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16. Abstract Project

Portable changeable message signs (PCMSs) are traffic control devices that advise motorists of unexpected traffic and routing situations. In contrast to static signing, PCMSs convey dynamic information in a variety of applications, such as work zones, incident management, traffic management, and warning of adverse conditions. Although PCMSs have been used in traffic control applications for many years, there are no established photometric standards for the device that can be used as the basis for a procurement specification. The only provision related to the visibility of PCMSs is a requirement in the *Texas Manual on Uniform Traffic Control Devices for Streets and Highways – Part VI* which indicates that PCMSs be visible from at least a half mile (under ideal day and night conditions) and the sign message be legible at a minimum of 650 ft. However, the manual does not provide a means for determining whether PCMSs meet these criteria.

This project reviewed the performance of PCMSs and developed photometric standards to establish performance requirements. In addition, researchers developed photometric test methods and recommended them for use in evaluating the performance of PCMSs. This report includes a review of the literature and provides documentation for the standards and procedures recommended.

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PHOTOMETRIC REQUIREMENTS FOR PORTABLE CHANGEABLE MESSAGE SIGNS

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1. INTRODUCTION

Portable changeable message signs (PCMSs) are traffic control devices that advise motorists of unexpected traffic and routing situations. In contrast to static signing, PCMSs convey dynamic information in a variety of applications such as work zones, incident management, traffic management, and warning of adverse conditions.

NEED FOR RESEARCH

Although PCMSs have been used in traffic control applications for many years, there are no established photometric standards for the device that can be used as the basis for a procurement specification. The only provision related to the visibility of PCMSs is a requirement in the *Texas Manual on Uniform Traffic Control Devices for Streets and Highways – Part VI* (*1*) which indicates that PCMSs be visible from at least a half mile (under ideal day and night conditions) and the sign message be legible at a minimum of 650 ft. However, the manual does not provide a means for determining whether PCMSs meet these criteria.

As a result of the lack of detailed measurement requirements, transportation agencies experience difficulty developing specifications that ensure all PCMSs purchased by the agency will communicate the desired information to motorists in an effective and consistent manner. This report presents the Texas Transportation Institute's (TTI) recommendations for test methods for measuring the photometric properties of PCMSs. The intent of the test method is to provide TxDOT with measurable criteria for qualifying PCMSs for use on TxDOT projects.

REPORT ORGANIZATION

Chapter 2 contains a review of general visibility principles and concepts, as well as past research that addresses the visibility and legibility of PCMSs. In addition, a sampling of other states' PCMS specifications are documented.

Chapter 3 discusses the development of the daytime and nighttime photometric standards for PCMSs. These standards are based on the results of the literature review and a small-scale field survey performed by TTI.

Chapter 4 summarizes the recommendations reached as a result of the research conducted.

Chapter 5 contains the recommended photometric testing procedure for use in the procurement and operation of PCMSs.

2. LITERATURE REVIEW

The literature review included herein contains a review of visibility principles and a discussion on the effect of sun interference on visibility. Past research that has addressed the visibility and legibility criteria of message signs, as well as a review of other states' PCMS specifications, are also documented.

The following terms are used frequently throughout this document:

- Character module – a matrix of elements (e.g., 5 by 7) that can display one alphanumeric character.
- Element – a single unit of a character module that is comprised of one or more pixels.
- Pixel – the smallest independently controlled component (e.g., light-emitting diode).

VISIBILITY PRINCIPLES AND CONCEPTS

The visibility of message signs depends on the photometric qualities of the device, as well as the visual capabilities of motorists. The two aspects of visibility are conspicuity and legibility. Conspicuity is the ability of an object to attract attention in a complex environment, while legibility (the focus of this research) is the ease with which the message can be read. The following sections describe the concepts associated with visibility.

Illuminance

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).

Luminance

Luminance is the measure of light reflected or emitted from a surface and is roughly equated to "brightness." It is independent of the distance to the object and is the product of illuminance and reflectance. It may also be derived by dividing the luminous intensity by the source area. It is expressed in foot-Lamberts (fL) or candelas per meter squared (cd/m^2).

Luminous Intensity

Luminous intensity is a measure of the strength of a light source. It is expressed in candelas (cd) and is sometimes referred to as a candlepower.

Reflectance

Reflectance is the ratio of reflected light (luminance) to the amount of light falling upon an object (illuminance), expressed as a percentage.

Contrast

The contrast between the sign message and sign panel influences the ability of motorists to read a message. Contrast is normally defined as

$$(L_T - L_B)/L_B$$

where L_T is the luminance of the target and L_B is the luminance of the background. The target may be an object, legend on a retroreflective sign, or character on a PCMS. Sometimes contrast is reported as a ratio, defined as

$$L_T/L_B$$

In calculating the contrast of changeable message signs, some researchers (e.g., Colomb and Hubert [*2*]) measure character luminance in a way that reflects a weighted average of the lighted and unlighted portion of a character module. Contrast is then defined as the ratio

$$L_{TW}/L_B$$

where L_{TW} is a weighted average of the character and its background. Other researchers (e.g., Jenkins [*3*]) have calculated L_T from measurements of pixel intensity. In this case, L_T is not weighted and contrast is defined in its normal form.

It can be shown that the contrast ratio (L_T/L_B) is always equal to contrast ($[L_T - L_B]/L_B$) plus one. However, the difference between (L_{TW}/L_B) and $(L_T - L_B)/L_B$ is actually less than one. Thus, for all practical purposes there is no difference between the formulae.

Irradiation

Irradiation refers to the spreading of emitted light over a perceptual area which is larger than the physical area of a reflective or internally illuminated surface such as an element of a matrix display. When the elements are small and the spacing between them large, irradiation results in the perception of a continuous pattern and not individual elements. When the elements are large and the spacing between them small, irradiation results in the blurring of the interior spaces of a character or symbol. Higher luminance of small elements (narrow stroke width) is necessary for legibility. Higher luminance of large elements (e.g., fat stroke widths and double stroke fonts) reduces legibility and may also produce excessive glare.

The effects of irradiation may be greater with negative contrast signs (dark-colored legend on light background). Garvey and Mace found that positive contrast messages (light-colored legend on dark background) were read at a significantly greater distance than their negative contrast counterparts (*4*).

REDUCED SIGN VISIBILITY DUE TO SUN INTERFERENCE

In addition to the visibility concerns previously discussed, the position of the sun relative to PCMSs also needs to be addressed. In particular, a reduction in visibility can occur when the sun appears to be directly behind the sign (backlight) or when the sun is facing the sign (washout). When light-emitting PCMSs are backlit, the direct sunlight as well as its reflections from the pavement and other vehicles cause a blinding glare through which only a silhouette of the sign is visible. Reductions in visibility because of backlighting occur most often when the rear surface of the sign is west-southwest oriented. Nonetheless, reductions can also occur when the rear surface of the sign is east-northeast oriented. However, the rising sun (east-northeast orientation) is less intense than a setting sun (west-southwest) due to more frequent haze in the morning (*5*).

Washout conditions will ordinarily enhance the legibility of light-reflecting PCMSs, such as reflective disk. However, all light-reflecting message signs are equipped with a clear sign face which causes visibility problems because it reflects and scatters incident light, thus obscuring the message. The legibility of light-emitting PCMSs is adversely affected in washout conditions because of the reduction in the contrast between the sign message and background. As with light-reflecting PCMSs, screens used to protect the face of light-emitting PCMSs will reflect sunlight and produce a glare that could further reduce the legibility of messages (*5*).

PCMS VISIBILITY AND LEGIBILITY CRITERIA

The two major components of PCMS design parameters are character and message. Character components consist of element and character variables. Element variables include the shape, size, number, spacing, luminance, and color of each individual element that make up the characters on a PCMS. Character variables include the height, width, font, mean luminance, contrast, and contrast orientation of alphanumeric characters. Message components are associated with the overall impression made by the sign copy and address spacing issues, such as inter-letter, inter-word, inter-line, and copy-to-border spacing.

Most of these variables interact with each other so that any recommendation with regard to any one variable, assumes certain limits on the others. These interactions are evident when one considers the inevitable confounding that occurs when manipulating many of these variables. For example, if the number of elements is increased, character height, width, and/or stroke width must also change. Thus, the problem of confounding variables makes it difficult to attribute any improvement in performance to the nominally manipulated variables.

Still, without luminance and contrast nothing else matters. Every specification with regard to all other element and message variables assumes a minimum luminance and contrast requirement. Therefore, the focus of this report will be on luminance and contrast with the understanding that the values attached to all of the other variables are reasonably close to the recommendations made by either the International Commission on Illumination (CIE) (*6*) or Garvey and Mace (*4*) (see Table 1). The differences between the recommendations in Table 1 may in part be due to the differences in procedure and measures of effectiveness found in this line of research. In particular, the different definitions of character luminance and contrast that have been used make it difficult to summarize this field of research.

Table 1. Summary of Previous Literature Recommendations for Character/Message Components Not Addressed in This Research.

Design Feature	CIE (*6*)	Garvey and Mace (*4*)	
		Optimal	**Acceptable**
Color	Follow CIE chromaticity guidelines	Match MUTCD	Red, amber/yellow, white, orange
Contrast Orientation	--	Light letters on a dark background	Light on black, Light on colored
Font and Matrix Form	5 by 7, 7 by 9 if lowercase	Alphanumerics that closely approximate Standard Highway font	Any reasonable non-serif font using at least a 5 by 7 matrix or equivalent
Letter Height	70 mph – 16 in 60 mph – 12 in 50 mph – 8 in 40 mph – 3.5 in	18 in	12 in if legibility < 400 ft is acceptable
Width:Height (W:H)	0.76	0.8	0.6-1.0
Stroke Width: Height (SW:H)	--	0.13	0.1-0.18
Inter-letter Spacing	2/7 letter height	Three times Standard Alphabet Series E or 1/2 letter height	3/7 letter height
Inter-word Spacing	3/7 letter height	Equal to letter height	Equal to 5/7 letter height
Inter-line Spacing	4/7 letter height	70% of letter height	20% of letter height with two-line PCMS

-- No recommendation

Character Luminance and Contrast

A standardized procedure for the photometric measurement of PCMSs has yet to be established. One of the principal issues is whether the unit of measurement should be the light emitted by individual elements or whether the luminance should be measured across an entire character matrix, including both lighted and unlighted areas when all elements are lit.

In 1987, Mazoyer and Colomb conducted a study using a computer simulation of nighttime conditions to determine the best combination of element size and luminance. Alphanumeric characters of five different element sizes and seven levels of element luminance from 1 to 230 cd/m^2 were evaluated. The percentage of correct responses was the measure of effectiveness (*7*).

Researchers found that as element size decreased, greater element luminance was needed. Small elements with low luminance could not be seen, and large elements with high luminance suffered a loss in legibility because of irradiation. Statistical analysis showed that the relationship between element size and luminance could be characterized by a constant luminous intensity. In addition, researchers found that a luminance between 30 and 230 cd/m^2 produced more than 70 percent correct responses (*7*).

In 1988, Padmos et al. published a study designed to optimize the photometric features of message signs. Using fiber-optic mock-ups, the researchers measured the subjective visibility of the number "5" at various levels of element spacing and luminance under a range of ambient light levels. The results of this procedure led researchers to conclude that dim sources spaced close together work as well as bright sources spaced widely apart (*8*). In 1991, Jenkins reached this same conclusion (*3*). In essence, the results of these studies mirrored those of Mazoyer and Colomb, by indicating that for a single character the importance of spacing, number, and intensity of individual elements is superseded by that of average character luminance. In addition, the 1988 study recommended a character luminance of 4000 cd/m^2 for daytime conditions and 100 cd/m^2 at night (*8*).

In a follow-up to the 1987 study, Colomb and Hubert conducted a controlled field study to determine the effects of element size, character luminance, and contrast ratio on letter legibility under both daytime and nighttime conditions. Using light-emitting diode (LED), single-character, mock-up message signs, they varied the luminance of the letters from 9 to 730 cd/m^2 at night and 280 to 4090 cd/m^2 during the day. The contrast ratio was varied from 1.5 to 20 in daylight. All the letters of the alphabet were viewed from a distance of 656 ft under six luminance conditions and six element sizes ranging from 1 to 36 LEDs per element. The dependent measure was the percent of correct responses (*2*).

The daytime field studies revealed that as the contrast ratio was increased from 1.5 to approximately 3 the percent of correct answers increased from 10 to 50 percent. The percentage of correct answers continued to rise with increasing contrast, leveling off at 85 percent for a contrast between 8 and 20. (No values above 20 were evaluated). The corresponding character luminance is between 1500 and 4000 cd/m^2 (*2*). These character luminance values are compatible with the results of Padmos et al. (*8*).

For the nighttime studies, there were no significant changes in the percentage of correct answers with increasing character luminance from 9 to 730 cd/m^2. Most observers judged the highest luminance levels to be uncomfortable, but this perceived discomfort did not affect reading performance (*2*).

These research studies exemplify the problem of the confounding of element variables previously discussed. Colomb and Hubert's methodology resulted in luminance and contrast being confounded with element size. While increased contrast had a positive effect on daytime legibility, the high-contrast letters had the greater number of LEDs per element, which resulted in a larger element size. The increased number of pixels (in an element with character size and luminous intensity of the pixels constant) decreased the spacing between elements and increased character luminance and contrast, although pixel and element luminance remained constant.

While the confounding of character luminance and element size limits the power of this study, based on the other research already reviewed we can infer that had the intensity of the pixels in the smaller elements been increased so that luminance of each element was greater, the high contrast obtained with the small elements would have resulted in similar legibility to that obtained with the contrast of the large elements. A similar problem occurred in the nighttime portion of the study.

The research of Colomb, Padmos, and Jenkins all seem to indicate that for a given character size and font, equivalent legibility is obtained with different element size and spacing with either constant character luminance or constant luminous intensity. However, only character luminance will be constant with respect to changes in character size. If character height is increased to increase the legibility distance, intensity must be increased to maintain character luminance.

One can see what is happening by looking at the equations for character and element luminance.

Character Luminance = Total intensity of pixels in character / Area of the character

Luminance of element = Total intensity of pixels in one element / Area of one element

If total intensity is kept constant, character luminance is not affected by the size of the elements or their spacing. However, as element size is reduced and the spacing between elements increases, the luminance of each element increases.

In another study, Bry and Colomb determined that optimum legibility was achieved with contrast ratios between 8 and 12, and acceptable legibility was achieved with contrast ratios between 3 and 25 (*9*). Therefore, France specifies that the contrast ratio should be between 3 and 25 for daytime operations (*10*). In 1990, the contrast ratio criteria proposed by the United Kingdom was as follows (*11*):

- 7 to 50 for daylight conditions (external illuminance between 4000 and 40,000 lux) and
- 3 to 25 for reduced lighting conditions (external illuminance between 4 and 400 lux).

Similarly, CIE recommends a contrast ratio between 7 and 50 during the day (lux > 4000) and between 3 and 25 at night (lux < 400) (*6*).

In 1996, Garvey and Mace studied the effect of character luminance and contrast in both static and dynamic field studies. The static field study utilized both a mock-up and actual message sign, while the dynamic field study used actual trailer-mounted message signs on public roadways. Both studies included both young and old subjects and were conducted during the day, as well as at night (*4*).

In the static field study, the independent variables were subject age, sign distance, letter height, and for the daytime studies only, sun position. The dependent measure was luminance threshold for legibility, defined as the lower of two consecutive luminances at which two-thirds of the letters in a condition were correctly identified. Researchers found that a character luminance of 350 cd/m^2 during the day and between 12 and 60 cd/m^2 at night accommodated 90 percent of the observers (young and old) under the conditions tested. The daytime value provides legible letters under overhead, backlit, and washout conditions, while the nighttime range of values provides glare-free legibility (*4*).

The purpose of the dynamic field study was to analyze message signs under real-world conditions and assess the results from the static field study. As with the static field study, testing of both young and old subjects occurred under daytime and nighttime conditions. The independent variables were subject age, contrast orientation, character height, lighting condition (during the day only), character luminance, inter-letter spacing (at night only), and sign lighting (at night only). Four daytime character luminance values (350, 570, 850, and 1200 cd/m^2) and six nighttime character luminance values (30, 80, 130, 200, 570, and 1200 cd/m^2) were evaluated. Character luminance levels greater than 1200 cd/m^2 were not assessed due to limitations in the capabilities of the message signs used in the study. The four daytime ambient lighting conditions were backlit, washout, overcast, and rain. The two dependent variables were legibility distance and detection distance (*4*).

Researchers found that a significant increase in legibility distance occurred when the daytime character luminance was increased from 350 to 850 cd/m^2. However, further increases in the character luminance (up to 1200 cd/m^2) did not produce additional benefits. At night, character luminance had no consistent effect on legibility or detection; however, this is not surprising given the fairly high level of 30 cd/m^2 for the lowest setting. An irradiation effect may have been expected at the 1200 cd/m^2 condition, but the results do not indicate a decrease in legibility performance with the higher levels. Neither daytime nor nighttime detection distance was affected by the change in character luminance (*4*).

Based on the results of this study, Garvey and Mace recommended the minimum character luminance values in Table 2 for message signs. In addition, Garvey and Mace recommended that the contrast ratio be between 5 and 50 for all ambient light conditions (i.e., backlit, washout, sun overhead, and nighttime) (*4*).

Table 2. Garvey and Mace Recommended Minimum Character Luminance Values (*4*).

Sun Overhead	Sun on Sign (Washout)	Sun Behind Sign (Backlit)	Nighttime
1000 cd/m^2 *	1000 cd/m^2 **	1000 cd/m^2 **	30 cd/m^2 *

* 85th percentile motorist accommodated at 650 ft

** Will accommodate less than 50 percent of motorists at 650 ft at any luminance level with extreme sun angles

In a recent TTI project for the New Jersey Department of Transportation (documented in several technical memorandums), researchers conducted nighttime legibility distance studies of an LED message sign at the TTI proving ground facilities. Researchers tested six different output luminance levels ranging from 750 to 5822 cd/m^2 under the following nighttime viewing conditions:

- completely dark ambient conditions (sign luminance only),
- a glare source in the left portion of the motorist's field of view to mimic an oncoming vehicle,
- overhead lighting present at the sign,
- simulated fog equivalent to 1/4-mile visibility, and
- simulated fog equivalent to 1/8-mile visibility.

The dependent variable was the percent of the words correctly identified as a function of character luminance. The preliminary results of the normal and reduced visibility nighttime legibility studies indicated that motorist age had a significant effect upon nighttime legibility distance. However, luminance level (at least over the range of values tested), external lighting condition, and visibility condition (normal or reduced) were not found to have a significant effect.

As part of these studies, researchers also obtained subjective brightness ratings from the motorists tested. However, there did not exist a single luminance value or range of values that were optimum (i.e., "bright enough") over all visibility conditions and age groups; however, the results did show that reduced visibility and older subjects require greater character luminance. In addition, researchers established the following nighttime character luminance ranges for side-mounted message signs: 1500 to 1700 cd/m^2 for normal and 1/4-mile visibility conditions; and 1800 to 2300 cd/m^2 for visibility conditions of 1/8-mile.

These character luminance values are much greater than the minimum luminance level of 30 cd/m^2 recommended by Garvey and Mace (*4*). There are three explanations for this difference. First, subject motorists in the TTI study were not rating minimum brightness levels, but rather optimum levels. Second, TTI evaluated message signs under reduced visibility conditions. Third, in the TTI study the character luminance measurements were taken from a straight-on position; however, the subjects viewed the message sign from a position similar to being in the median lane on a 10-lane divided roadway and looking over at a message sign beyond the right shoulder. At the viewing distance of 800 ft, the actual angle between the message sign and the subject motorist was approximately five degrees.

As mentioned previously, a standardized procedure for photometric measurement of PCMSs has yet to be established (element luminance versus character luminance). Measuring character luminance as opposed to calculating it from intensity measures appears to provide a more realistic picture of what a motorist observes, since at most distances characters appear to be a coherent whole with the lighted elements "blending in" with the inter-element spacing.

Based on the results of the reviewed studies, it can be concluded that the design of the element variables, including their size, shape, spacing, and color can be flexible as long as the character has sufficient height (at least 16 inches for legibility at 650 ft), the average character luminance and contrast are within acceptable ranges, and the PCMS uses a non-serif font using at least a 5 by 7 character module.

Tables 3 and 4 summarize the character luminance and contrast findings from past research, respectively. While the research summarized has focused primarily at legibility distances of approximately 650 ft, these recommendations should apply to a range of distances as long as sufficient character height is provided. The inverse square law will result in greater intensity being required to maintain the minimum luminance when character height is increased. Conversely, less intensity will be required to provide the same luminance at nearer distances.

Table 3. Summary of Character Luminance Recommendations.

Past Research	Daytime Character Luminance (cd/m^2)	Nighttime Character Luminance (cd/m^2)
Mazoyer and Colomb (*7*)	--	30 to 230
Padmos et al. (*8*)	4000	100
Colomb and Hubert (*2*)	1500 to 4000	Not Conclusive
Garvey and Mace (*4*)	1000	30
TTI	--	1500 to 1700

-- Did not evaluate

Table 4. Summary of Contrast Recommendations.

Past Research	Contrast
Colomb and Hubert (*2*)	8 to 20
Bry and Colomb (*9*)	8 to 12 optimum 3 to 25 acceptable
France (*10*)	3 to 25 for daytime
United Kingdom (*11*)	7 to 50, lux > 4000 3 to 25, lux < 400
CIE (*6*)	7 to 50, lux > 4000 3 to 25, lux < 400
Garvey and Mace (*4*)	5 to 50 optimum 5 acceptable

OTHER STATES' PCMS SPECIFICATIONS

Researchers reviewed five other states' PCMS specifications in order to determine existing practices. Table 5 contains a summary of the characteristics documented in these specifications. As shown in this table, only one out of the five states (New York) addresses the photometrics of the PCMS by specifying minimum intensity levels per pixel or individual LED. However, none of these states address the issue of minimum luminance or contrast. Converting the New York specifications, researchers estimated that the solar-powered PCMS will produce about 3300 cd/m^2, while other types of PCMSs will produce about 4700 cd/m^2.

Table 5. Summary of Other States' PCMS Specifications.

State	Color	Minimum Character Height	Minimum Legibility Distance	Elements	Output
California			755 ft [a] (visible at 1500 ft)		
Florida		18 in	900 ft [b]	Minimum 35 elements per character	
New Jersey	Orange at a wavelength of 590 nm	17 in	900 ft [c] (visible at 2600 ft [d])	Cluster of 35 LED lamp elements which have minimum of 4 LEDs and a maximum of 6 LEDs per element; full LED matrix character board; full LED matrix board	Lamp minimum 20 watts
New York [e]					
Solar-Powered PCMSs	ITE amber	Type A 18 in; Type B 9 in	17 degree viewing angle [f]	Minimum 4 LEDs per element; 3.5 cd of light per LED at 30 ma of current	Array Type A 450 watts; Type B 300 watts
PCMSs	ITE amber	18 in	30 degree viewing angle [f]	Pixel minimum of 20 cd at 30 ma of current	Array 450 watts
Washington	Yellow or orange	18 in	800 ft [g]	No larger than 2.5 in by 2.5 in	

a At noon on cloudless day with 20/20 vision
b Under all light conditions
c Under all weather conditions
d Under ideal day and night conditions
e Department of Transportation Region 11
f Day and night legibility
g Viewer with 20/20 vision
ITE Institute of Transportation Engineers

3. DEVELOPMENT OF PCMS PHOTOMETRIC STANDARD

This chapter documents the development of the daytime and nighttime photometric standards for PCMSs. These standards are based on the results of the literature review and a small-scale field survey performed by TTI.

DAYTIME PHOTOMETRIC STANDARD

Previous research suggests that under "normal" daylight conditions a minimum character luminance of 1000 cd/m^2 accommodates the 85^{th} percentile motorist at 650 ft. However, under extreme sun angles (backlit and washout) the literature recommends that the character luminance be between 1500 to 4000 cd/m^2. In addition, the contrast ratio of character luminance to background luminance should be between 5 and 50.

In order to assess the character luminance needed under various ambient light conditions, TTI conducted a field survey of PCMSs. Through this survey researchers identified the amount of light falling on a PCMS (illuminance) and the amount of light reflected by a PCMS (luminance) under various ambient light conditions. Using these measurements and the minimum character luminance values recommended in past research, researchers determined under what conditions a minimum contrast requirement of 5 would be met.

Field Survey of PCMSs

A TxDOT PCMS located on State Highway 6 in College Station, Texas was utilized in the field survey. The characteristics of this PCMS are documented in Table 6. It should be noted that the width-to-height ratio (0.57) and stroke width-to-height ratio (0.09) are less than the optimum and minimums specified by either CIE (*6*) or Garvey and Mace (*4*).

Table 6. Characteristics of PCMS Used in Field Survey.

Parameter	Dimensions
Module Type	5 by 7
Character Height	20.75 in
Character Width	11.875 in
Element Height	1.25 in
Element Width	1.875 in
Vertical Spacing Between Elements	2 in
Horizontal Spacing Between Elements	0.625 in
Number of LEDs per Element	4
Vertical Spacing Between Modules	6.5 in
Horizontal Spacing Between Modules	4.25 in

Using a luminance meter, a series of background luminance measurements (sign "off") was taken under sun overhead, backlit, and washout conditions. Figure 1 shows the location of the luminance meter aperture during the measurements. Additional luminance measurements of the sign's immediate surroundings were taken and used to evaluate external contrast (Figure 2). The vertical illuminance (amount of light falling on the sign face) was determined with a hand-held illuminance meter.

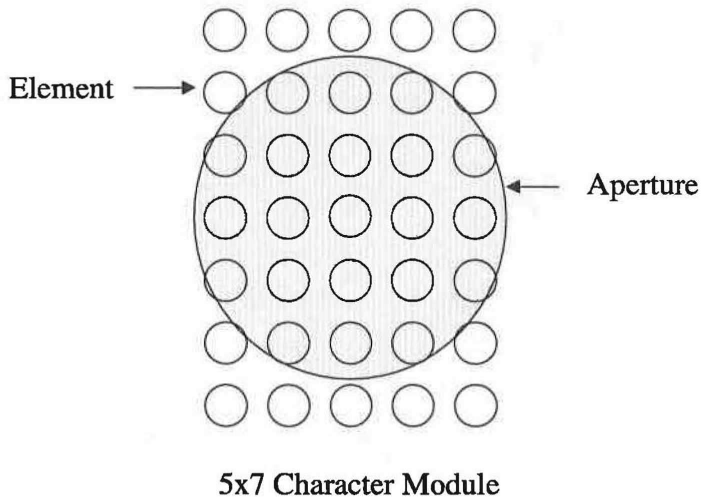


Figure 1. PCMS Character Module and Photometer Aperture.

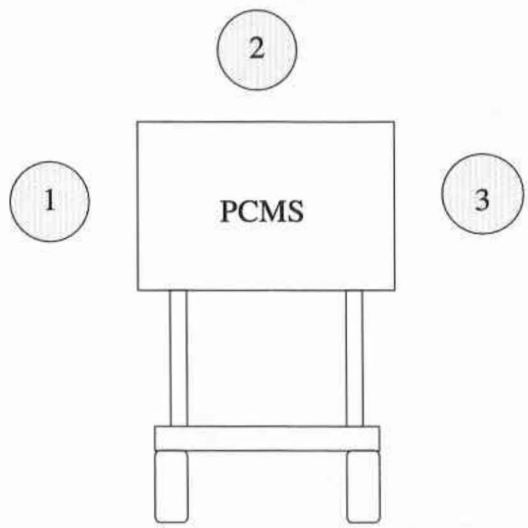


Figure 2. Surrounding Luminance Measurements.

Figure 3 presents the relationship between the vertical illuminance and background luminance measurements. The three distinct sections in the plot represent the three different ambient light conditions under which the measurements were taken. More specifically, the observations below 25,000 lux were considered to be backlit, those between 25,000 and 55,000 lux were grouped as sun overhead, and those above 55,000 were classified as washout. As shown in the figure, background luminance increases as the sun moves from behind the sign to facing the sign and peaks at approximately 1400 cd/m^2.

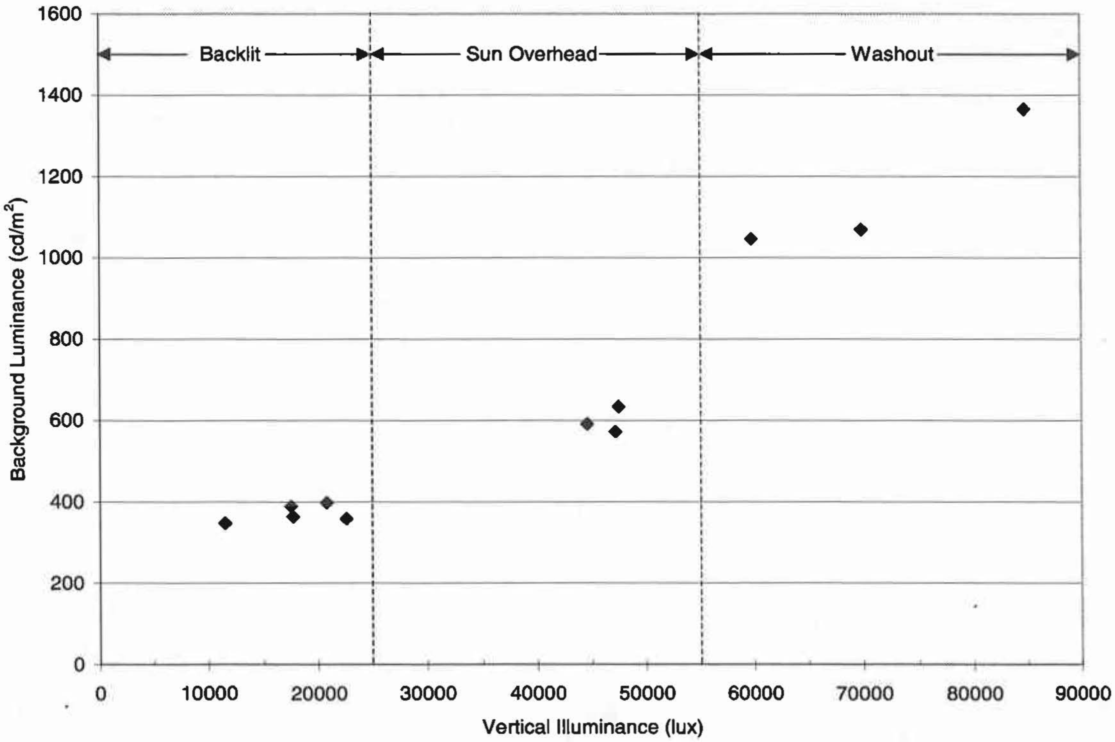


Figure 3. Background Luminance as a Function of Vertical Illuminance.

Comparing these measurements with the recommended minimum character luminance values from previous research (1000 cd/m^2 for normal conditions and 1500 to 4000 cd/m^2 for extreme sun angles), researchers developed Table 7. This table illustrates the conditions where a minimum contrast requirement of 5 would be met. Since the measurements of character luminance included a weighted measure of the background luminance, the contrast ratio (formula below) was used instead of the traditional measure of contrast.

$$C = L_{CW}/L_B$$

Where L_{CW} = luminance of the character module with all elements "on"

L_B = background luminance of the character module with all elements "off"

Table 7. Resultant Contrast Based on Character and Background Luminance Values. [a]

Background Luminance (cd/m^2)	Character Luminance (cd/m^2)								
	1000	**1500**	**2000**	**2500**	**3000**	**3500**	**4000**	**4500**	**5000**
100	10	15	20	25	30	35	40	45	50
200	5	8	10	13	15	18	20	23	25
300	3	5	7	8	10	12	13	15	17
400	3	4	5	6	8	9	10	11	13
500	2	3	4	5	6	7	8	9	10
600	2	3	3	4	5	6	7	8	8
700	1	2	3	4	4	5	6	6	7
800	1	2	3	3	4	4	5	6	6
900	1	2	2	3	3	4	4	5	6
1000	1	2	2	3	3	4	4	5	5
1100	1	1	2	2	3	3	4	4	5
1200	1	1	2	2	3	3	3	4	4
1300	1	1	2	2	2	3	3	3	4
1400	1	1	1	2	2	3	3	3	4
1500	1	1	1	2	2	2	3	3	3

a Shaded region does not meet the minimum contrast requirement

As seen in Table 7, a character luminance of 1000 cd/m^2, only meets the contrast requirement when the background luminance is below 300 cd/m^2. Conversely, a character luminance of 4000 cd/m^2 yields an appropriate contrast for background luminance values between 100 and 800 cd/m^2. Thus, a character luminance of 4000 cd/m^2 achieves the desired contrast under backlit and sun overhead conditions (referencing Figure 4). Washout conditions present tremendous problems for PCMS visibility, particularly with older motorists, such that no minimum luminance level can ensure that the sign be read by all observers under all conditions.

Figure 4 is a plot of the intersection between the non-shaded (meets minimum requirement) and shaded regions (does not meet minimum requirement) shown in Table 7. In this figure, the minimum contrast of 5 is represented as the line. If the intersection of the background and character luminance is below this line, the minimum contrast of 5 is not met.

NIGHTTIME PHOTOMETRIC STANDARD

At night in an unlighted area, the luminance of the background tends toward zero. Therefore, the luminance of the character is the only photometric criterion used for determining the legibility of a PCMS at night. Previous research recommends that the minimum nighttime character luminance of PCMSs be 30 cd/m^2.

Most observations with respect to a maximum nighttime character luminance to prevent unacceptable glare have been made as a result of other research. In other words, previous research has not been conducted with the objective to assess the nighttime glare of PCMSs. In the study conducted by Colomb and Hubert, observers judged the highest luminance level (730 cd/m^2) to be uncomfortable, but this perceived discomfort did not affect reading performance (*2*). In addition, Garvey and Mace found that with high levels of luminance at night (1200 cd/m^2 highest level tested) irradiation did not decrease the legibility performance (*4*).

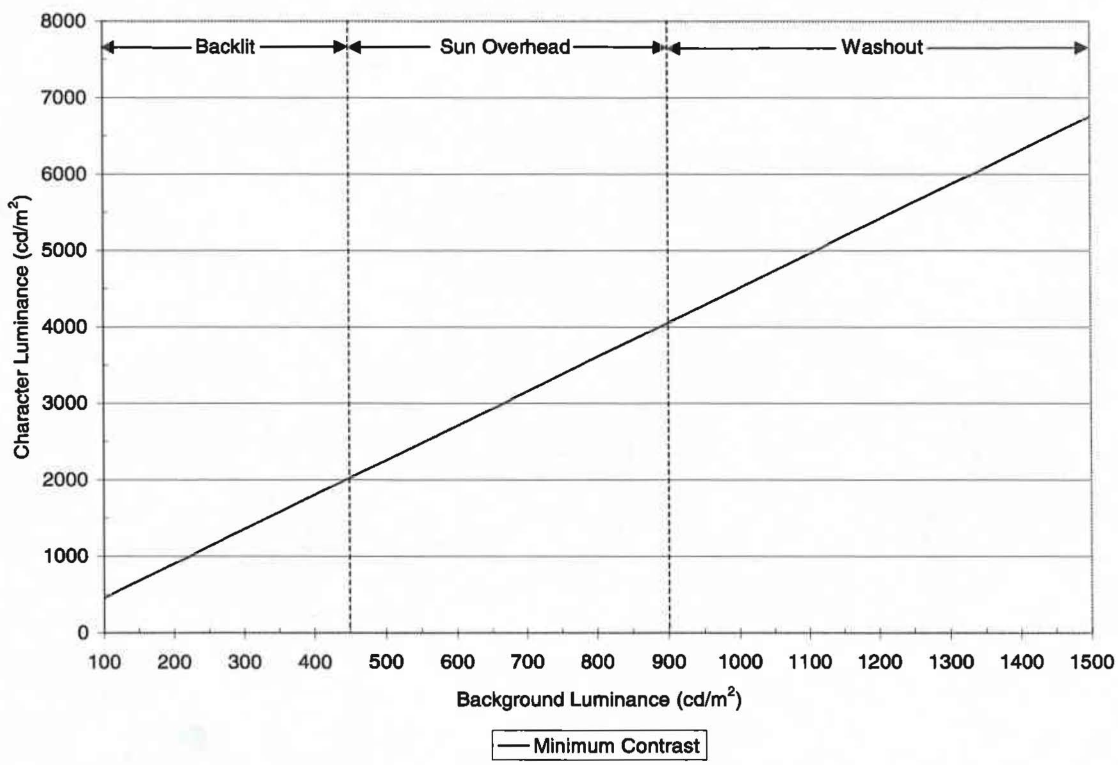


Figure 4. Plot of Minimum Contrast.

4. RECOMMENDATIONS

The performance of PCMSs is important to enhance the safety and efficiency of traffic operations. Ensuring that PCMSs meet their objectives of advising motorists of unexpected traffic and routing situations is important.

The review of previous research and results of a small-scale field study documented in this report provides information regarding the character luminance and contrast of PCMSs. The conclusions and recommendations with respect to PCMS character luminance and contrast are described below.

DAYTIME CHARACTER LUMINANCE AND CONTRAST

Previous research suggests that under "normal" daylight conditions a minimum character luminance of 1000 cd/m^2 accommodates the 85th percentile motorist at 650 ft. However, under extreme sun angles (backlit and washout) the literature recommends that the character luminance be between 1500 to 4000 cd/m^2. In addition, the contrast ratio of character luminance to background luminance should be between 5 and 50.

Following these results, researchers recommend that the minimum luminance contrast between the sign character and its background be 5 to optimize visibility. For this report, contrast was calculated as the ratio of the character luminance (luminance of character module with all elements "on") to the background luminance (luminance of character module with all elements "off").

The results of a small-scale field survey showed that a character luminance of 1000 cd/m^2 only met the contrast requirement for low levels of background luminance. Conversely, a character luminance of 4000 cd/m^2 achieves the desired contrast under backlit and sun overhead. Thus, researchers recommend a minimum daytime character luminance of 4000 cd/m^2, a level that will permit most drivers to read a PCMS under most conditions.

NIGHTTIME CHARACTER LUMINANCE

Based on previous research, researchers recommend a minimum nighttime character luminance of 30 cd/m^2. Little research has been conducted with respect to a nighttime maximum character luminance needed to prevent unacceptable levels of glare; thus, a maximum value is not recommended.

FUTURE RESEARCH

In addition to character luminance and contrast, a number of characteristics are critical to the performance of PCMSs. As discussed previously, other variables effect the visibility and legibility of PCMSs (Table 1) and thus should be considered in future research. Other issues that need to be addressed through future research include full-matrix PCMSs, the maximum nighttime character luminance needed to prevent unacceptable glare, and the angularity of PCMSs (i.e., minimum off-axis luminance requirements).

Also note that the National Electrical Manufacturers Association (NEMA) is currently in the process of developing a hardware standard for changeable message signs which will include optical component and visual presentation requirements. When this standard is finalized, the TxDOT changeable message sign specifications should be reviewed and revised to be consistent with the NEMA standard.

5. PCMS PHOTOMETRIC TESTING PROCEDURE

The purpose of this chapter is to describe the recommended photometric procedure to be used when measuring the daytime and nighttime character luminance of PCMSs. Based on these measurements, TxDOT personnel can then determine if the character luminance and contrast (daytime only) meet the minimum daytime and nighttime requirements. The data form in the Appendix has been developed to aid the testing procedure.

CHARACTER MODULE TESTING

Character luminance is defined as the weighted average of lighted elements and the unlighted spaces between elements. The contrast is calculated as the ratio of the character luminance (luminance of character module with all elements "on") to the background luminance (luminance of character module with all elements "off"). The "off" measurement represents the amount of light reflected by the background.

Character and background luminance measurements should be taken during the day with the sun behind the sign (backlit), the sun overhead, and the sun on the sign (washout) in order to evaluate whether the minimum character luminance and contrast requirements are met. It is strongly recommended that the daytime evaluations not occur under partly cloudy conditions as the ambient light changes too rapidly to obtain accurate measurements. At night, only character luminance measurements need to be taken, since in an unlighted area the luminance of the background tends toward zero (negating the need to calculate contrast).

The luminance meter used should include the following attributes:

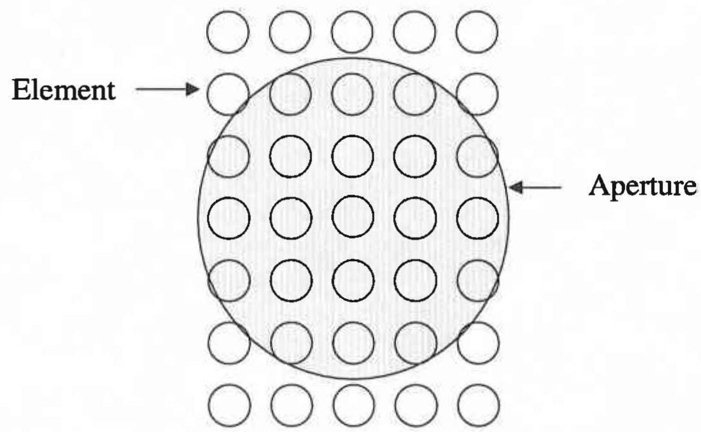
- an aperture of 1 degree,
- a continuous reading function,
- allow for mounting on a tripod, and
- a through-the-lens targeting system.

Step 1: Set Up of PCMS

Place the PCMS into position and level it by adjusting the jack stands. Turn one character module "on" and make sure all elements (35 in a 5 by 7 module) are illuminated. Measure and document the vertical distance from the road surface to the center of the character module being measured (i.e., center of the elements on the fourth row up from the bottom of the character module).

Step 2: Set Up of Luminance Meter

In order to obtain repeatable measurements, a tripod must be used to stabilize the luminance meter since slight differences in aperture placement can affect the luminance readings. Attach the luminance meter to a tripod. Set up the tripod so that the aperture of luminance meter is centered on a character module (Figure 5). To accomplish this, both the horizontal and vertical position of the meter must be established with respect to the character module being measured.



5x7 Character Module

Figure 5. Luminance Meter Aperture Relative to Character Module.

For on-axis measurements, the horizontal position of the luminance meter should be located using a surveying instrument to establish a straight line parallel to the PCMS and a perpendicular crossing line (Figure 6). Orient the PCMS so that the face of the panel is centered on the straight line and directly over the crossing line. A sight tube or other device as provided on the PCMS can be used as an aid to initial aiming efforts, but the use of surveying instruments is recommended to ensure that the luminance meter is in the correct position to record the photometric measurements.

To position the luminance meter vertically, the distance between the ground and the center of the meter aperture should be equal to the distance between the ground and the center of the character module being measured (documented in Step 1). Note that the terrain between the arrow panel and luminance meter should be relatively flat.

As seen in Figure 5, the aperture should include the entire horizontal component of the character module, but does not capture the whole vertical component. If the entire vertical length of the module was included in the aperture, a disproportionate amount of dark area would be incorporated into the measurement, underestimating the character luminance.

After the luminance meter location is finalized, measure and document the distance between the PCMS and luminance meter.

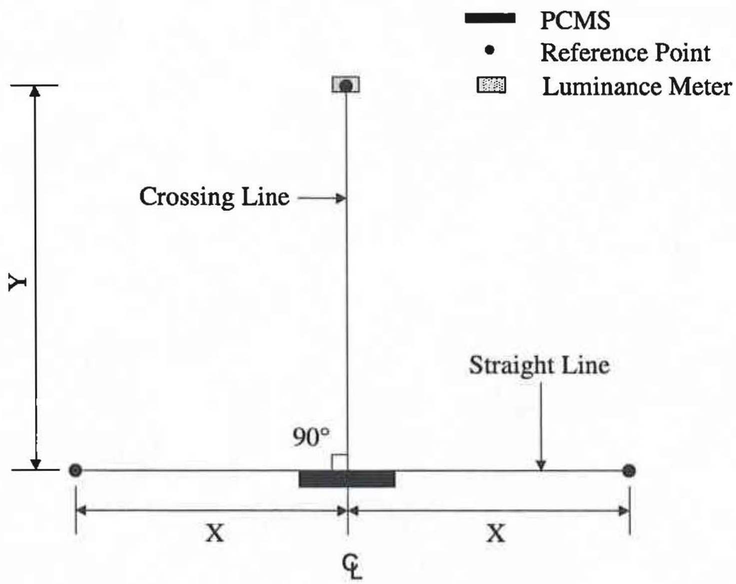


Figure 6. Horizontal Position of Luminance Meter.

Step 3: Measuring the Luminance of the PCMS

Turn the luminance meter on and check to ensure that the following settings (if available) are selected:

- units are in cd/m^2,
- preset calibration,
- absolute measuring mode, and
- continuous reading function.

Measure and record the luminance of the selected character module with the entire character module "on" (all 35 elements illuminated). Turn "off" the character module and measure the luminance of the character module with the entire character module "off." This procedure should be repeated a minimum of three times, with the "off" measurement being taken immediately after each "on" measurement. Calculate the average character luminance (average of the "on" measurements) and average background luminance (average of the "off" measurements). Note that at night in an unlighted area, the background luminance ("off" measurement) tends toward zero and thus does not need to be measured.

Step 4: Determine if the PCMS Meets the Character Luminance Requirements

Using Table 8, determine if the average character luminance is equal to or greater than the minimum on-axis requirements (i.e., meets specification).

Table 8. PCMS Character Luminance Requirements.

Time	Minimum On-Axis (cd/m^2)
Day	4000
Night	1500

Step 5: Calculating Contrast (Daytime Only)

Calculate the contrast ratio by dividing the average "on" measurement by the average "off" measurement.

Step 6: Determine if the PCMS Meets the Contrast Requirement (Daytime Only)

Determine if the calculated contrast is equal to or greater than 5 (i.e., meets the minimum requirement).

6. REFERENCES

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3. Jenkins, S. E. *Optical and Photometric Standards for Variable Message Signs.* Report Summary ARR-216. Australian Road Research Board, 1991.

4. Garvey, P. M. and D. J. Mace. *Changeable Message Sign Visibility.* Report FHWA-RD-94-077. FHWA, U.S. Department of Transportation, 1996.

5. Dudek, C. L. *Guidelines on the Use and Operation of Changeable Message Signs.* Report FHWA/TX-92/1232-9. FHWA, U.S. Department of Transportation, 1992.

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10. *Specification of the Approval of Variable Message Road Signs.* (Draft) Ministere des Transports et de la Mer, Direction de la Securite et de la Circulation Routieres, SETRA – CSTR, Edition No. 5, August 1988.

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APPENDIX

ON-AXIS PCMS PHOTOMETRIC TEST

Date: ____________________ Time: ____________________
Test Administrator: ________________________ Recorder: ______________________________
Location of Test: ____

Manufacturer: ____
Model No.: ____________________________ Serial No.: ______________________________

Condition: Sun Behind Sign (Backlit) Sun Overhead Sun on Sign (Washout) Night

Step 1: Set Up of PCMS

Vertical distance from ground to the center of the character module being measured (i.e., center of elements on the fourth row up from the bottom of the character module) ______________ ft

Step 2: Set Up of Luminance Meter

Horizontal distance between the PCMS and luminance meter ___________ft

Step 3: Measuring the Luminance of the PCMS

"On" Luminance Measurement 1 ______________________ cd/m^2 (*A*)
"Off" Luminance Measurement 1 ______________________ cd/m^2 (*B*)

"On" Luminance Measurement 2 ______________________ cd/m^2 (*C*)
"Off" Luminance Measurement 2 ______________________ cd/m^2 (*D*)

"On" Luminance Measurement 3 ______________________ cd/m^2 (*E*)
"Off" Luminance Measurement 3 ______________________ cd/m^2 (*F*)

Average Character Luminance = $(A+C+E)/3$ = ________________ cd/m^2 (*G*)
Average Background Luminance = $(B+D+F)/3$ = ____________________ cd/m^2 (*H*)

NOTE: The character luminance (*A*, *C*, and *E*) measurements should be similar. In addition, the background luminance (*B+D+F*) measurements should be similar. If one is very different, take another set of readings and incorporate them into the calculations. This would most likely occur when measuring the PCMS during the day, but could also happen at night due to transient light.

"On" Luminance Measurement 4 ______________________ cd/m^2 (__)
"Off" Luminance Measurement 4 ______________________ cd/m^2 (__)

Step 4: Determine if the PCMS Meets the Character Luminance Requirements

Is the average character luminance (*G*) _________cd/m^2 equal to or greater than the minimum on-axis requirement found in Table 1 __________ cd/m^2 (circle one)? YES NO

Table 1. PCMS On-Axis Character Luminance Requirements.

Time of Day	Minimum On-Axis (cd/m^2)
Day	4000
Night	1500

Step 5: Calculating Contrast (Daytime Only)

Contrast = $(G \div H)$ = ________ cd/m^2 (*I*)

Step 6: Determine if the PCMS Meets the Contrast Requirement (Daytime Only)

Is the calculated contrast (*I*) _________ equal to or greater than 5 (circle one)? YES NO

Step 7: Acceptance or Rejection

Does the PCMS character luminance and contrast (daytime only) pass the current specification (question in Step 4 and 6 were both answered "YES")? PASS FAIL

____

Signature of Test Administrator Date

____

Print Name of Test Administrator