Traffic Control Devices Pooled Fund Study

Analysis of Potential Need for Enlarged Pedestrian Countdown Signals From a Visibility Perspective

Final Report

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The objective of the Traffic Control Devices Pooled Fund Study (TCD PFS) is to assemble a group composed of State and local agencies, appropriate organizations and the FHWA to 1) establish a systematic procedure to select, test and evaluate approaches to novel TCD concepts as well as incorporation of results into the MUTCD; 2) select novel TCD approaches to test and evaluate; 3) determine methods of evaluation for novel TCD approaches; 4) initiate and monitor projects intended to address evaluation of the novel TCDs; 5) disseminate results; and 6) assist MUTCD incorporation and implementation of results.

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EXECUTIVE SUMMARY

The present research investigated the potential effectiveness of employing enlarged countdown pedestrian crossing signal heads, with larger symbols and numerals, to assist pedestrians with low vision (visual impairment). It did so primarily from a visibility perspective. Three questions were addressed: 1) Can existing pedestrian crossing signals be adequately detected and comprehended by pedestrians with normal vision? 2) Can existing pedestrian crossing signals be adequately detected and comprehended by pedestrians with low vision? 3) Would employing larger symbols and numerals on pedestrian countdown signals assist pedestrians with low vision?

The detectability, contrast, legibility and conspicuity of the signal indications were considered, along with the visual acuity of both pedestrians with normal vision and those with low vision. The specifications for existing pedestrian signal heads were reviewed, and predictions were made concerning how well these existing devices would perform for pedestrians with normal vision and with varying degrees of visual impairment. For pedestrians with normal vision, the predicted performance of the existing standard countdown crossing signals indicated excellent detectability distances at night and good detectability distances during the day. The predicted performance indicated excellent contrast ratios during the day, making standard sized symbols and numerals easy to comprehend. These contrast ratios were found to be too high during the night, however, contributing to numeral glare and blooming, and thereby reducing numeral comprehension to some extent. Longer crosswalk lengths tend to reduce all of the above visual performance characteristics.

The present report also reviewed the visual capabilities of pedestrians with low vision, and predicted that the performance of the existing standard countdown crossing signals would not be adequate for this segment of the population. A potential benefit of employing larger pedestrian signal heads was demonstrated, but this benefit must be weighed against increased costs and the deployment of auditory and tactile accessible pedestrian signal alternatives. In conclusion, the present report recommended that a systems engineering approach be taken in further investigation of the efficacy of employing larger pedestrian signal heads.

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DISCLAIMER

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

1.1 BACKGROUND

In urban areas pedestrian collisions with motor vehicles often result in serious injury or death. Although urban collisions between pedestrians and motor vehicles represents a small percentage of the total number of all urban motor vehicle collisions, the probability that a pedestrian/vehicle collision will result in a fatality is much higher than the probability that a vehicle/vehicle collision will result in a fatality (Chang, 2008). The urban pedestrian population is extremely vulnerable, and must be provided with adequate information when crossing a roadway in order to reduce the likelihood of a pedestrian/vehicle crash.

One of the popular pedestrian crossing signals being installed in urban environments includes the standard walking man and raised hand symbols, as well as countdown numerals to give pedestrians an indication of the time remaining before the traffic signal changes (MUTCD, 2003). This type of pedestrian crossing signal head comes in a variety of sizes and configurations, but the vast majority of these signals have medium to small-sized numerals and symbols (between 6 and 12 inches in height). An example of such a signal head is shown in Figure 1. Such symbols and numerals can appear relatively small to a pedestrian with normal vision when viewed from across a wide roadway with a total of 10 to 12 or more travel and parking lanes for motor vehicle operations. It is not certain that such a signal could be adequately detected and comprehended from such a distance by a pedestrian with low vision (visual impairment).

Figure 1: Example of a Countdown Pedestrian Crossing Signal Head in McLean, Virginia.

1.2 RESEARCH QUESTION

The objective of the present research report is to investigate the potential effectiveness of employing enlarged pedestrian crossing signal heads with larger symbols and numerals. This potential effectiveness is investigated primarily from a visibility perspective. The basic research question has three parts: 1) can the present pedestrian crossing signals be adequately detected and comprehended by pedestrians with normal vision; 2) can the present pedestrian crossing signals be adequately detected and comprehended by pedestrians with low vision, i.e. pedestrians with visual impairments; and 3) would employing larger symbols and/or numerals on pedestrian countdown signals assist pedestrians with low vision?

1.3 RESEARCH APPROACH

The present project addresses visibility issues associated with the potential of employing enlarged pedestrian countdown signals. It does not investigate auditory and tactile warnings used in accessible pedestrian signals. These supplemental signals in other sensory modalities can be of substantial assistance to pedestrians with low vision, but they are not covered in the present effort. The present project took an analytical approach to answering the questions posed above, with only a minimum of newly collected empirical data. When the project was originally conceived, there was a larger empirical component. It was originally anticipated that enlarged pedestrian signal heads would be installed on an experimental basis at a few intersections in Las Vegas, Nevada. However, during the course of the present project the experiment in Las Vegas was cancelled. Consequently the present report consists almost entirely of an analysis of information published in the technical literature and accessed from the internet. The only exception is a small amount of empirical data collected from informal tests conducted in the greater Washington, DC, area. The present report is composed of six sections: Introduction, Visual Capabilities of Pedestrians with Normal Vision, Standard Pedestrian Countdown Signals, Visual Capabilities of Pedestrians with Low Vision, Potential Benefits from Enlarged Crossing Signals, and Summary and Recommendations.

2.0 VISUAL CAPABILITIES OF PEDESTRIANS WITH NORMAL VISION

This Section explores the visual capabilities of pedestrians with normal vision in increasing order of complexity, from simple visual sensations to more complex visual perceptions. It progresses from detectability: the ability to perceive faint visual stimuli, to acuity: the ability to resolve fine differences in visual stimuli, to contrast: the ability to perceive luminance changes in different parts of the visual field, to legibility: the ability to recognize and comprehend visually presented words and numbers, to conspicuity: the ability to perceive visual stimuli as standing out from a background of visual noise and visual clutter. These capabilities are explored as they relate to pedestrian crossing signals.

2.1 DETECTABILITY

The minimum detectability of light signals is usually measured by determining the absolute threshold for the human detection of faint visual stimuli in a uniform completely dark background. The human eye is exquisitely sensitive to small amounts of light. Careful experiments on the absolute threshold for an extended luminous source of white light under optimal conditions reveal a just perceptible luminance of 0.75 x 10^{-6} candelas per square meter (cd/m^2). For extra-foveal viewing of white light, a mean absolute threshold value of 4 x 10^{-12} lumens per square meter (lm/m^2) has been determined. This value implies that a light of one candela could be seen from a distance of 16 kilometers (km), or about 10 miles, under optimal viewing conditions, consisting of full dark adaptation, a completely dark background, minimal light pollution, etc (Buser et al. 1992).

Even lower threshold values have been obtained when measuring purely scotopic (night) visual sensitivity, in terms of energy rather than photometric or radiometric flux. These values were obtained from a classical experiment conducted by Hecht et al. (1942). The measurements made by Hecht and his colleagues were for a fully dark adapted eye at 20 degrees to the right of the fovea in the most sensitive part of the retina. They were for a red colored light of 510 nanometers (nm) in wavelength, close to the maximum sensitivity for scotopic (rod) vision, in a small brief flash subtending an arc of 10 minutes in visual angle, and having a duration of 1 ms. In this case the emission of only about 90 photons was found to be sufficient to elicit human vision (one photon at 570 nm, using Planck's constant, contains 3.72 x 10^{-12} ergs of energy). When reflections and absorptions within the eye were taken into account, between 5 and 14 photons are all that were needed to fall upon the retina to produce the sensation of vision. Furthermore, since these photons were most probably spread over many rods along the surface of the retina, the probability of more than one photon landing on a single rod was extremely small. Therefore, it is believed that only one photon of light is required to excite one rod in order to trigger the visual response (Hecht et al., 1942). However, a small number of rods need to be simultaneously excited in order to overcome background neuronal noise (dark light) in the visual nervous system. When one considers that the photon is the indivisible unit of light, this exquisite sensitivity of the human eye is a true testimony to the efficacy of the evolutionary process.

