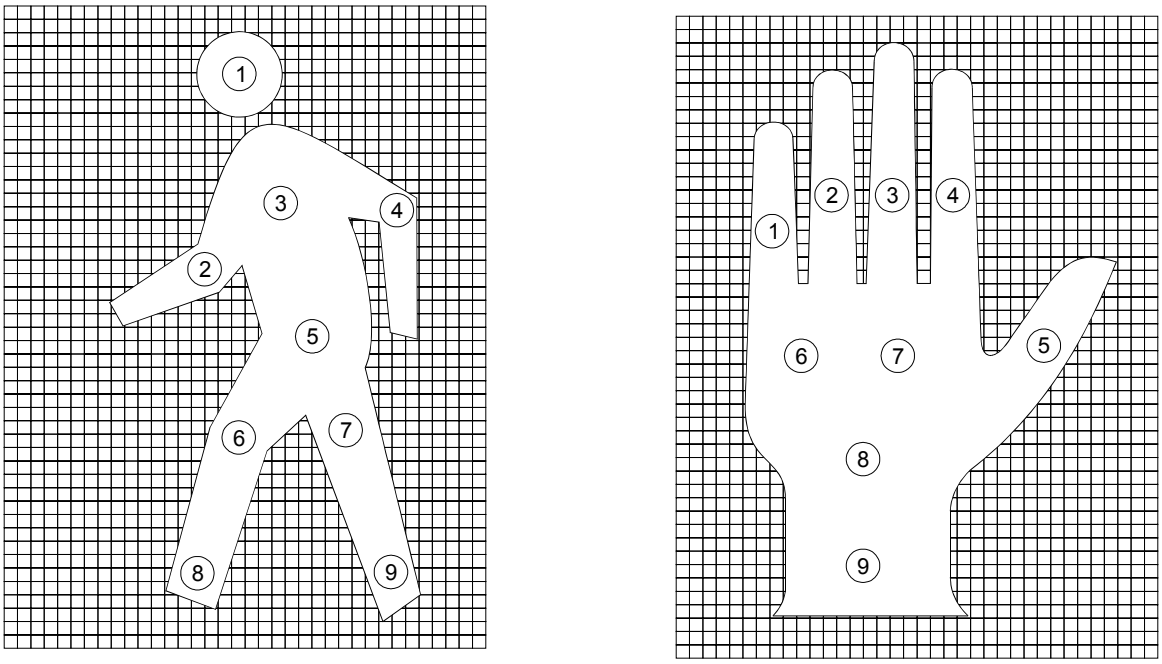
Illuminate either the walking person or upraised hand indication. Using a luminance meter with a 6-minute aperture, measure the luminance of the indication perpendicular to the surface of the optical unit at nine separate points spread across the icon. Figure B1 provides an example of the nine measurement points for each indication. Calculate the average luminance of the indication by averaging the nine separate luminance measurements.

Step 3: Determine if the Indication Meets the Luminance Requirements.

Using Table B1, determine if the measured luminance meets the minimum and maximum visibility performance requirements. With respect to the minimum requirements, the indication's luminance must be equal to or greater than the requirements to meet the specification (i.e., pass the test). With respect to the maximum requirements, the indication's luminance must be equal to or less than the requirements to meet the specification.

Table B1. ITE Test Method Luminance Requirements

Time of Day	Walking Person Indication		Upraised Hand Indication	
	Minimum	Maximum	Minimum	Maximum
Day	5300 cd/m^2	10,600 cd/m^2	3750 cd/m^2	7500 cd/m^2
Night	1590 cd/m^2	3100 cd/m^2	1125 cd/m^2	2600 cd/m^2



a) Walking Person **b) Upraised Hand**

Figure B1. Example of the Nine Measurement Points.

FORM

The following form may be used in conjunction with the testing procedure to document the setup and results.

Pedestrian Signal Head ITE Test Method

Date: _____ Time: _____
Test Administrator: _____
Recorder: _____

Manufacturer: _____
Manufacture Date: _____
Model No.: _____ Serial No.: _____

Current: _____ Voltage: _____
Total Harmonic Distortion: _____ Power Factor: _____

Indication Tested (circle one): Walking Person Upraised Hand
Luminance Tested (circle one): Day Night

Step 1: Setup of Pedestrian Signal and Luminance Meter

Vertical distance from the ground to the center of the indication: _____ ft

Distance between the pedestrian signal and luminance meter: 24 ft

Step 2: Measuring the Luminance of the Indication at Nine Separate Points

Luminance Measurement at Point 1: _____ cd/m^2 (*A*)

Luminance Measurement at Point 2: _____ cd/m^2 (*B*)

Luminance Measurement at Point 3: _____ cd/m^2 (*C*)

Luminance Measurement at Point 4: _____ cd/m^2 (*D*)

Luminance Measurement at Point 5: _____ cd/m^2 (*E*)

Luminance Measurement at Point 6: _____ cd/m^2 (*F*)

Luminance Measurement at Point 7: _____ cd/m^2 (*G*)

Luminance Measurement at Point 8: _____ cd/m^2 (*H*)

Luminance Measurement at Point 9: _____ cd/m^2 (*I*)

Average Luminance Measurement = $(A+B+C+D+E+F+G+H+I)/9$ = _____ cd/m^2 (*J*)

Step 3: Determine if the Indication Meets the Luminance Requirements

Minimum Luminance Requirement

Is the measured average luminance _____ cd/m^2 equal to or greater than the minimum requirement found in Table 1 _____ cd/m^2 (circle one)? YES NO

Maximum Luminance Requirement

Is the measured average luminance _____ cd/m^2 equal to or less than the maximum requirement found in Table 1 _____ cd/m^2 (circle one)? YES NO

Table 1. Luminance Requirements.

Time of Day	Walking Person Indication		Upraised Hand Indication	
	Minimum	**Maximum**	**Minimum**	**Maximum**
Day	5300 cd/m^2	10,600 cd/m^2	3750 cd/m^2	7500 cd/m^2
Night	1590 cd/m^2	3100 cd/m^2	1125 cd/m^2	2600 cd/m^2

Does the pedestrian signal indication pass the current specification requirements (questions in Step 3 were answered "YES")? PASS FAIL

_____

Signature of Test Administrator Date

_____

Print Name of Test Administrator

Comments:

APPENDIX C:
FULL INDICATION TEST METHOD

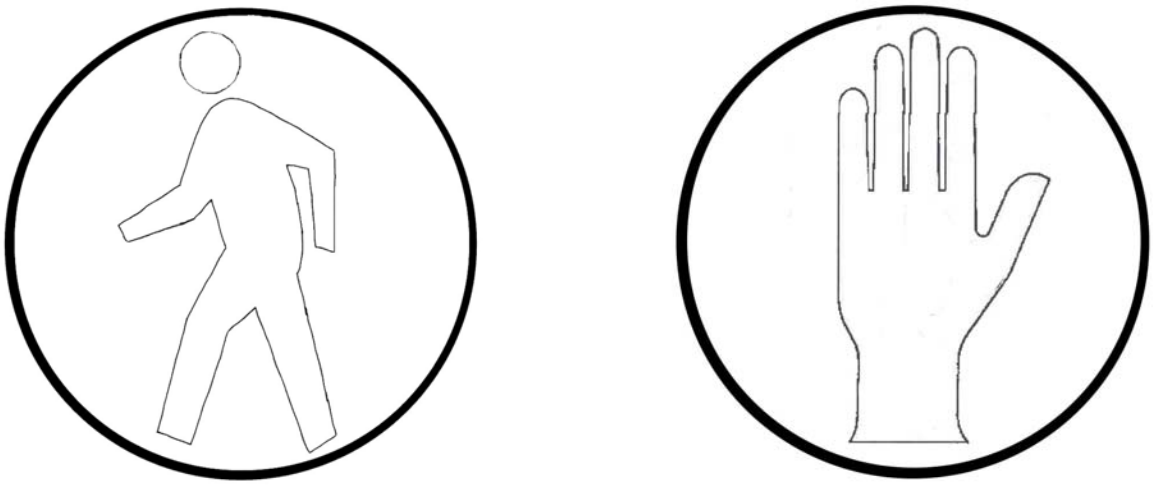
The procedure and form contained in this Appendix can be followed to measure the luminance of an entire pedestrian signal head indication, and determine if the luminance values meet the minimum and maximum visibility performance requirements. The procedure should be conducted in an area with no ambient lighting (e.g., a completely dark room).