In summary, the acute sensitivity of the normal human eye can detect practical luminance levels of about of 1 x 10^{-6} cd/m^2 in a completely dark environment. Under optimal conditions a flash of light containing about 100 photons, or about 4 x 10^{-10} ergs of energy, is detectable by a person with normal vision.

2.2 ACUITY

Visual acuity may be defined as the capability to discriminate small separations between objects in the visual field. Visual acuity can be measured in a number of ways, three of which are most common, the Landolt C, the Snellen Chart, and Spatial Frequency. The first two of these are closely related, since they both use optotypes, standardized visual symbols used for testing visual functions. Visual acuity can be measured in terms of the visual angle subtended in minutes of arc, the reciprocal of the visual angle, or in terms of viewing distances relative to a certain criterion for normal vision.

The Landolt C is composed of a ring with a gap, like the letter C. The gap can be oriented in any of a number of positions, usually on the top, bottom, left or right portion of the symbol, or sometimes also at intermediate positions. The observer's task is to determine where the gap is located as the overall symbol is reduced in size or contrast until the gap can be no longer seen. The stroke width and the gap separation are both equal to 0.2 times the outside diameter of the symbol. These are the same proportions as the letter C in the Snellen Chart. Depending upon a number of conditions, such as contrast and retinal illumination, the visual gap threshold measured in this way can be between 0.5 and 1.0 minutes of arc (cited in Stevens, 1951). The advantage of this method is that the observer does not have to be familiar with a particular alphabet to complete the task, as is the case with the more prevalent Snellen Chart. A variant of this method employs the ophthalmological E Chart, which uses the letter E rotated in different orientations.

The Snellen Chart consists of rows of letters of progressively smaller sizes. The chart is typically viewed from a distance of 6 meters, or 20 feet. Stroke width and gap width subtend 0.2 times the total letter height. Visual acuity is determined by the smallest row of letters that the observer can read, expressed in terms of relative viewing distances. The Snellen Chart relates to seeing small letters with high contrast, and does not necessarily predict human vision for larger objects or objects with poor contrast. Nevertheless, this method is convenient, simple to administer and easy to interpret. Therefore, the Snellen method is the most prevalent procedure used for ophthalmological screening. With this procedure visual acuity is measured as the ratio of the standard viewing distance (usually 20 ft) to the distance at which each letter of the threshold line subtends 5 min of arc, and each stroke or gap subtends 1 min of arc. Thus the standard 20/20 line on the Chart contains letters which are 8.9 or almost 9 mm high, and have gaps which are 1.8 mm across (Montgomery, accessed 2008).

The Snellen ratio compares the tested person's visual acuity with that of a "normal" person. The denominator represents the distance that the average eye can see the letters on the threshold line of the Chart. Thus 20/20 means that the person being tested can just read the standard size letters from 20 ft away. A ratio of 20/40 means that the person being tested can just read the larger line of letters that a person with 20/20 vision could read at 40 ft away. A ratio of 20/200 means that the person being tested can just read the still larger line of letters that a person with 20/20 vision could read at 200 ft away, and so on. The Snellen "normal" vision criterion of 20/20 is only a reference standard. In the population, average visual acuity for healthy young adults can be somewhat better, 20/15 or even 20/10 for certain individuals (Watt, accessed 2008).

The Spatial Frequency method uses a repeating pattern of light and dark striations to determine visual acuity. Spatial frequency is usually defined as the number of luminosity fluctuations per degree of visual angle, expressed in cycles/degree. Spatial frequency depends upon four major factors:

- The level of retinal illumination (amount of light adaptation),
- The contrast between the light and the dark portions of the striations or grating,
- The orientation of the stripes (horizontal, vertical or at an angle),
- The waveform (square wave, sinusoidal, sawtooth, etc.) of the alternating light and dark stripes.

By employing Fourier Analysis, the Spatial Frequency method enables the computation of the contrast sensitivity and the visual modulation transfer function for the human eye (Buser et al., 1992). This capability offers many advantages in terms of vision research and ophthalmological diagnosis. For relatively high retinal illumination, the contrast sensitivity function for the human eye measured in this way shows a peak at about 2 to 10 cycles/degree, and high frequency cutoff of about 50 to 60 cycles/degree, or approximately 1 min of arc (Webvision, accessed 2008).

In summary, for normal vision, human visual acuity, the ability to resolve fine differences in stimulus detail, is generally regarded to be capable of perceiving gaps, lines or gratings the size of about 1 min of visual angle.

2.3 CONTRAST

The first two visual acuity measures described above refer to high contrast recognition tasks. The Landolt C symbols or Snellen letters are in high contrast with their background, either dark on light, or light on dark. Not all visual tasks represent such high contrast situations. Once a minimum luminance of about 35 cd/m^2 has been reached, visual contrast becomes important for ease of detection and comprehension of symbols and letters. There are several different ways to define a luminance contrast ratio. For display systems it is defined as the ratio of the luminance of the brightest color (white) to the darkest color (black). In this case a contrast ratio of 5:1 means that the white area has a luminance that is 5 times that of the dark area. Human visual performance in discriminating characters and reading text of different sizes and contrasts reveals that people perform faster over a range of contrast ratios from 2:1 to 40:1. Preferred contrast ratios are in the range of 15:1 to 20:1. A minimum contrast ratio of 3:1 is sometimes allowed, but for rapid and accurate perception of symbols a contrast ratio of 20:1 is recommended (Lenovo, accessed 2008).

In the recently published Final Rule on Maintaining Traffic Sign Retroreflectivity, the FHWA specifies a minimum contrast ratio of 3:1 for white retroreflectivity divided by red retroreflectivity (FHWA, 2007). For Variable Message Signs (VMS) used for traveler information, the contrast ratio is sometimes measured differently. First the difference between the target luminance and the background luminance is computed, and that difference is then divided by the background luminance. This method of calculation is related to the Weber fraction, and takes into account the effect of the background on the difference threshold for visual discrimination. When measured in this way, for typical VMS signs used to convey roadway or transit information to travelers, either drivers or pedestrians, the luminance contrast ratios obtained are usually between 8:1 and 12:1.

In summary, luminance contrast ratios range from a minimum value of 3:1 for marginally acceptable visual performance with regards to the symbols and text on signs and signals, to recommended values of 15:1 and 20:1 for accurate and rapid perception of the symbols and text.

2.4 LEGIBILITY

For roadway signs, legibility is commonly measured in terms of a legibility index. In the United States the legibility index is expressed as the number of feet of viewing distance per inch of letter height at which a roadway sign can be read. The U.S. Manual for Uniform Traffic Control Devices (MUTCD, 2003) is based on a legibility criterion that 1 inch of letter height provides 40 feet of legibility (Section 2A.14), or a legibility index 40ft/in. Thus a sign with 8 inch lettering should be visible at a distance of 320 feet. This legibility index is designed to accommodate a person with an approximate visual acuity of 20/30. However, many States issue driver’s licenses to citizens with a corrected visual acuity of 20/40, requiring a legibility index of about 30 ft/in. Many jurisdictions are considering larger sign and letter sizes to take into account the aging driver population and the resultant increase in visual impairment (MUTCD, accessed 2008).

The United States Sign Council (USSC) has sponsored many studies on the legibility of on-premise signs for motorists who pass by them. The USSC has issued Best Practices which give methods to compute size, legibility and height criteria for on-premise signs. These criteria are dependent upon letter font, letter color, background color, illumination and letter case. However, the USSC has summarized these criteria into a legibility index “rule of thumb” of 30 ft/in. This “rule of thumb” considers the 15 percent increase in letter height needed with all upper case letters, instead of the more legible upper and lower case letters with initial capital letters (Bertucci, 2006).

In 2007 the American National Standards Institute (ANSI, 2007) published an “American National Standard for Environmental and Facility Safety Signs” (ANSI Z535.2, 2007). This standard relates to safety signs which are used to visually alert observers of potential hazards in an environment. Such environmental safety signs are distinguished from product signs and labels, which generally contain more information in a smaller format. The types of signs covered by this ANSI Standard are close in purpose and intent to roadway safety signs, and may be viewed from both a walking (pedestrian) and driving (e.g., operating a forklift or pickup truck) perspective. This Standard gives a minimum legibility index of 25 ft/in for favorable reading conditions and a recommended legibility of 12.5 ft/in for unfavorable reading conditions, like poor illumination or poor contrast ratios.

In summary, recommended legibility indices for safety signs or legible signals range from a liberal value of 40 ft/in to a conservative value of 12.5 ft/in for people with normal vision. The mean between these two extreme values is 26.3 ft/in, and the mean of all four recommended indices is 26.9 ft/in, both of which are close to the ANSI Standard legibility index of 25 ft/in for favorable viewing conditions. In the present report, this value of 25 ft/in is taken to serve as the best single estimate for the legibility index for people with normal vision.

2.5 CONSPICUITY

A sign or signal may have a sufficient luminance to be detectable in a uniform background. The observer may have adequate visual acuity to perceive the sign or signal. The sign or signal may have sufficient contrast and an adequate legibility index. Yet the sign or signal may not be seen by the observer in complex visual background consisting of distracting visual clutter, especially if the observer is not expecting to see a sign or signal at a particular location and at a particular time. The roadway or pedestrian sign or symbol may be in conflict with other visual cues in the environment, and needs to attract the observer's attention.

The problem of visual conspicuity or saliency has been subject of a number of investigations. One operational definition of a conspicuous symbol or signal is one that will be seen with near certainty (greater than 90 percent probability of detection) with a short presentation time (250 ms or less) no matter where the symbol or sign is in the visual field (Cole and Jenkins, 1978). Regardless of how it is defined, conspicuity is affected by visual scene complexity, the size, color, contrast and luminance of the sign in relation to other visual objects, as well as by the alertness, motivation and expectancy of the observer. The conspicuity distance of a sign or signal is usually considerably shorter than its recognition distance. For example, under natural driving conditions, a 30-in yellow warning sign may have a different sign recognition distance depending upon the luminance and scene complexity of the environment. This difference may exceed a factor of two times, with observed sign recognition distances ranging from 600 ft (14 min of visual angle) to 1400 ft (6 min of visual angle), as cited by Mace et al. (1984). An excellent review of the technical literature regarding the conspicuity of traffic signs in complex visual backgrounds can be found in CIE 137 – 2000 (CIE, 2000).

In summary, in complex real environments, the visual conspicuity threshold usually exceeds the visual detectability threshold by a considerable amount, possibly by a factor of 2:1 or more. This would result in an approximate halving of the sign or signal recognition or legibility distance in order to account for conspicuity factors, based on the extremely limited data cited.

3.0 STANDARD PEDESTRIAN COUNTDOWN SIGNALS

This Section reviews the specifications for standard pedestrian countdown signals. It then examines these specifications in light of the visual capabilities of pedestrians with normal vision explored in Section 2.0. The outcome of this comparison is a series of predictions of the expected performance of pedestrian signal heads meeting the minimum performance specifications as regards people with normal vision. The Section concludes with the outcome of some informal measurements made to determine compliance with some of the specifications and to validate some of the predictions.

3.1 SPECIFICATIONS

The MUTCD (2003) specifies the characteristics of Pedestrian Signal Heads (Sections 4E.01 to 4E.10). The most important parts for the present discussion are Section 4E.04 on Size, Design and Illumination of Pedestrian Signal Head Indications, and Section 4E.07 on Countdown Pedestrian Signals. These Sections specify that the Walking Person signal indication shall be white, and that the Upraised Hand and Pedestrian Countdown signal indications shall be Portland orange, and that all symbols and numerals shall be at least 150 mm (6 in) high on an opaque background. In the case of countdown numerals, the opaque background shall be black. The MUTCD also provides the following guidance: "pedestrian signal head indications should be conspicuous and recognizable to pedestrians at all distances from the beginning of the controlled crosswalk to a point 3 m (10 ft) from the end of the controlled crosswalk during both day and night." In addition this guidance further suggests that all symbols and numerals should be at least 225 mm (9 in) in cases where the pedestrian enters the crosswalk more than 30 m (100 ft) from the pedestrian signal display.

By reference, the 1985 version of the "Pedestrian Traffic Control Signal Indications" specification published by the Institute of Transportation Engineers (ITE) is also incorporated into these Sections of the MUTCD. In the present report the more recent 2004 version entitled "Part 2 – Light Emitting Diode (LED) Pedestrian Traffic Signal Modules" will be employed instead, as it refers to the more prevalent current LED implementation method (ITE, 2004). This latter ITE Performance Specification covers three sizes and four classes of pedestrian signal modules. Class 1 is for crosswalks less than or equal to 18.2 m (60 ft) in length and recommends a minimum message height to width size of 152 mm x 89 mm (6 in x 3.5 in). For crosswalks greater than 18.2 m (60 ft) in length, Classes 2-4 may be used. These three classes specify progressively larger minimum message height to width sizes, ranging from 229 mm x 134 mm (9 in x 5.25 in) to 305 mm x 190 mm (12 in x 7.5 in). This ITE Specification also provides Photometric Requirements. As in the MUTCD, the Walking Person shall be white and the Upraised Hand shall be Portland orange, but the ITE document also specifies the acceptable color regions for each color based on the 1931 CIE chromaticity diagram. In addition, the document specifies minimum luminance requirements of 2,200 cd/m^2 for the Walking Person and of 1,400 cd/m^2 for the Upraised Hand.

Although the minimum Federal symbol and numeral height requirement is 152 mm (6 in), many State specifications for purchasing pedestrian signal heads require a minimum symbol and numeral height which exceeds the MUTCD minimum. This situation also holds for minimum luminance requirements, where many State specifications require higher luminance values than the MUTCD. Table 1 shows a small sample of the values for relevant pedestrian signal head specifications from two States, the District of Columbia and the MUTCD (2003). Table 1 contains neither a sufficient nor representative sample of States or jurisdictions, so no general conclusions may be drawn from it. However, the fact that the sampled State purchase specifications uniformly exceed Federal requirements may indicate that the technology is ahead of the standards formulation process for these types of devices.

Table 1: Minimum Specifications for Pedestrian Countdown Signal Heads

Source	**Year**	**Symbol/ Numeral Height**	**Symbol/ Numeral Width**	**Walking Person Luminance**	**Raised Hand Luminance**
		mm (in)	mm (in)	cd/m^2	cd/m^2
MUTCD/ITE	2003/2004	150 (6)	89 (3.5)	2,200	1,400
California	2007	250 (9.9)	165 (6.5)	3,750	3,750
Utah	2007	178 (7)	None	5,300	3,750
Dist. Columbia	*	250 (9.9)	165 (6.5)	5,300	3,750

*- not specified

In summary, this brief review of specifications reveals that pedestrian countdown crossing signals have a range of characteristics. Depending upon the application, minimum symbol and numeral dimensions (height x width) range from 150 mm x 89 mm (6 in x 3.5 in) to 305 mm x 190 mm (12 in x 7.5 in), roughly separated by a factor of 2.0. Likewise, depending upon the symbol/numeral color, minimum luminance values range from 1,400 cd/m^2 to 5,300 cd/m^2, roughly separated by a factor of 3.7.

3.2 PREDICTED PERFORMANCE

Section 2.0 described the visual capabilities of pedestrians with normal vision. Section 3.1 reviewed some of the specifications regarding pedestrian signal heads which are currently employed. In this Section the visual capabilities of pedestrians with normal vision will be compared with the physical capabilities of current signaling devices to predict how well these devices might be expected to perform for pedestrians with normal vision.

As concerns detectability, seeing whether there is any signal present at all, or not, the present standard pedestrian countdown signal heads produce a minimum luminance of about 1.4×10^2 cd/m^2. The normal human eye can detect practical luminance levels of about of 1×10^{-6} cd/m^2 in a completely dark environment under optimal conditions. For nighttime viewing, the standard pedestrian signal indication represents a stimulus which is more than 8 log units, or 100,000,000 times, greater than the absolute threshold for normal human vision. Even though realistic viewing conditions in a real urban environment are suboptimal (e.g., competing light sources, background light pollution, imperfect dark adaptation), if a pedestrian is expecting to find a pedestrian crossing signal at a certain location, she/he should be able to detect it readily at night, and even see it from a great distance, although the symbols may be obscure and the numerals illegible.

Since the typical LED-based pedestrian signal head is composed of an array of highly directional radiators of light, and therefore represents neither a uniform extended diffuse luminous source of light, nor a single point source of light, it is difficult to predict from just how far away such a signal could be detected at night. The inverse square law could be used as a rough approximation for such a prediction at great distances, where the signal indications appear very small, and approximate a point source. According to this formulation, the intensity (illuminance or irradiance) of a point source of light falls off as the square of the distance from that source. Thus for every order of magnitude increase in the distance, there will be two orders of magnitude of reduction in intensity of the source. Since the difference between the luminance of a standard pedestrian countdown signal and the detectability threshold in the dark is 8 log units, this would translate into a predicted threshold viewing distance of about 4 log units, or 10, 000 ft, under optimal viewing conditions. Suffice it to say that the predicted nighttime detectability distance should be at least several thousand feet (2,000 to 5,000 ft) under suboptimal realistic urban viewing conditions (light pollution, imperfect dark adaptation, etc.).

In the daytime, the absolute luminance is less of a governing factor, and contrast ratio comes more into play. Once a minimum background luminance of about 35 cd/m^2 has been reached, visual contrast becomes important for ease of detection and comprehension of symbols and letters. The luminance values of typical objects in the daylight scene may range from about 50 cd/m^2 to several hundred, or even several thousand, cd/m^2. For example, the luminance of the average cloudy sky is about 2,000 cd/m^2. However the symbols and numerals of the pedestrian signal head are typically presented in an opaque black surround, and the entire signal head is usually protected by a sunshield. Furthermore, pedestrian signal heads are generally seen against a complex urban built environment, and not in the background of the open sky.

A reasonable estimate for the daylight luminance of the vertical black shaded surface surrounding the LED signal source might be 50 to 100 cd/m^2, depending to a large degree on the specular reflectance of the black surface. For the minimum signal luminance specification of 1,400 cd/m^2, such a situation would produce a contrast ratio between 14:1 and 28:1, close to the recommended range for accurate and rapid detection and comprehension of symbols and letters. Thus, under daylight viewing conditions, the predicted average contrast ratio of about 21:1 should support not only excellent detectability, but also excellent comprehension and readability as well, so long as the symbols and numerals are large enough. Whereas comprehension and readability can be negatively affected by excessive contrast between light signals and a dark background (glare), the absolute detectability threshold is not so affected. Thus, as long as an adequate contrast ratio has been achieved, the inverse square law prediction of a nighttime visibility distance of 2,000 to 5,000 ft may be used as a basis for estimating the visibility distance of pedestrian signal indications during the day, with an overall adjustment by a factor of about 0.5 for light adaptation. Therefore, daytime detectability distances for such signals should be at about 1,000 to 2,500 ft.

Nighttime contrast ratios portray a somewhat different picture. In this case, the nighttime luminance of the black surface surrounding the LED signal source might be well below 0.01 cd/m^2, producing a contrast ratio in excess of 140,000:1. On the one hand, this extreme contrast ratio is likely to enhance detectability at night, making the signal highly detectable at great distances, as was indicated earlier purely on the basis of luminance. On the other hand, this extreme contrast ratio might become a source of direct glare, making nighttime comprehension of countdown numerals difficult, particularly at large viewing distances. Such a contrast ratio might also become a source for “blooming” of the numerals, impeding nighttime comprehension to a certain degree, especially when viewed from close distances.

When the contrast ratio is within the proper range, under either daytime or nighttime viewing, the legibility distance of the pedestrian countdown numerals will depend for the most part on their size, primarily on their height, if the numeral proportions are kept reasonable. Section 3.1 revealed a range of specified minimum numeral heights from 150 mm (6 in) to 305 mm (12 in), with several other specified values in between. For people with normal vision, Section 2.4 revealed recommended legibility indices for safety signs or legible safety signals which ranged from 12.5 ft/in to 40 ft/in, with several other recommended values in between. Table 2 combines this information to show the predicted numeral legibility distances (NLDs) for various countdown numeral heights, depending upon which legibility index is chosen. Table 2 extends the range of numeral heights beyond those recommended in the present small sample of current specifications to a value of 457 mm (18 in), in order to demonstrate the predicted performance of enlarged pedestrian signal heads, with larger symbols and numerals than are now contemplated.

As was suggested in Section 2.4, the ANSI legibility index of 25 ft/in is close to the mean of the various indices shown in Table 2, and can serve as a single best estimate to predict the overall legibility distances for countdown numerals of different sizes when viewed by pedestrians with normal vision. A correction factor may be applied to these single best estimates of legibility distances (column 3) in order to account for conspicuity factors. As was suggested in Section 2.5, the conspicuity distance may be considered to be about one half of the recognition or legibility distance, which would be equivalent to a conspicuity index of 12.5 ft/in. However, a legibility index of this magnitude is already represented in Table 2, and thus the values given in column 2 can serve two purposes: 1) to represent the predicted numeral legibility distances (NLDs) based on the ANSI recommended legibility index for unfavorable reading conditions, or 2) to represent the predicted numeral conspicuity distances (NCDs), which take into account visual clutter and low pedestrian expectancy. The implication in this correspondence is that unfavorable viewing conditions can be equivalent to low conspicuity viewing conditions, a not wholly unreasonable conclusion.

Table 2: Predicted Numeral Legibility Distances (NLDs), and Predicted Numeral Conspicuity Distances (NCDs), for Various Numeral Heights, and for Various Legibility or Conspicuity Indices

Numeral Height, in	NLD or NCD, ft for 12.5 ft/in	NLD, ft for 25 ft/in	NLD, ft for 30 ft/in	NLD, ft for 40 ft/in
6	75	150	180	240
8	100	200	240	320
10	125	250	300	400
12	150	300	360	480
14	175	350	420	560
16	200	400	480	640
18	225	450	540	720

Thus column 2 in Table 2 can be used to estimate numeral conspicuity distances, and column 3 can be used to estimate numeral legibility distances, when there are few visual distractions and pedestrians are expecting to find a pedestrian countdown crossing signal on the opposite side of the controlled crosswalk. In this latter case (column 3), all of the numeral legibility distances are above 120 feet, which is equivalent the crossing distance for a pedestrian crosswalk traversing 10 motor vehicle travel or parking lanes each 12 ft wide (without a median or refuge). Consequently, for pedestrians with normal vision, there should be no legibility problem with any of the numeral heights given in Table 2, including the MUTCD minimum of 6 in, for roads of 10 motor vehicle lanes or less. The outcome for conspicuity distances is not as favorable. A numeral height of about 10 in would be required to be conspicuous to pedestrians with normal vision when crossing such wide roadways.

In summary, the predicted performance of the present standard pedestrian crossing signals for people with normal vision indicates excellent detectability distances at night and good detectability distances during the day. The predicted performance indicates excellent contrast ratios during the day, making standard sized symbols and numerals easy to comprehend. These contrast ratios may be too high at night – contributing to numeral glare and blooming, and thereby reducing numeral legibility to some extent. For numeral heights of about 9 to 10 in, comparable to those found in the Washington, DC, area, numeral legibility should be satisfactory for most roadway crossings, with legibility distances of about 240 ft for daytime viewing, but somewhat reduced legibility distances for nighttime viewing due to signal numeral glare and blooming.

3.3 LOCAL MEASUREMENTS

A series of informal measurements was made to determine compliance with some of the specifications for standard pedestrian countdown signals given above, and to validate some of the performance predictions made by a comparison of those specifications with the visual capabilities of pedestrians with normal vision. Figure 2 shows researchers making daytime measurements of the luminance of a pedestrian signal head in McLean, VA.

Figure 2: Researchers Making Luminance Measurements in McLean, VA.

Two types of instruments were used for these luminance determinations: a PR 650 spectral radiometer with a 1-degree observation spot, and an LMT L1009 luminance meter with a 1-degree spot. Luminance measurements were made for the center portion of the Raised Hand symbol from various observation distances during the day (partly cloudy weather). Luminance measurements were also made of the black opaque background surrounding both the Raised Hand symbol and the countdown numerals, from a distance of 6 ft, both during the day and at night. Table 3 shows the results of these measurements. All of the luminance measurements for the Raised Hand symbol exceeded the relevant specifications listed in Table 1, although the PR 650 measurement for the 69 ft distance did not exceed the highest relevant specification by much. The L 1009 measurement for the 6 ft distance exceeded the highest relevant specification by a factor of about two times. The average of all of the luminance measurements for the Raised Hand symbol was 4,913 cd/m^2, considerably above the highest relevant specification.

The luminance measurement for the black background was 50 cd/m^2 during the day, producing an average contrast ratio of 98:1. Such a contrast ratio is considerably higher than the predicted daytime contrast ratio of 21:1, but the measured signal luminance was considerably higher than the minimum standard value. The daytime contrast ratio for the highest luminance measured was 151:1. These contrast ratios are somewhat higher than optimal. However, during the day, although they may not represent the most comfortable contrast ratio for viewing and reading, they should not interfere with signal legibility. The highest nighttime contrast ratio was more than 750,000:1, which suggests that direct glare and blooming might interfere with numeral recognition, unless some sort of signal dimming is implemented during the night or in low ambient lighting conditions.

Table 3: Luminance Measurements for a Pedestrian Signal Head in McLean, VA

Source	Color	Instrument	Distance, ft	Time	Luminance, cd/m^2
Hand	Orange	PR650	69	Day	3,817
Hand	Orange	PR650	12	Day	4,329
Hand	Orange	L1009	69	Day	4,150
Hand	Orange	L1009	6	Day	7,536
Background	Black	L1009	6	Day	50
Background	Black	PR650	6	Night	<0.01

Informal measurements of overall signal detectability distance and numeral legibility distance were conducted on a series of pedestrian countdown crossing signals in Washington, DC. These crossing signals had LED symbols and numerals which were between 9 and 10 inches high. For these detectability measurements, a long straight stretch of Constitution Avenue containing many such pedestrian crossing signals was selected. This stretch of urban roadway was driven several times both during the day and at night. A driver with normal vision detected the farthest pedestrian signal in the view ahead, and then drove up to that signal while monitoring the vehicle odometer. The average daytime detectability distance determined in this manner was 0.3 miles, or about 1, 600 ft. The average nighttime detectability distance was 0.5 miles, or about 2,600 ft. These values compare favorably with the detectability distances predicted in Section 3.2.

For the numeral legibility distance measurements, a single pedestrian crossing signal along Virginia Avenue was selected such that it had a long straight sidewalk approach. An observer with normal vision first marked off various distances along this straight sidewalk by means of a measuring wheel. The observer then approached the pedestrian signal from the greatest marked distance, stopping at each closer marked distance to make a judgment of the numeral legibility of the crossing countdown from that distance. Such judgments were repeated both during the day, around 9 AM, and at night around 9 PM. The results are shown in Table 4. The threshold for numeral legibility was taken to be the "marginal" judgment category, making the daytime (morning) legibility distance equal to 526 ft, and the nighttime distance equal to 340 ft. These observed legibility distances were considerably higher than the predicted legibility distance of about 240 ft for a 9-in numeral height. In fact the observed legibility distances agree more closely with those calculated based upon a 40 ft/in legibility index, like the one specified in the MUTCD (2003). As indicated in the Table, the poorer performance at night was due to direct glare surrounding the countdown numerals when viewed from a large distance. Minor blooming of the numerals was also evident at night when viewed from a closer distance. The nighttime legibility was reduced by a factor of almost one half (0.6) relative to the daytime legibility distance for the same numerals. Nighttime dimming of the signal luminance to about one quarter (inverse square law) of the daytime luminance might help the situation.

Table 4: Results of Numeral Legibility Distance Measurements in Washington, DC

Viewing Distance, ft	Morning, 9 AM	Night, 9 PM
190	Sharp	Minor Blooming
249	Sharp	Very Easy
340	Very Easy	Marginal
526	Marginal	Very Difficult, Glare
647	Very Difficult	Impossible, Glare

In summary, the results of local informal measurements indicated that the observed average luminance value for the Raised Hand symbol (4,913 cd/m^2) exceeded all relevant sampled specifications. Daytime contrast ratios derived from these luminance measurements also exceeded both predicted and recommended values by a factor of 5 to 7 times. Nighttime contrast ratios were extremely high, about 750,000:1, resulting in poorer numeral comprehension at night due to direct glare and numeral blooming. Observed legibility distances exceeded predictions as well, and conformed more closely to the MUTCD legibility index (40ft/in), than to the best single legibility index based on an analysis of the technical literature (25ft/in). Average observed detectability distances were 0.3 mi (1, 600 ft) in the day, and 0.5 mi (2,600 ft), close to what was predicted. The general outcome of these local measurements confirmed that the overall performance of standard pedestrian signals should be satisfactory for pedestrians with normal vision, as had been predicted. Unfortunately, conspicuity distances were not measured in the present study, so no evidence can be offered concerning the possible predicted problem with conspicuity distances for the minimum numeral heights specified in the MUTCD.

4.0 VISUAL CAPABILITIES OF PEDESTRIANS WITH LOW VISION

This Section provides background on the incidence of blindness and low vision in the United States and internationally. It also reviews some of the more prominent types of low vision impairment and provides and indication of the incidence of these conditions in the American population. In addition it covers some of the visual acuity criteria used to define blindness and low vision both in the United States and internationally.

4.1 INCIDENCE OF BLINDNESS AND LOW VISION

Estimates of the severity of the problem of blindness and visual impairment vary considerably. Different criteria are employed in different surveys. Many consider blindness to be the complete loss of vision and no perception of light. In fact this form of complete blindness is relatively rare. Most people with visual impairments have a loss of some, but not all, of their eyesight (Vision, 2002). If one considers all levels of eyesight loss, the threat of blindness due to age-related diseases is on the increase in the United States. According to one estimate, over one million Americans over the age of 40 are blind, and this number increases to 3.4 million when the visually impaired are included (NEI, 2002). Blindness and visual impairment are estimated to cost the Federal government $4 billion annually in health benefits and lost taxable income. The number of Americans with age-related eye diseases and vision impairment is expected to double in the next 30 years as the baby-boomers age (Vision, 2002).

The American Federation for the Blind (AFB) estimates that about 10 million people in the United States are blind or visually impaired. This organization recommends using a functional limitation criterion to define two types of low vision. Severe functional limitation in seeing refers to not being able to see words and letters in ordinary print, even with eyeglasses. Non-severe functional limitation refers to having difficulty seeing words and letters in ordinary print, even with eyeglasses. By these definitions, in 1994-95, 8.1 million Americans were estimated to have functional limitations in seeing (AFB, accessed 2007). Worldwide, in 2002, more than 161 million people were visually impaired, of which 37 million were blind and 124 million had low vision (excluding refractive error, which is correctable by eyeglasses). Since much of the world’s population cannot afford eyeglasses, the actual magnitude of the global problem of functional low vision is much greater. Globally, for each blind person, 3.4 people have low vision (WHO, accessed 2008).

4.2 CAUSES OF LOW VISION AND BLINDNESS

There are four leading causes of low vision and blindness in the United States:

- ***Cataracts***. A cataract is a clouding of the lens of the eye, generally occuring with advancing age. The exact cause of cataracts is unknown, but it may be related to exposure to ultra-violet radiation from the sun, as well as to certain lifestyle factors. Treatment usually involves surgical removal of the clouded lens and replacement with an artificial intraocular lens (IOL). It has been estimated that the Federal government spends more than $3.4 billion per year on treating cataracts through Medicare (Vision, 2002). Cataracts are the leading cause of blindness in the world, and they affect nearly

- ***Diabetic Retinopathy***. Diabetic retinopathy is a complication of diabetes which affects the small blood vessels of the retina. Retinal blood vessels break down, leak or become blocked, causing a loss of vision over time. Sometimes serious damage can occur when abnormal new blood vessels grow on the retina (Vision, 2002). Diabetic retinopathy is believed to be the leading cause of blindness in industrialized countries for people between 25 and 74 years old, and affects more than 5.3 million Americans 18 years of age and older (NEI, 2002).
- ***Glaucoma***. Glaucoma is characterized by a gradual degeneration of the cells that comprise the optic nerve. Vision is gradually lost, usually starting at the periphery. Because the loss is gradual, many people with glaucoma do not realize that they have the disease until significant nerve damage has occurred. Elevated pressure levels in the fluid of the eye (intraocular pressure) seem to be related to glaucoma. Although interventions by means of medications, laser treatments and surgery have been found effective in reducing the intraocular pressure, once vision is lost to glaucoma, it cannot be restored (Vision, 2002). Glaucoma is a chronic disease which often requires long-term treatment. It is estimated that about 2.2 million Americans have been diagnosed with the disease, and another 2 million do not know that they have it (NEI, 2002).
- ***Age-related Macular Degeneration***. Age-related macular degeneration (AMD) is a disease which primarily effects sharp central (foveal) vision. Dry AMD (non-exudative) involves the formation of fatty deposits under the photoreceptor cells of the retina in its early stages, and may involve atrophy of the supportive layers under the photoreceptor cells in later stages. Wet AMD (exudative) involves the growth of tiny new blood vessels under the retina which leak, break open and may cause scar tissue. Wet AMD is the less common, but more threatening, form of AMD (Vision, 2002). AMD often results in black spots with no vision located in the center of the visual field. AMD is the most common cause of blindness and low vision in older Americans (60 years and older). More than 1.6 million Americans have advanced stages of AMD (NEI, 2002).

4.3 VISUAL ACUITY CRITERIA

The criteria for determining low vision and blindness vary in different parts of the world. In the United States blindness is defined as visual acuity with the best correction in the better eye of worse than or equal to 20/200, or a visual field that is less than 20 degrees in diameter. Visual impairment is defined as having 20/40 visual acuity or worse in the better eye, even with correction. Even people with the least amount of visual impairment by this criterion may have difficulty in daily activities. For example, citizens with a visual acuity of 20/40 cannot obtain an unrestricted driving license in most states (Vision, 2002).

The World Health Organization (WHO) has proposed the following classification criteria for visual impairment. They refer to vision in the better eye with the best possible correction:

- Category 0. Mild or no visual impairment. Visual acuity from 20/20 to 20/70.
- Category 1. Moderate visual impairment. Visual acuity from 20/70 to 20/200.
- Category 2. Severe visual impairment. Visual acuity from 20/200 to 20/400.

- Category 3. Blindness – first level. Visual acuity from 20/400 to 20/1200.
- Category 4. Blindness – second level. Visual acuity from 20/1200 to Light Perception.
- Category 5. Blindness – third level. No light perception (WHO, accessed 2008).

In summary, it has been estimated that about 10 million Americans are blind or have low vision. This represents about 3 percent of the population. In the United States blindness is defined as having a visual acuity of 20/200 or worse, and low vision is defined as having a visual acuity of 20/40 or worse. The main causes are cataracts, diabetic retinopathy, glaucoma and age-related macular degeneration. The incidence of blindness and low vision is expected to double in the next 30 years.

5.0 POTENTIAL BENEFITS FROM ENLARGED CROSSING SIGNALS

5.1 PREDICTED PERFORMANCE

In the present report, the best single estimate for a legibility index for the countdown numerals in pedestrian crossing signal heads was 25ft/in for pedestrians with normal vision (20/20) based on the literature reviewed (see Section 3.2). Table 5 shows the predicted numeral legibility distances for various numeral heights for pedestrians with normal vision (column 2), and for pedestrians with various degrees of low vision according to the different criteria reviewed in Section 4.3 above. Thus column 2 in Table 5 is a repeat of column 3 from Table 2, based on the normal legibility index. The remaining columns reveal the distance from which a pedestrian countdown indication might be comprehended for people with differing amounts of visual impairment.

For the sake of comparison, as was done for Table 2, a reference crossing distance of 120 feet will be employed, which is equivalent to the crossing distance for a pedestrian crosswalk traversing 10 motor vehicle travel or parking lanes each 12 ft wide (without a median or refuge). For 9-in high numerals, the legibility distance would be about 225 ft for a person with normal vision (20/20), making it easy to cross a 10 lane roadway (120 ft). For a person at the high end of the low vision range (mild impairment) as specified in the United States (20/40), the legibility distance would 113 ft, not quite enough to cross a 10 lane roadway. For a person at the high end of the low vision range (mild impairment) as specified in by the World Health Organization (20/70), the legibility distance would 64 ft, only enough to cross about 5 lanes. For a person at the low end of the low vision range as specified in the United States (20/200), on the boarder of being legally blind, the legibility distance would 17.5 ft, just enough to cross a one lane roadway. For a person at the low end of the low vision range as specified in by the World Health Organization (20/400), on the boarder of blindness, the legibility distance would 11 ft, not enough to cross even one lane.

Table 5: Predicted Numeral Legibility Distances (NLDs), For Various Numeral Heights, and for Various Degrees of Visual Acuity (VA)

Numeral Height, in	NLD, ft for VA=20/20	NLD, ft for VA=20/40	NLD, ft for VA=20/70	NLD, ft for VA=20/200	NLD, ft for VA=20/400
6	150	75	43	15	7.5
8	200	100	57	20	10
10	250	125	71	25	12.5
12	300	150	86	30	15
14	350	175	100	35	17.5
16	400	200	114	40	20
18	450	225	129	45	22.5

From the perspective of the reference crossing distance of 120 ft, a 6-in high numeral would be adequate to cross such a 10 lane roadway for a pedestrian with normal vision (20/20). A 10-in numeral would be required for a pedestrian at the high end of the U.S low vision range (20/40). An 18-in numeral would be needed for a pedestrian at the high end of the international low vision range (20/70). These numerals would only accommodate the high end (better vision) of the range of visual acuities which define low vision. Even an 18-in numeral would not accommodate the low end (worse vision) of the range of visual acuities which define low vision, either by the U.S. or by the international criterion. By the U.S. criterion for the high end of low vision (20/200), an 18-in numeral would only support crossing a 3 to 4 lane roadway. By the international criterion for the high end of low vision (20/400), an 18-in numeral would not even support crossing a two lane roadway. In this context it is understandable how Yee (1985) found that 25 percent of elderly drivers had difficulty reading traffic signs. Visual impairment that sometimes accompanies old age can make it difficult to read even relatively large letters and numerals on signs and signals.

Table 5 reveals that the MUTCD minimum numeral height of 6-in for crossings of less than 100 ft is adequate for pedestrians with exactly normal vision (20/20). The further MUTCD specification of a minimum numeral height of 9-in for crossings of 100 ft or more accommodates most of the range of pedestrians with normal vision (20/20 to 20/40). However, a cutoff criterion for shifting from a 6-in numeral height to a 9-in height of 60 ft, as is used in the ITE Specification (see Section 3.1), might be better than the present cutoff criterion of 100 ft, as is used in the MUTCD. Such a change would ensure covering the entire range of normal vision as defined in the U.S. It would also assist pedestrians with mild degrees of low vision. The 9-in minimum numeral height would not, however, cover the entire range of normal vision as defined internationally (20/20 to 20/70), and would be wholly inadequate for supporting pedestrians with low vision. At the low (poor vision) extremes of low vision, no matter how they are defined, a 9-in numeral height would be barely sufficient to cross a one lane roadway. Thus, as revealed in Table 5, the present 9-in pedestrian countdown signals cannot be adequately comprehended by pedestrians with low vision, and employing larger numerals on such pedestrian signals could be of assistance. Although Table 5 relates to the legibility of numerals, if the color coding is ignored, it can be used as a first approximation for discriminating the two symbols used on pedestrian crossing signals, the Walking Man and the Raised Hand, as well. The visual features that distinguish these two symbols are about the same size as the features that distinguish the individual numerals. Thus enlarging the symbols proportionately with the numerals would also be of assistance to pedestrians with low vision.

An experiment conducted by Williams et al. (2006) is relevant in this regard. These researchers employed a sample of 41 research participants with low vision (visual acuities ranging from about 20/70 to 20/300). These participants started at a distance of 200 ft away from a pedestrian crossing signal comprised of combinations of three LED symbols, a Portland orange Raised Hand, a white Walking Man and white Animated Eyes that scan left to right at one cycle per second. The Walking Man and the Raised Hand symbols were 11.2 in high. For a given stimulus configuration, the research participants walked toward the pedestrian crossing signal until they could correctly identify the symbol being displayed. The most relevant symbol for the present report is the Raised Hand, which had a mean correct recognition distance of 92 ft, with a standard deviation of 42 ft. If one considers the range of visual impairment, this outcome represents much better performance than would be predicted by Table 5. For visual impairments of this magnitude, Table 5 would have predicted a numeral recognition distance of about 28 ft for an 11-in high symbol. However, there is one important feature of the Williams et al. experiment which must be taken into account. The important distinction among the symbols, to walk or not walk, was conveyed by color coding. Thus, as long as the participants could perceive a faint light and determine its color, it was not important to decipher the details of the symbol shape or configuration. This would not be the case for comprehending uniformly colored symbols or numerals. In addition, conspicuity was not an issue, since the participants presumably knew where the signals were.

5.2 ADVANTAGES/DISADVANTAGES

Table 5 can be used to make a case for investigating the use of enlarged pedestrian signal heads for people with low vision. The LED technology exists for creating extremely large symbol and text (numeral) displays, as witnessed by the growing number of digital billboards and other digital advertising signage alongside the roadway. Off-premise digital billboards portray crisp graphic and textual information in standard formats of 14 x 48 feet that change every few seconds. Gasoline stations employ large numeral LED displays to inform motorists of the changing price of fuel. As was mentioned before, in many ways, the technology is ahead of the standards in the area of digital visual signs and signals. Thus creating enlarged pedestrian signal heads is technically possible without extensive research and development, at least on an experimental basis. The advantages to pedestrians with low vision appear evident from the present analysis, but this inference should be tested by having low vision individuals view experimental versions of countdown signals with enlarged symbols and numerals from varying distances. Such testing can be conducted with LED arrays similar to those that would be used in proposed actual pedestrian signal heads, but mounted on temporary panels without the environmentally robust housings and electronics. If such testing confirmed the possible effectiveness of enlarged pedestrian signal heads, a trade study should be undertaken to evaluate the potential advantages and disadvantages of recommending such larger signals.

The main disadvantage to enlarged pedestrian signal heads is increased cost. Although the cost of an enlarged LED signal face and mask may not represent a great increase over that of a standard one, there are numerous other factors and costs which must be considered. For example, the larger signal heads will require more electric power, larger and heavier housings and sunshields, more weight and wind loading on mounting poles, and more complex logistics for maintenance and spare parts, if enlarged signal heads are employed for wider crossings and standard signal heads are employed for shorter crossings. Thus, in his comprehensive review of design considerations for traffic signs to meet the needs of older drivers, Mace (1988) does not recommend changing the legibility index of 40 ft/in, as used in the MUTCD. He recommends that enhancements be accomplished instead by changes in symbols, color and shape codes, multiple signing and placement. Thus the conservative argument might be to leave pedestrian countdown signals as they are, and not to entertain enlarged signal heads. Furthermore, accessible pedestrian signals employing auditory and tactile cues are already being deployed for the blind and low vision segment of the population. These auditory and tactile devices can possibly serve as supplements to currently deployed countdown signals, thus obviating the need for enlarged signal heads.

On the other hand, the most liberal interpretation would be to develop an array of enlarged pedestrian signal heads to accommodate all American citizens with low vision, covering the entire range of visual acuities from 20/40 to 20/200. At the low end (poorer vision) of this range (20/400) the countdown numerals would have to be 48 in high to cross a 10 lane roadway, an obviously impractical numeral size. Thus it is not possible to accommodate all American citizens with low vision using distal countdown signals located on the opposite side of a wide roadway. In fact, with present signal heads, some pedestrians with low vision often glance quickly at the countdown signal located very close to them on the departing sidewalk to obtain an initial estimate of the remaining crossing time before stepping off the curb. Once they have initiated their crossing, however, they are not provided with any more visual signal indications, since they cannot comprehend the distal countdown numerals in front of them until they have almost arrived to the opposite curb.

Depending upon the degree of visual impairment, larger signal indications could be helpful in some situations, but a careful trade study needs to be conducted to determine the costs / benefits of installing enlarged signal heads. This trade study needs to consider the portion of the low vision community to be served, the length of the roadways to be crossed, as well as the use of other auditory and tactile accessible pedestrian crossing signal alternatives. In short, a systems engineering approach is needed to comprehensively integrate various possible technical solutions, of which possible enlarged pedestrian signal heads is only one. Such a systems engineering approach is even more critical when considering extremely wide roadways (more than 10 lanes), with high pedestrian crossing volumes, in places frequented by many visitors who are not familiar with the surroundings.

5.3 LESSONS FROM CANCELLED LAS VEGAS EXPERIMENT

Las Vegas, Nevada, is an American city with extremely wide roadways experiencing high pedestrian crossing volumes consisting of a large proportion of visitors. Thus Las Vegas was the city selected for a planned experiment to install enlarged pedestrian signal heads with 12-in high countdown numerals at a small number of intersections. Unfortunately, the planned Las Vegas experiment was cancelled. However, a site visit to Las Vegas was made to discuss issues surrounding the proposed experiment. In February of 2007, discussions were held with O. C. White, the City Traffic Engineer for Las Vegas, and with Mukund Dangeti, a researcher from the University of Nevada at Las Vegas. Their main concern was elderly pedestrians with low vision crossing wide roadways where the vehicular traffic was traveling at relatively high speeds. Figure 3 shows one of the sites that had been selected for installation of enlarged pedestrian signal heads. There is a shopping center on one side of the street and residences on the other. Many pedestrians cross this street to go to the shopping center. As can be seen in the Figure, the shopping center is on the opposite side of the street, and a different pedestrian safety countermeasure has been installed instead, but the crossing pedestrians are ignoring it.

Figure 3: Possible Site for Installation of Enlarged Pedestrian Countdown Signals in Las Vegas, NV.

Other potential installation sites were also examined in Las Vegas. One of these sites is shown in Figure 4. At this site the crossing spanned 12 lanes of traffic. Although the existing countdown pedestrian crossing signals could be comprehended from the opposite side of the roadway, the numerals were small and competed with many other visual distractions. This site represents a situation where comprehension of the numerals was adequate for persons with 20/20 vision, but the signal conspicuity was small for visitors with normal vision who might not know to expect such a signal. This site definitely represents a situation which would be extremely challenging for a pedestrian with low vision, or even for a pedestrian at the low end of the normal vision range, near the 20/40 boundary for visual impairment.

Figure 4: Another Possible Site for Installation of Enlarged Pedestrian Countdown Signals in Las Vegas, NV.

In summary, the predicted performance of present standard signal heads indicates that the countdown numerals cannot be comprehended by pedestrians with low vision from across a wide roadway. The predicted performance of enlarged pedestrian signal heads indicates that such enhanced devices could be helpful for a certain portion of the American population with low vision when crossing wide roadways. Enlarged signal heads could not, however, accommodate the entire range of low vision from a visual acuity of 20/40 to a visual acuity of 20/200. A site visit to Las Vegas, Nevada, provided some examples of unusually wide intersections which would be extremely challenging to cross for a pedestrian with low vision. A systems engineering approach is needed to integrate various technical solutions to the problem of low vision pedestrian crossings, including consideration of auditory and tactile accessible signal alternatives.

6.0 SUMMARY AND RECOMMENDATIONS

This Section provides a brief summary of the findings of the present project, and offers some recommendations for possible future action.

6.1 SUMMARY OF FINDINGS

The present research effort investigated the potential effectiveness of employing enlarged pedestrian crossing signal heads, with larger symbols and numerals, to assist pedestrians with low vision (visual impairment). Three questions were addressed: 1) Can the existing pedestrian crossing signals be adequately detected and comprehended by pedestrians with normal vision? 2) Can the existing pedestrian crossing signals be adequately detected and comprehended by pedestrians with low vision? 3) Would employing larger symbols and numerals on pedestrian countdown signals assist pedestrians with low vision?

First, the visual capabilities of pedestrians with normal vision were explored. For the pedestrian with normal vision, practical luminance levels of about of 1 x 10^{-6} cd/m^2 can be detected in a completely dark environment. For normal vision, human visual acuity, the ability to resolve fine differences in stimulus detail, was found to be about 1 min of visual angle. Luminance contrast ratios ranged from a minimum value of 3:1, for marginally acceptable visual performance, to recommended values of 15:1 and 20:1, for accurate and rapid perception of the symbols and text. As concerns legibility, a value of 25 ft/in was taken to serve as the best single estimate for the legibility index for normal vision. In the case of conspicuity, it was determined that an approximate halving of the sign or signal recognition or legibility distance would be needed in order to account for conspicuity factors.

Next, the characteristics of standard pedestrian countdown signals were reviewed. A brief examination of pedestrian signal specifications revealed minimum symbol and numeral dimensions (height x width) that range from 150 mm x 89 mm (6 in x 3.5 in) to 305 mm x 190 mm (12 in x 7.5 in). Likewise, depending upon the symbol/numeral color, minimum luminance values ranged from 1,400 cd/m^2 to 5,300 cd/m^2. These signal characteristics were then compared with the visual capabilities of pedestrians with normal vision. For pedestrians with normal vision, the predicted performance of the existing standard countdown crossing signals indicated excellent detectability distances at night and good detectability distances during the day. The predicted performance indicated excellent contrast ratios during the day, making standard sized symbols and numerals easy to comprehend. These contrast ratios were found to be too high during the night, however, contributing to numeral glare and blooming, and thereby reducing numeral comprehension to some extent. Nighttime dimming of the signal luminance to about one quarter of the daytime luminance was suggested to help the situation. The results of informal local measurements made with a small sample of pedestrian countdown signals in the Washington, DC, metropolitan area tended to confirm these conclusions. Average observed detectability distances were 0.3 mi (1,600 ft) in the day, and 0.5 mi (2,600 ft) at night, close to what was predicted. Luminance (4,913 cd/m^2 for the Raised Hand symbol) and legibility measurements (close to 40ft/in) generally exceeded expectations, based upon equipment specifications and performance predictions. In general, the overall performance of standard pedestrian signals should be satisfactory for pedestrians with normal vision.

Next, the visual capabilities of pedestrians with low vision were explored. This investigation revealed that about 10 million Americans are blind or have low vision. This represents about 3 percent of the population. The main causes are cataracts, diabetic retinopathy, glaucoma and age-related macular degeneration. In the United States blindness is defined as having a corrected visual acuity of 20/200 or worse, and low vision is defined as having a corrected visual acuity of 20/40 or worse.

Finally, the predicted performance of present standard signal heads indicates that countdown numerals cannot be comprehended by pedestrians with low vision from across a wide roadway. The predicted performance of enlarged pedestrian signal heads indicated that such enhanced devices could be helpful for a certain portion of the American population with low vision when crossing wide roadways. Enlarged signal heads could not, however, accommodate the entire range of low vision from a visual acuity of 20/40 to a visual acuity of 20/200. It was suggested that a cutoff criterion for shifting from a 6-in numeral height to a 9-in height of 60 ft, as is used in the ITE Specification, might be better than the present cutoff criterion of 100 ft, as is used the MUTCD. Such a change would ensure covering the entire range of normal vision as defined in the U.S. A site visit to Las Vegas, Nevada, provided some examples of unusually wide intersections which would be extremely challenging to cross for a pedestrian with low vision. A systems engineering approach was suggested to integrate various technical solutions to the problem of low vision pedestrian crossings, including consideration of auditory and tactile accessible signal alternatives.

In summary, on the basis of the present report, answers to the three parts of the basic research question may be deduced as follows: 1) Can the existing pedestrian crossing signals be adequately detected and comprehended by pedestrians with normal vision? YES. 2) Can the existing pedestrian crossing signals be adequately detected and comprehended by pedestrians with low vision? NO. 3) Would employing larger symbols and numerals on pedestrian countdown signals assist pedestrians with low vision? YES, but a comprehensive systems engineering approach is needed to evaluate the problem, with enlarged pedestrian signal heads being only one of the possible alternative solutions. Cost / benefit analyses need to be conducted as part of that approach.

6.2 RECOMMENDATIONS

The present report offers several recommendations based primarily upon a review of the technical literature, and to a small degree on informal local measurements:

- The present version of the MUTCD specifies a 6-in minimum countdown numeral height for pedestrian crossings of less than 100 ft, and a 9-in high minimum numeral height for crossings of more than 100 ft. This present cutoff criterion is adequate for pedestrians with exactly 20/20 visual acuity, but does not cover the entire range of normal vision, which extends up to a visual acuity of 20/40. An investigation should be undertaken of the consequences of changing this cutoff criterion to 60 ft, as is recommended in the ITE

Standard. Such a change would ensure accommodating the entire range of normal vision as defined in the U.S. It would also assist pedestrians with mild degrees of low vision.

- The present standards and specifications for signal luminance, as well as the capability of existing pedestrian signal heads, are adequate for daytime viewing, ensuring sufficient brightness and contrast to support rapid and accurate numeral legibility across moderately wide roadways for pedestrians with normal vision. However, these signal luminances are too high for nighttime viewing. Such signal luminances produce direct glare and numeral blooming, which interfere with signal legibility. Without any signal dimming, nighttime legibility distances are less than daytime legibility distances. An investigation should be undertaken of the consequences of specifying a dimming feature for nighttime operation of pedestrian signal heads. Such a feature would substantially improve the nighttime legibility of countdown signals for pedestrians with normal vision, and assist those with low vision.
- The present report demonstrated that, from a visibility perspective, enlarged pedestrian signals could be of possible benefit to a portion of the pedestrian population with low vision. A systems engineering trade study should be conducted to more comprehensively assess the potential role of enlarged countdown signals to accommodate low vision pedestrians. This study should investigate the potential role of such enlarged signals in the context of other pedestrian safety countermeasures directed at supporting blind and low vision pedestrians, including already implemented auditory and tactile accessible pedestrian signaling devices. This trade study needs to consider the portion of the low vision community to be served, the length of the roadways to be crossed, the relative need for legibility vs. conspicuity, as well as the overall benefits and costs of fielding enlarged pedestrian signal head equipment.
- If the above trade study demonstrates a potentially viable role for enlarged visual numerals on pedestrian countdown signals, then a small-scale field study should be undertaken to validate the predicted legibility benefits of such signals with a sample of pedestrians with varying degrees of low vision. The technology is in place to create enlarged countdown numerals with relative ease on an experimental basis. Such testing can be conducted with LED arrays similar to those that would be used in proposed actual pedestrian signal heads, but mounted on temporary panels without the environmentally robust housings and electronics. In a safe outdoor field testing environment, visually impaired pedestrians could view the experimental numeral displays that have been enlarged by varying amounts from different distances. In this manner, the potential benefit of enlarged countdown signals predicted in the present investigation, based on a review of the technical literature, could be confirmed or refuted by empirical data.

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