This measurement procedure uses a luminance meter with a 3-degree aperture. Luminance meters with other aperture sizes may be used; however, this will affect the distance at which the luminance meter is located away from the pedestrian signal.

PROCEDURE

Step 1: Setup of the Pedestrian Signal and Luminance Meter

The pedestrian signal should be positioned on a flat surface and leveled. In order to obtain repeatable measurements, use a tripod to stabilize the luminance meter. Attach the luminance meter to a tripod and set up the tripod so that the luminance meter is stationed 22 ft away from the pedestrian signal. After the luminance meter is positioned, it should be leveled. To measure the pedestrian signal indication luminance, the indication must be centered in the aperture of the luminance meter such that the indication is completely contained in the aperture (see Figure C1). Thus, both the horizontal and vertical position of the luminance meter must be established with respect to the center of the pedestrian signal indication.



a) Walking Person **b) Upraised Hand**

Figure C1. Luminance Meter Aperture Relative to Indications.

Step 2: Measuring the Luminance of an Entire Indication

Illuminate either the walking person or upraised hand indication. Using a luminance meter with a 3-degree aperture, measure the luminance of the indication perpendicular to the surface of the optical unit at one point that encompasses the entire indication. Multiple luminance measurements may be taken; however, before each additional measurement, the luminance meter aperture should be moved and then repositioned over the indication.

Step 3: Determine if the Indication Meets the Luminance Requirements.

Using Table C1, determine if the measured luminance meets the minimum and maximum visibility performance requirements. With respect to the minimum requirements, the indication's luminance must be equal to or greater than the requirements to meet the specification (i.e., pass the test). With respect to the maximum requirements, the indication's luminance must be equal to or less than the requirements to meet the specification.

Table C1. Full Indication Method Luminance Requirements.

Time of Day	Walking Person Indication		Upraised Hand Indication	
	Minimum	Maximum	Minimum	Maximum
Day	1300 cd/m^2	2700 cd/m^2	1500 cd/m^2	3000 cd/m^2
Night	400 cd/m^2	800 cd/m^2	400 cd/m^2	1000 cd/m^2

FORM

The following form may be used in conjunction with the testing procedure to document the setup and results.

Pedestrian Signal Head Full Indication Test Method

Date: _____ Time: _____
Test Administrator: _____
Recorder: _____

Manufacturer: _____
Manufacture Date: _____
Model No.: _____ Serial No.: _____

Current: _____ Voltage: _____
Total Harmonic Distortion: _____ Power Factor: _____

Indication Tested (circle one): Walking Person Upraised Hand
Luminance Tested (circle one): Day Night

Step 1: Setup of Pedestrian Signal and Luminance Meter

Vertical distance from the ground to the center of the indication: _____ ft

Distance between the pedestrian signal and luminance meter: 22 ft

Step 2: Measuring the Luminance of an Entire Indication

Luminance Measurement 1: _____ cd/m^2 (*A*)

Optional Luminance Measurement 2: _____ cd/m^2 (*B*)

Optional Luminance Measurement 3: _____ cd/m^2 (*C*)

Optional Average Luminance Measurement = (*A*+*B*+*C*)/3 = _____ cd/m^2 (*D*)

Step 3: Determine if the Indication Meets the Luminance Requirements

Minimum Luminance Requirement

Is the measured luminance _____ cd/m^2 equal to or greater than the minimum requirement found in Table 1 _____ cd/m^2 (circle one)? YES NO

Maximum Luminance Requirement

Is the measured luminance _____ cd/m^2 equal to or less than the maximum requirement found in Table 1 _____ cd/m^2 (circle one)? YES NO

Table 1. Luminance Requirements.

Time of Day	Walking Person Indication		Upraised Hand Indication	
	Minimum	**Maximum**	**Minimum**	**Maximum**
Day	1300 cd/m^2	2700 cd/m^2	1500 cd/m^2	3000 cd/m^2
Night	400 cd/m^2	800 cd/m^2	400 cd/m^2	1000 cd/m^2

Does the pedestrian signal indication pass the current specification requirements (questions in Step 3 were answered "YES")? PASS FAIL

_____

Signature of Test Administrator Date

_____

Print Name of Test Administrator

Comments: