USSC **FOUNDATION**

On-Premise Electronic Message Center (EMC) Lighting Levels Phase 1 Phase 2

USSCF ON-PREMISE SIGNS / RESEARCH CONCLUSIONS

PHASE 1: On-Premise Electronic Message Center (EMC) Nighttime Dimming Research Review and State of the Practice Industry Survey

A Research Project Of The
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Background and Objectives

If an on-premise electronic message center (EMC) is not set at the appropriate light level for the given ambient brightness (i.e., the level of light around the sign), it will either be too dim, in which case it will not be optimally detectable or legible, or it will be too bright, reducing sign legibility because of overglow or blooming of the sign copy. The goal of this research was to develop appropriate EMC brightness and nighttime lighting level standards through a literature review of existing research and standards and a survey of the EMC industry.

Virtually all on-premise exterior EMC signs being installed today use light-emitting diodes (LEDs) as the source of illumination. LEDs are the current industry standard for the illumination of EMC signs, and it is likely that this will remain so until another technology is perfected that is tolerant to outdoor environmental conditions, sufficiently bright, and cost effective. The research reported here deals only with LED EMC applications, and only those LED EMCs used for on-premise signing; this publication does not deal with so-called “digital billboards” (i.e., off-premise or outdoor advertising EMCs). On-premise signage is an integral part of the wayfinding system that motorists use to safely navigate roadways (Kuhn et al., 1997), while billboards or off-premise signs are predominantly intended to advertise products or services.

The main objective of this research, hereinafter referred to as Phase 1 research, was to determine appropriate EMC brightness as a function of ambient light level (associated with either daytime and nighttime conditions), with particular emphasis on ensuring that these signs are bright enough in daylight and sufficiently dimmed at night and under dark daytime condition to optimize sign visibility. A related objective was to determine the metrics, methods, and procedures to be used to describe EMC lighting levels. To accomplish this, a review of the knowledge base maintained by the United States Sign Council (USSC) and the International Sign Association (ISA) was conducted, along with a review of recent research literature on modern (i.e., LED) EMC lighting levels, and a state-of-the-practice EMC industry survey.

The intended result of this research was an on-premise EMC brightness and nighttime lighting level standard, based on solid science and human factors engineering that would ultimately be incorporated into every EMC manufactured by reputable U.S. manufacturers, and written into local U.S. sign codes. However, as will become apparent, the research findings were not strong enough to support the development of standards that would optimize EMC lighting levels. The result of this report, therefore, includes a detailed proposal to conduct the additional research necessary to develop these standards.

Sign Association Knowledge and Research Literature Review

Overview

This section consists of a review of research and information related to on-premise EMC sign lighting level adjustment that has been created or funded by the two major U.S. sign associations, the United States Sign Council and the International Sign Association, along with the results of a literature review of recent research on current, modern EMC lighting. The latter includes any existing recommendations or proposed standards for on-premise EMC brightness. The reviews focused on three main questions:

1. How are EMC lighting levels best measured and reported?
2. What is the appropriate EMC brightness, given the ambient light level?
3. How much does an EMC need to be "dimmed," or the lighting level adjusted at night?

Lighting Levels for Highway Signs

Changeable message signs (CMS, the highway traffic control device equivalent of EMCs) are required by the Federal Highway Administration (FHWA)'s *Manual on Uniform Traffic Control Devices* to "automatically adjust their brightness under varying [ambient] light conditions" (USDOT, 2009). Two studies of CMS legibility for the FHWA (Dudek, 1991; Garvey and Mace, 1996) made precise photometric recommendations for dimming these signs based on human factors research. Garvey and Mace established a nighttime sign luminance of 30 cd/m^2 (also known as "nits") and 1,000 cd/m^2 for bright daytime viewing, while Dudek's nighttime luminance recommendations ranged from 30 to 230 cd/m^2. However, while these older studies provide useful brightness benchmarks and research methods for the development of appropriate CMS luminance levels, any modern standards for on-premise EMCs will have to be developed using current commercial sign technologies. Unfortunately, to date there have been very few published studies that have looked at this issue.

Sign Associations: The USSC, ISA, and OAAA

The United States Sign Council Foundation (USSCF), the International Sign Association, and the Outdoor Advertising Association of America (OAAA) have independently sponsored research to evaluate the brightness levels of commercial signs. The USSCF has mainly focused on the effects of sign lighting on traditional (i.e., non-EMC) on-premise sign visibility and safety. Most notable was a study to assess the possible impact of on-premise commercial sign lighting on light trespass and glare (Garvey, 2005), and its series of studies conducted by Penn State to compare various lighting technologies (Kuhn et al., 1999), compare the visibility of internally versus externally illuminated signs (Garvey et al., 2004; Garvey et al., 2010), and establish optimal nighttime brightness levels for internally illuminated signs (Garvey et al., 2008). In the 2008 study, the optimum average level of black-on-white sign brightness was 660 cd/m^2

and in the 2010 study, an internally illuminated black-on-white sign set at about the same luminance levels (700 cd/m^2) outperformed an identical externally illuminated sign.

The USSC's first venture into sponsoring EMC research was a literature review (Garvey and Pietrucha, 2005). While this report addressed numerous EMC issues, including color, size, dynamic display, font, safety, and research needs, it only briefly touched on the issue of EMC brightness and nighttime dimming. The two critical statements these researchers made related to this issue were:

1. "Some manufacturers recommend a 50 percent voltage reduction from daytime to nighttime conditions, while others suggest that at night signs should be dimmed to 20 percent of daytime brightness."
2. "The European highway community has been attempting to derive standard optical test methods for CMS for decades, but they have been slowed down by, among other factors, rapidly changing technology. Currently, there are no photometric standards to specify what aspect of the sign should be measured."

The ISA recently sponsored a research project aimed at developing EMC brightness and measurement standards for on-premise sign use (Lewin, 2009). The same researchers conducted a related project for the OAAA for outdoor advertising signs (reported in Lewin, 2008). The ISA technical report (Lewin, 2009) is summarized as a document on the ISA website titled: *ISA Electronic Message Display Brightness Guide*. This document makes the following statements:

1. "Dr. Lewin recommended the development of brightness criteria based on the Illuminating Engineering Society's (IES) well-established standards pertaining to light trespass."
2. "Footcandle [fc] measurements are taken with the sign displaying all white (maximum brightness) and then taken again with the sign switched off."
3. "If the difference is less than or equal to the Eye Illuminance Limit for the particular lighting zone where the display is located, then the display conforms to an appropriate brightness level."

An EMC illuminance of 0.3 fc (3.23 lx) was established. By knowing the measurement distance and the sign area, this can then be converted to EMC luminance (i.e., cd/m^2 or "nits"). Table 1 displays the distances that Lewin recommended for taking the illuminance reading of various size billboards (this is not for on-premise signs), and the resultant luminance standards. On average, the established illuminance level converts to approximately 300 cd/m^2 for all billboard sign sizes (Lewin, 2008). For on-premise signs, Lewin recommended three luminance levels depending on ambient lighting: 108 cd/m^2 for IES Lighting Zone 2; 323 cd/m^2 for Zone 3; and 861 cd/m^2 for Zone 4 (Lewin, 2009). Lewin, however, goes on to state: "*Before adoption of these values, Lighting Sciences Inc. advises that field evaluations of EMC signs should be conducted to verify that such levels produce the desired attention-gathering legibility and public acceptance*" [original italics].

Table 1. Recommended illuminance measurement distances and proposed luminance standards for various size billboards.

Billboard Size	Billboard Dimensions (ft)	Measurement Distance (ft)	Luminance cd/m^2
Small	11 x 22	150	300
Medium	10.5 x 36	200	342
Large	14 x 48	250	300
Very Large	20 x 60	350	330

Analysis

While Lewin states that EMC nighttime dimming has to allow for "adequate brightness for clear visibility," the basic premise behind his recommendations to both the OAAA and the ISA is that EMCs should not exceed the illuminance levels set in place by the IES to control for light trespass, even though, as Lewin wrote, "Digital signs are not the form of lighting that [the Illuminating Engineering Society of North America, IESNA's] TM-11-00 was developed to address. In fact, digital signs are specifically intended to be seen over a wide area, much of which may be remote from the sign itself" (Lewin, 2009). Lewin himself conducted no objective visibility studies to ensure that the recommended levels resulted in "adequate brightness for clear visibility," stating only: *"By experience and through field evaluation* [by Dr. Lewin's and ISA's staff members]*, luminance levels of this order have been found to produce highly acceptable legibility, conspicuity and visibility, while avoiding over-brightness"* (Lewin, 2009) [original italics].

Furthermore, the selection of an illuminance (fc) metric to define appropriate sign lighting level is a questionable decision. While it is true that illuminance meters are a good deal less expensive than luminance meters, the latter have several advantages over the former:

1. Luminance is independent of sign size and viewing distance, so, unlike with illuminance, it would not be necessary to know the sign area or establish "somewhat arbitrary" measurement distances (Lewin, 2009) when taking field measurements.
2. Luminance, not illuminance, is the photometric equivalent of brightness and therefore is the metric associated with sign visibility.
3. Luminance meters are not affected by changing ambient light such as vehicle headlamps, while illuminance meters are.
4. Depending on the level of ambient light, illuminance meters may not be sensitive enough to distinguish between measurements taken with the "sign on" and the "sign off."
5. Luminance is the standard used by EMC manufacturers in specifying sign lighting levels.
6. Both IESNA and the International Commission on Illumination (Commission internationale de l'éclairage, or CIE) specify road sign lighting in terms of luminance values (Wachtel, 2009).
7. According to 3M: "luminance is the best measure available to judge relative sign brightness" (from Wachtel, 2009).

NEMA Standards for EMC

In 2005, the National Electrical Manufacturers Association (NEMA) Standards Publication TS-2005, “Hardware Standards for Dynamic Message Signs (DMS) with NTCIP Requirements,” was published (NEMA, 2005). This document provides consensus standards for the luminance of DMS and their measurement that are consistent with the techniques and findings of earlier FHWA research conducted on CMS (Garvey and Mace, 1996) and are the standards used by the FHWA for highway CMS. While designed for highway signs, they can be applied to on-premise EMCs (not all EMC applications are “commercial”—many are at schools, municipalities, hospitals, etc.).

Measurement Area

When taking a luminance reading of a sign, “the whole of the optical test area must be fully populated with elements, must be a minimum size of 100 x 100 mm, and must contain at least 5x5 = 25 elements” (NEMA, 2005). This is illustrated in Figure 1.

Lighting Levels

The standard states that DMS “shall control pixel illumination with an automatic dimming system. The system shall adjust the light output to predefined brightness levels in accordance with ambient light conditions.” Tables 2 and 3 contain NEMA’s minimum and maximum sign luminance values for light-emitting signs (e.g., LEDs) as a function of ambient illumination from bright daylight (40,000 lx) to nighttime (less than 4 lx). Table 2 shows this for signs set on all white, and Table 3 shows these values for monochromatic “red” signs.

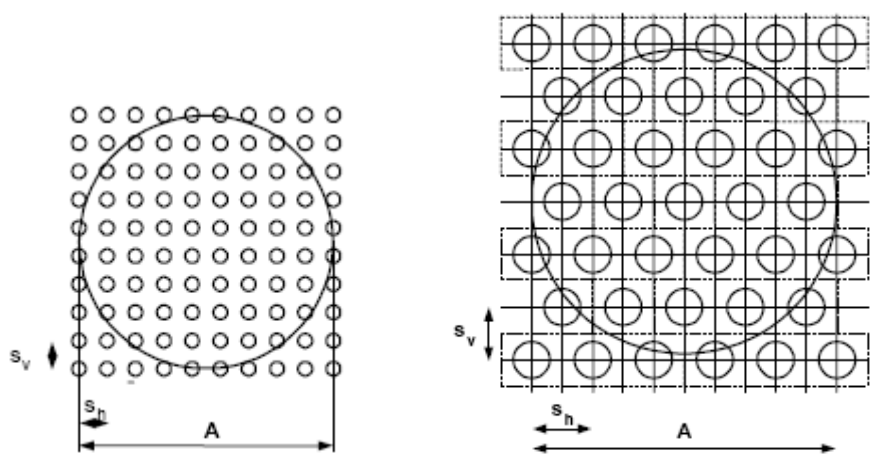


Figure 1. Positioning of the test area for EMC luminance measurement (NEMA, 2005)

Table 2. Recommended sign luminance (cd/m^2) as a function of ambient illuminance (lx) for white EMC (NEMA, 2005).

Sign Illuminance (lx)	Recommended Sign Luminance (cd/m^2)	
	Minimum	Maximum
40,000 (bright daylight)	12,400	62,000
4,000	2,200	11,000
400	600	3,000
40	250	1,250
Less than 4 (nighttime)	75	375

Table 3. Recommended sign luminance (cd/m^2) as a function of ambient illuminance (lx) for monochromatic red EMC (NEMA, 2005).

Sign Illuminance (lx)	Recommended Sign Luminance (cd/m^2)	
	Minimum	Maximum
40,000 (bright daylight)	3,100	15,500
4,000	550	2,750
400	150	750
40	63	313
Less than 4 (nighttime)	19	94

ILE Guidelines

While not specifically addressing EMCs, the Institution of Lighting Engineers (ILE) published guidelines for “establishing suitable levels for illuminated advertisements” and field measurement procedures to ensure that the signs comply with the established sign luminance guidelines (ILE, 2001). The measurement procedure specifies using a luminance meter with a 1.0-degree aperture, taking the readings at night, and ideally at right angles to the sign face and “a distance appropriate to the measuring field.” The recommended maximum luminance levels were not based on sign visibility, but rather (like Lewin’s research) on environmental zones and sign size. The goal was to establish an “acceptable degree of subjective brightness” that “can be achieved without detrimental effects to amenity and public safety.” Smaller signs (up to 10 m^2) are allowed luminance levels of 100, 600, 800, and 1,000 cd/m^2 for zones 1-4 respectively and larger signs 300, 600, and 600 cd/m^2 for zones 2-4 (assuming that no larger signs would be allowed in zone 1).

IESNA Guidelines and Recommended Practices

In the 1990s and early 2000s, IESNA published a number of guidelines and recommended practices for sign lighting (IESNA, 2001) and its measurement (IESNA, 1998), including commercial signs (IESNA, 1993). Unfortunately, these documents are not applicable to the establishment of modern EMC daytime lighting levels, nighttime dimming, or photometric measurement.

Recent Research Documents

Rensselaer Polytechnic Institute's Lighting Research Center was hired by NYSDOT to measure the luminance of standard static billboards (RPI, 2008). The purpose of this was to establish baseline maximum luminance levels that could then be applied to electronic billboards. The results were daytime and nighttime luminance maximums of 5,000 and 280 cd/m^2, respectively. In the process, RPI also established measurement techniques that could be used on both static and electronic billboards. These are very similar to those recommended by NEMA (2005) and ILE (2001):

- Take measurements at right angles to the sign.
- Luminance meter should have 1 degree or smaller aperture.
- Measure from approximately 50 ft from the sign (a 1-degree aperture will capture a 10-inch-diameter portion of the sign at this distance).
- Take measurement while the sign display is "white."

In 2009, Australia's Queensland Government published a guidance document for "roadside advertising" (Queensland Government, 2009). Although the document specifically stated: "Guidelines for the management of Category 1 electronic billboard Advertising Devices are currently under development," it did establish maximum nighttime luminance levels for illuminated advertising in general. The authors note: "The maximum luminance levels … were determined following field investigations." The maximums were again based on environment zones, with maximum sign luminance in zone 1 = 500 cd/m^2; zone 2 = 350 cd/m^2; and zone 3 = 300 cd/m^2. (They define "environment zones" in the reverse order of the IES and ILE, with zone 3 being low levels of ambient light and zone 1 being high.) The luminance measuring methodology is close to that recommended by RPI and others; however, because it was developed for static billboards, it is not reproduced in this document.

Jerry Wachtel (2011) published a paper that addressed digital billboards (DBBs) and traffic safety. Wachtel discussed the automatic "moth effect" related to the attraction of the human eye to bright lights, and the placement of billboards where they will attract the greatest driver attention (e.g., intersections, horizontal curves, etc). Wachtel also discussed possible increased distraction related to more advanced DBB technology available now, or on the horizon, including: personalized messages, interactive displays, facial recognition, and automatic license plate recognition. He also provides recommendations on how to design and place DBBs so they will be minimally distracting to drivers. These are:

1. *Control the Lighting* – The author recommended "adopting a measurement protocol and setting an upper luminance."
2. *Lengthen Dwell Time* – The author recommended ensuring "that no motorist will see more than one message change."
3. *Keep it Simple* – The author recommended ensuring "minimum standards of legibility" and reducing complexity of the message.
4. *Prohibit Message Sequencing* on a single sign, or an array of signs.

Wachtel (2009) conducted a literature review to provide "readily usable guidelines…related to the safety aspects of digital display technology for outdoor advertising signs." The bulk of this 194-page document deals with topics and research already covered in Wachtel's 2011 report discussed above.

While in its scope this report was limited to off-premise applications where the recommendations "are those that (a) have worked elsewhere, and (b) are based on sound research or science," it also contains a section devoted to the use of on-premise EMCs in which Wachtel goes beyond the project's scope to speculate, "From the traffic safety perspective, it is possible that the risk of driver inattention and distraction is higher for some on-premise signs than for some DBBs, because on-premise signs may be larger and closer to the road, mounted at elevations closer to the approaching driver's eye level, and placed at angles that may require excessive head movements. In addition, many such signs may display animation, full motion video, sound, and other stimuli." He then goes into detail about keeping on-premise EMCs out of the right-of-way and recommends that agencies might want to consider "restrictions for on-premise sign operations at least as rigorous as those for billboards, as well as restrictions on size, height, proximity to the right-of-way, and angular placement with regard to the oncoming driver's line of sight. … In addition, consideration must also be given to such signs' capacity for animation, flashing lights or other special effects, and full motion video."

In a study funded by The Signage Foundation, researchers (Hawkins et al., 2013) collected sign, crash, and roadway data on 135 digital on-premise sign locations in California, North Carolina, Ohio, and Washington, and conducted a statistical analysis of these signs and traffic safety. Using the Empirical Bayes statistical analysis method, they looked at the change in crashes before and after the signs were installed. The results: "for the 135 sites included in the analysis, there was no statistically significant change in crashes due to the installation of on-premise digital signs." The researchers concluded that "The results of this study provide scientifically based data that indicate that the installation of digital on-premise signs does not lead to a statistically significant increase in crashes on major roads."

This report was reviewed by Paul Jovanis, who was at the time a professor of civil and environmental engineering at Penn State, the director of the Transportation Operations Program at Penn State's Larson Transportation Institute, and an expert in statistical crash analysis. This is Jovanis's report: "The third author, Dominique Lord is an outstanding guy in the field; he certainly knows the method. ... I have one problem with the paper. I am not sure about the adjustments he made to the "after" estimates. Those may not be correct and we did not do those adjustments in our OAAA study (Jovanis, 2010). Lastly, I am a little concerned about the statement in the conclusions, as it is not strictly correct in statistical terms. They failed to find the effect on safety of on-premise signs; this is not the same as saying that there is no effect." Upon further reflection, Jovanis added: "It is a respectable work, similar to ours, particularly in use of EB [empirical Bayes method] for crash analysis. There were differences [between this study and Penn State's (Jovanis, 2010)]. They did not visit sites (too far away from multiple states) and did not seem as concerned about the idea of influencing zones of the signs. We spent a lot of time on these concepts. They also did not clearly identify how crashes were associated with the signs."

In a report prepared for Sydney Australia's Austroads (Roberts et al., 2013), the authors conducted a literature review on roadside advertising (on- and off-premise) and distraction, reviewed existing guidelines, and developed guidelines for the use of roadside advertising. Special attention was paid to DBBs (off premise). The researchers found that the literature supports the idea that "motion and luminance changes in digital billboards are likely to be highly effective in capturing attention involuntarily. [And billboards in general are] likely to reduce the processing capacity available for other visual information processing required for driving." However, one simulator study they cited found that "the time taken to change lanes in response to [highway] signs…was delayed by the presence of billboards, although not to a greater extent for changeable digital billboards."

For DBBs not to divert drivers' attention involuntarily, the authors suggested the following steps be taken:

- *Movement:* "Digital billboards should not display moving or flashing images (or lighting) or change in a way that produces an impression of movement."
- *Dwell Time:* "The length of time for which an image is displayed should be as long as possible to reduce the frequency of those sudden environmental changes…"
- *Transition Time:* "Transition time between images should be instantaneous…"
- *Luminance:* "Digital signs should have luminance levels no greater than any other sign and preferably lower than non-changeable signs.
- *Content*: Emotional content and "content that mimics the content of traffic signs would also be undesirable."

In an exploratory research study conducted at Penn State for the Outdoor Advertising Association of America, Jovanis (2010) conducted Empirical Bayes crash analysis at 23 DBB locations in Reading, PA, wherein the number of crashes at sites with EBBs were compared to crashes before the signs were installed. The results as described by the author are as follows: "The EB method showed that 18 sites could not be differentiated from the average crash frequency while 5 sites were significantly above the average. Analysis of the five problematic sites indicates that they had a high average crash frequency even before the signs were implemented. The implication is that the five problematic sites are inappropriately described within the EB model; additional data are needed in order for the comparison of the five sites to the average to be valid." Jovanis recommended a Phase 2, full-scale study, but that has yet to be funded.

Dikic and his colleagues (2012), funded by the Swedish Transportation Administration, evaluated the effect on visual behavior and driving performance of 12 electronic billboards recently placed on a highway in Stockholm. Forty-one subjects drove an instrumented vehicle past the signs while experimenters used an eye-tracking device and measured their driving performance. The following are the results reported by the researchers: "The visual behaviour data showed that drivers had a significantly longer dwell time, a greater number of fixations and longer maximum fixation duration when driving past an electronic billboard compared to other signs on the same road stretches. No differences

were found for the factors day/night, and no effect was found for the driving behaviour data." They concluded that "Whether the electronic billboards attract too much attention and constitute a traffic safety hazard cannot be answered conclusively based on the present data."

Summary

The literature and Sign Association reviews found no consensus on any of the three main questions posed in the present study (i.e., How to measure and report EMC lighting levels; What are appropriate EMC lighting levels under various ambient light conditions; and How much nighttime EMC lighting adjustment should occur). The review did make it clear, however that luminance is a better choice than illuminance for measuring and reporting EMC lighting (e.g., there are established standards for the luminance measurement technique, and luminance is a more appropriate metric to describe sign brightness and legibility than illuminance).

With regard to sign lighting level appropriate for ambient conditions, the research found that most existing guidelines are merely an attempt to keep signs from producing unacceptable levels of light trespass, rather than attempting to do what FHWA accomplished for CMS in the 1990's, which was to optimize lighting for sign visibility. Even with those reports that spoke about maintaining lighting at appropriate levels for drivers to read the signs (e.g., NEMA), there was no empirical research reported to support their numbers.

EMC Industry Survey

Although literature reviews can uncover a good deal of useful information, to ensure that the most up-to-date procedures and practices are captured, an EMC industry state of the practice survey was also conducted. This task was accomplished through a telephone and email survey of the EMC industry's experience with adjusting sign brightness levels. The survey instruments were developed with USSC input (Appendices A and B). Information was requested from each respondent regarding their own company's standards, practices, and any in-house or contracted research they have performed related to dimming at night. The survey instrument was designed to identify how the EMC industry determines the brightness of their signs and how they modify brightness as a function of ambient illumination.

Seventeen major U.S. EMC manufacturers were identified with the assistance of the USSC (Appendix C), and contacted by phone and email. All of the contacted manufacturers produce EMC signs that exclusively use LED technology as the source of illumination. Of the 17, twelve responded to the survey, three did not respond, one was no longer in business, and one did not manufacture signs for on-premise use. The individual responses to the surveys are provided in Appendix D. The following is a summary of those responses:

- Not surprisingly, all of the manufacturer's signs were capable of changing brightness depending on the ambient lighting level.

- Ten of the respondents stated that their signs changed lighting levels relative to the ambient lighting throughout the day and at night; one stated that it changed in a binary “day/night” fashion; and one stated that it was capable of doing both.
- Four of the respondents said their signs changed brightness “automatically” using signals sent to the sign from photo sensors on the sign face. Six respondents said they can either be set to change automatically using photo sensors, or manually, and one said they could be changed automatically, manually, or using a timer. The day/night, binary sign changed automatically using an astronomical clock.
- Of the eleven that changed brightness throughout the day based on ambient light, all of them said the sign used an equation or algorithm to do so.
- None of the respondents were willing or able to provide their algorithm or equation. Four respondents stated that their algorithm was proprietary and confidential, four did not know what the algorithm was, two said that it was based on various levels of dimming, and one provided tables (Appendix E).
- When asked how these algorithms were developed, four didn’t know, three said that this was proprietary and confidential information, and the rest stated that it was the result of a combination of undocumented research, in-house studies, standards, field tests, customer feedback, industry recommended practice, and LED manufacturer specifications.
- When asked how they measured sign brightness, most (seven) of the respondents said that all the LEDs were turned on and that luminance measurements were taken with the sign displaying a blank white field. This was referred to as the “standard bench test for EMC signs” because it put all signs on a level playing field. Of those who did not report using this method, four were non-responsive and one said they lit 75 to 80 percent of the LEDs and measured various colors.
- Most respondents did not indicate what their maximum sign luminance was; of the three who did, the range in maximum luminance for full-color signs was from 7,500 to 15,000 cd/m^2.
- For the ten respondents who reported a recommended daytime sign luminance, the levels were: 3,200; 5,000; 5,000; 5,500; 6,500; 6,500; 7,000; 7,000; 8,000; 15,000 cd/m^2.
- For the five respondents who reported a single recommended nighttime sign luminance, the levels were: 500; 750; 1,200; 1,625; and 1,875 cd/m^2. Two respondents gave ranges depending on ambient nighttime lighting: 3,000-5,000 and 108-861 cd/m^2; three did not respond and three said simply that the nighttime luminance level was “variable.”
- Only one respondent indicated that they used different nighttime dimming levels for off-premise versus on-premise EMCs. That respondent used a lower number for the former.

As with the literature and sign association reviews, the state of the practice survey did not result in a consensus of EMC lighting measurement techniques or lighting levels for various ambient conditions. While the manufacturers were on the whole very cooperative and extremely knowledgeable, one of the problems with the state-of-the-practice survey responses was the general inability and/or unwillingness to provide specific information on: (1) their sign measurement procedures, (2) their sign lighting adjustment algorithms/equations, and 3) the data behind those equations. However, while the general measurement procedures that most of the manufacturers reported using seem somewhat standard (e.g., luminance readings of white signs), the wide range in recommended daytime and nighttime luminance levels clearly show that there is no industry-wide agreement in EMC lighting levels.

Conclusions

The findings from the literature review and state-of-the-practice survey do not support specific recommendations for on-premise EMC lighting levels or measurement techniques, and therefore it is not possible at this point to begin the development of standards language for the lighting level adjustment or measurement of on-premise EMCs. Consequently, as stated at the beginning of this report, a research proposal to conduct the scientific work necessary to develop these standards was developed, and the research has been conducted. The details of the research approach and results are documented later in this publication.

References

Dudek, C.L. (1991). *Guidelines on the use of changeable message signs*. Final Report -DTFH61-89-R-00053. U.S. DOT Federal Highway Administration, Washington, D.C. 269 pgs.

Dukic, T, Christer, A, Patten, C., Kettwich, C., and Kircher, K. (2012). Effects of electronic billboards on driver distraction. *Traffic Injury Prevention*. http://www.scenic.org/storage/PDFs/eebdd.pdf

Garvey, P.M. (2005). On-premise commercial sign lighting and light pollution. *Leukos: The Journal of the Illuminating Society of North America*. Vol. 1(3), 7-18.

Garvey, P.M. and Mace, D.J. (1996). *Changeable message sign visibility*. Federal Highway Administration Report No: FHWA-RD-94-077, Final Report, 137 pgs.

Garvey, P.M. and Pietrucha, M.T. (2005). *Electronic message center research review*. United States Sign Council Foundation Final Report, 60 pgs. USSC, Bristol, PA.

Garvey, P.M., Pietrucha, M.T., and Cruzado, I. (2008). *The effect of internally illuminated on premise sign brightness on nighttime sign visibility and traffic safety*. United States Sign Council (USSC) Final Report.

Garvey, P.M., Pietrucha, M.T., Damin, S.J., Deptuch, D. (2010). Relative visibility of internally vs. externally illuminated on-premise signs. *Transportation Research Record*, No. 2149, 94-102. National Academy Press, Washington, D.C.

Garvey, P.M., Ramaswamy, C., Ghebrial, R., De la Riva, M., and Pietrucha, M.T. (2004). *Relative visibility of internally and externally illuminated on-premise signs*. Report to the United States Sign Council Foundation.

Hawkins, H.G., Kuo, P., and Lord, D. (2013). *Statistical Analysis of the Relationship between On-Premise Digital Signage and Traffic Safety*. Final Report for The Signage Foundation.

[IESNA] Illuminating Engineering Society of North America. (1998). *IESNA guide for photometric measurements of roadway sign installations*. New York: Illuminating Engineering Society of North America. IESNA LM-82–98. 9 p.

[IESNA] Illuminating Engineering Society of North America. (2000b). Chapter 29: Lighting for advertising. *IESNA Lighting Handbook*, 9th Edition. New York: Rea, M., editor.

[IESNA] Illuminating Engineering Society of North America. (2001). *IESNA recommended practice for roadway sign lighting*. New York: Illuminating Engineering Society of North America IESNA RP-19–01. 9 p.

[ILE] Institution of Lighting Engineers. 2001. *Brightness of illuminated advertisements*. 3rd edition. Rubgy (England): Institution of Lighting Engineers.

Jovanis, P.P. (2010). *Proof of Concept Comparison of Reading Sites With-Without Signs*. OAAA Final Report.

Kuhn, B.T., Garvey, P.M., Pietrucha, M.T. (1997). Model guidelines for visibility of on-premise advertisement signs. *Transportation Research Record*, No. 1605:80–87. Washington, D.C: National Academy Press.

Kuhn, B.T., Garvey, P.M., and Pietrucha, M.T. (1999). On premise sign legibility and illumination. In *1999 Compendium of Technical Papers*. Washington, DC: Institute of Transportation Engineers.

Lewin, I. (2008). Digital billboard recommendations and comparisons to conventional billboards. Available at: http://www.ies.org/E-Newsletter/pdf/Billboards.pdf

Lewin, I. (2009). Electronic message center sign luminance. Available at: www.signs.org/LinkClick.aspx?fileticket=coM8vfbNNIg%3d&tabid=745.

Lewis, D.J. (2000). Photometric requirements for arrow panels and portable changeable message signs. *AASHTO Conference Proceedings* Juneau, Alaska, pp. 215-221.

Molino, J.A., Wachtel, J., Farbry, J.E., Hermosillo, M.B., and Granda, T.M. (2009). *The Effects of Commercial Electronic Variable Message Signs (CEVMS) on Driver Attention and Distraction: An Update*. FHWA Final Report No. FHWA-HRT-09-018.

NEMA (2005). Hardware standards for dynamic message signs (DMS) with NTCIP requirements. NEMA Standards Publication TS-2005.

NEMA (2008). Standardization policies and procedures of the National Electrical Manufacturers Association. Available at: http://www.nema.org/stds/aboutstds/upload/SPP-2008_final_updated.pdf

Queensland Government (2009). *Queensland Government roadside advertising guide*: Edition 1.1" Available at: http://www.transportandmainroads.qld.gov.au

[RASC] Royal Astronomical Society of Canada (2003). Light pollution abatement site. Calgary: Royal Astronomical Society of Canada. Available at: http://www.rasc.ca/light/home.html.

Rensselaer Polytechnic Institute (2008). Technical memorandum: Evaluation of billboard sign luminances. Prepared for New York State Department of Transportation.

Roberts, P., Boddington, K. and Rodwell, L. (2013). *Impact of Roadside Advertising on Road Safety*. Austroads Publication No. AP-R420-13.

USDOT (2009). *Manual on Uniform Traffic Control Devices*. Available at: http://mutcd.fhwa.dot.gov

Wachtel, J. (March, 2011). Digital Billboards, Distracted Drivers. *Planning* (the online journal). http://www.planning.org/planning/2011/mar/

Wachtel, J. (2009). *Safety Impacts of the Emerging Digital Display Technology for Outdoor Advertising Signs*. NCHRP Final Report. Submitted Under NCHRP Project 20-7 (256). Available at: http://www.scenic.org/pdfs/NCHRP%20Digital%20Billboard%20Report.pdf

Appendix A: State of the Practice Survey Instrument (Phone interview version)

USSC/Penn State On-Premise Electronic Message Center Brightness and Dimming Survey (Phone Interview Version)

Hi, my name is Philip Garvey; I'm a researcher at Penn State doing a survey for the United States Sign Council on EMC sign brightness and dimming. I was wondering if you wouldn't mind answering a couple of quick questions. Thank you.

1. Are your outdoor EMCs that are used as On-Premise signs capable of changing brightness depending on how bright it is outside? For example daytime vs. nighttime.

If yes to question 1

2. Is there just a "day/night" switch or do they change relative to the daytime brightness, like are they brighter on a sunny day than a cloudy day?

3. Do they change automatically or manually? [ask how this is done]

If Day/Night only

4. What is the daytime brightness?

5. What is the nighttime brightness?

6. How were these numbers selected?

7. How are they measured?

8. Is this the same for all your sign models?

If they change relative to daytime brightness

4. How does the sign know what brightness to use for a given sky brightness? Is there some kind of equation or algorithm?

5. How were these numbers/algorithm selected?

6. How are they measured?

7. Is this the same for all your sign models?

If "no" to question 1

2. What is the brightness level of your sign?

3. How was this number selected?

4. How is this measured?

5. Is this the same for all your sign models?

Follow-up Question:

Are your signs also used as billboards and if so do you light them differently?

Appendix B: State of the Practice Survey Instrument (Email-version)

USSC/Penn State On-Premise Electronic Message Center Brightness and Dimming Survey (email version)

1. Are your outdoor EMCs that are used as On-Premise signs capable of changing brightness depending on how bright it is outside? For example daytime vs. nighttime.

If yes to question 1

2. Is there just a "day/night" switch or do they change relative to the daytime brightness, like are they brighter on a sunny day than a cloudy day?

3. Do they change automatically or manually or both; and how is this done?

If Day/Night only

4. What is the daytime brightness (in nits)?

5. What is the nighttime brightness?

6. How were these numbers selected (research, in house testing, etc)?

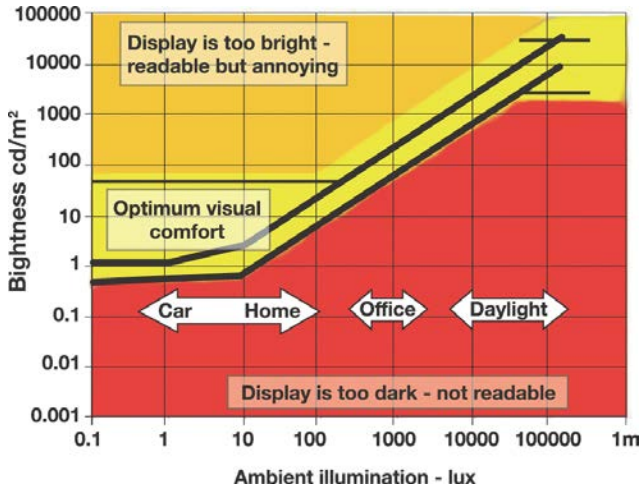
7. How are the signs measured?

8. Is the brightness the same for all your sign models?

If they change relative to daytime brightness:

4. How does the sign know what brightness to use for a given sky brightness? Is there some kind of equation or algorithm or curve?

5. Below is a graph for laptop screen brightness, do you have a similar graph that you could provide that shows brightness of your signs as a function of ambient illumination?



6. How were these numbers/algorithm/curve selected?

7. How are the signs measured?
8. Is this algorithm the same for all your sign models?
9. What are the brightest and dimmest settings (in nits if possible)?

If “no” to question 1

2. What is the brightness level of your sign?
3. How was this number selected?
4. How is this measured?
5. Is this the same for all your sign models?

Follow-up Question:

Are your signs also used as billboards and if so do you light them differently?

Appendix C: Survey Participants

Companies identified by the USSC for inclusion in the state of the practice EMC manufacturer/distributer survey. (Green highlight are those who responded; red for those who no longer exist or do not make on-premise signs; yellow for those who would not respond to the survey after numerous phone calls and emails):

1. Adaptive Displays
2. Barco
3. D3LED
4. Daktronics
5. Data-Tronic Control
6. Electro-matic
7. Grandwell Industries
8. Hi-Tech Electronic Displays
9. McKay Data Systems
10. Sign Co E.D.S. (formerly, Electronic Display Systems)
11. SmartLite Communications
12. Survey Technology Inc. (a.k.a., Agile Displays)
13. Watchfire (formerly, Time-O-Matic)
14. Wagner Zip Change
15. YESCO
16. OPTEC DISPLAYS INC.
17. Trans-Lux

Appendix D: Summary of Survey Responses

See the Survey Charts on Pages 21-26

Question	Adaptive Displays	Daktronics	Electro-matic (Makes what Wagner sells)	Wagner Zip Change (Sells what Electro-matic makes)	Grandwell Industries	Hi-Tech	Optec Displays
Are your outdoor EMCs that are used as On-Premise signs capable of changing brightness depending on how bright it is outside?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Is there just a "day/night" switch or do they change relative to the daytime brightness?	Relative	Relative	Both	Relative	Relative	Relative	Relative
Do they change automatically or manually?	Automatic	Both	Both	Both	Automatic	Both or Timed	Both
If they change relative to daytime brightness							
How does the sign know what brightness to use for a given sky brightness? Is there some kind of equation or algorithm?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
What is the algorithm?	Didn't know.	Proprietary	See supplementary tables	128 levels of dimming	Didn't know	Proprietary	Proprietary
How were these numbers/algorithm selected?	Research	In house studies/ research/ standards	Field tests and customer feedback	Didn't know	Didn't know	Proprietary	Didn't know
How are they measured?	Digitally	All white		White sign	75-80% of the sign lit using various colors	White	Lab: White sign; Field: Brightest part of sign
Is this the same for all your sign models?	No	Differ between full color and monochrome			No	Proprietary	

Question	Adaptive Displays	Daktronics	Electro-matic (Makes what Wagner sells)	Wagner Zip Change (Sells what Electro-matic makes)	Grandwell Industries	Hi-Tech	Optec Displays
What is the maximum brightness? In cd/m^2			Monocrome: 1,000; Color: 15,000		8-12,000		
What is the daytime brightness? In cd/m^2	6,500	Regulatory Standard RGB - 5,000	90-100% of max	5,000	Minimum: 3,200-3,600	5500 minimum	6,500
What is the nighttime brightness? In cd/m^2	Variable	Regulatory Standard RGB - 500	12.5% of max (1,875)		1,200	Variable	20-30% of daytime
Are your signs also used as billboards and if so do you light them differently?	No difference	No difference	No difference			No difference	Lower lum for Billboards

Question	Sign Co E.D.S. (Electronic Display Systems)	Solar Technology (Agile Displays or Dynamic Sign Marketing)	Trans-Lux	Watchfire (Time-O-Matic)	YESCO
Are your outdoor EMCs that are used as On-Premise signs capable of changing brightness depending on how bright it is outside?	Yes	Yes	Yes	Yes	Yes
Is there just a “day/night” switch or do they change relative to the daytime brightness?	Relative	Relative	Relative	Day/Night	Relative
Do they change automatically or manually?	Automatic	Automatic	Both	Automatic Astronomical	Both
If they change relative to daytime brightness					
How does the sign know what brightness to use for a given sky brightness? Is there some kind of equation or algorithm?	Yes	Yes	Yes	N/A	Yes
What is the algorithm?	256 levels of dimming	Proprietary	Didn't know	N/A	Proprietary
How were these numbers/algorithm selected?	Didn't know	Proprietary	Based on provided specs from LED manufacturer	In house testing, customer feedback, industry recommended	Proprietary
How are they measured?	White sign	In nits		Luminance Meter with sign "White"	White sign
Is this the same for all your sign models?		Yes	No		Yes

Question	Sign Co E.D.S. (Electronic Display Systems)	Solar Technology (Agile Displays or Dynamic Sign Marketing)	Trans-Lux	Watchfire (Time-O-Matic)	YESCO
What is the maximum brightness? In cd/m^2			7,500		
What is the daytime brightness? In cd/m^2	8,000			7,000	7,000
What is the nighttime brightness? In cd/m^2	3,000-5,000			750	108-861 depending on ambient (4.6 to 12.3% of daytime)
Are your signs also used as billboards and if so do you light them differently?		No difference	No difference	No difference	No difference

Question	Barco (Does not make on-premise signs)	D3LED (No Response)	Data-Tronic Control (No Response)	McKay Data Systems (No longer exists)	SmartLite Communications (No Response)
Are your outdoor EMCs that are used as On-Premise signs capable of changing brightness depending on how bright it is outside?					
Is there just a “day/night” switch or do they change relative to the daytime brightness?					
Do they change automatically or manually?					
If they change relative to daytime brightness					
How does the sign know what brightness to use for a given sky brightness? Is there some kind of equation or algorithm?					
What is the algorithm?					
How were these numbers/algorithm selected?					
How are they measured?					
Is this the same for all your sign models?					

Question	Barco (Does not make on-premise signs)	D3LED (No Response)	Data-Tronic Control (No Response)	McKay Data Systems (No longer exists)	SmartLite Communications (No Response)
What is the maximum brightness? In cd/m^2					
What is the daytime brightness? In cd/m^2					
What is the nighttime brightness? In cd/m^2					
Are your signs also used as billboards and if so do you light them differently?					

Appendix E: Electro-matic Detailed Dimming Response

Table 1: Manual Brightness settings table with respective brightness of the LED display

Set the value in our software	Value	Brightness of sign	Notes
From 1-15	N/A	100%	This is a special function that keeps the display at full brightness intensity. The minimum brightness value of the sign is 16.
16	12.5%	12.5%	It is linear in degree of brightness from value 16 to 128
32	25.0%	25.0%	
64	50.0%	50.0%	
96	75.0%	75.0%	
128	100.0%	100.0%	

If “AUTO” is chosen, the display utilizes light sensors built into each face of the display. The sensor will automatically adjust the display on a linear basis based on the ambient light available at each face of the display. The table below details the brightness of the sign when the “AUTO” dim feature is chosen and depicts the brightness based on the prevailing weather or time of day.

Table 2: Sample for external environment and sign’s brightness.

Sample for external environment	Brightness of sign
Full darkness	12.5%
Cloudy	50-60%
Partly cloudy	70-80%
Sunshine	90-100%

We express all ratings in percentages of full brightness. This is done because if all other settings are set for maximum, then this will be the percentage of the display’s maximum. But if we have utilized the half brightness control or the system setting reduction of maximum brightness, then the percentage will be of this new maximum value.

PHASE 2:
The Development of On-Premise Electronic Message Center (EMC) Lighting Levels and Measurement Techniques

A Research Project Of The
UNITED STATES SIGN COUNCIL FOUNDATION

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Background and Objectives

Research conducted by Penn State's Thomas D. Larson Pennsylvania Transportation Institute (Larson Institute) for the United States Sign Council Foundation (USSCF) found no consensus on lighting measurement techniques or optimal lighting levels for on-premise EMCs (electronic message centers) in either the research literature or commercial EMC industry practices, nor were any national standards for EMC lighting levels identified (Garvey, 2015). The results of that research can be summarized as follows:

1. The USSCF, the International Sign Association (ISA), the Outdoor Advertising Association of America (OAAA), the National Electrical Manufacturers Association (NEMA), Australia's Queensland Government, and New York State Department of Transportation (NYSDOT) have all independently sponsored research to evaluate the brightness levels of commercial signs.
    a. The USSCF's research, using traditionally illuminated (non-LED) signs, recommended nighttime luminance levels around 700 cd/m^2 (Garvey et al., 2008).
    b. The ISA and OAAA's research established 3.23 lx as the optimal nighttime illuminance (equivalent to about 300 cd/m^2, depending on illuminance measurement distance) for LED billboards, and for on-premise EMCs from 108 to 861 cd/m^2 depending on ambient light levels (Lewin, 2008; 2009).
    c. NEMA's minimum and maximum sign luminance values for light-emitting signs (e.g., LEDs) are also a function of ambient illumination (from bright daylight to nighttime) and range from a maximum daytime sign luminance of 62,000 cd/m^2 to maximum nighttime sign luminance of 375 cd/m^2 for full color EMCs (NEMA, 2005; 2008).
    d. The maximum nighttime luminance levels established by Australia's Queensland Government (for standard billboard signs) were based on Environment Zones as well, with maximum sign luminance in high-brightness zones set at 500 cd/m^2 and in low-brightness zones set at 300 cd/m^2 (Queensland Government, 2009).
    e. New York State DOT research, conducted by Rensselaer Polytechnic Institute's Lighting Research Center, recommended daytime and nighttime luminance maximums of 5,000 and 280 cd/m^2, respectively (RPI, 2008).

Virtually all on-premise exterior EMC signs being installed today use light-emitting diodes (LEDs) as the source of illumination. LEDs are the current industry standard for the illumination of EMCs, and it is likely that this will remain so for the near future, until another technology is perfected that is tolerant to outdoor environmental conditions, sufficiently bright, and cost effective. The research reported here deals only with LED EMC applications, and only those LED EMCs used for on-premise signing; not so-called "digital billboards" (i.e., off-premise or outdoor advertising EMCs). On-premise signage is an integral part of the wayfinding system that motorists use to safely navigate roadways (Kuhn et al., 1997), while billboards are predominantly intended to advertise products or services.

It is clear from the findings noted above that to optimize the lighting of these signs during daytime hours and at night, EMC lighting levels must be adjusted as a function of ambient light level. Most in-use EMCs have built-in methods of automatically adjusting brightness output; however, the procedures for measuring EMC light levels and the recommended levels vary widely and are not supported by empirical, independent, human factors data. This has led to complaints of EMCs being overly bright, primarily at night.

The objective of the present research was to begin addressing this situation by developing, through original test track human factors research that heretofore had not been performed, EMC lighting levels that optimize nighttime sign lighting from the perspective of a motorist on a roadway who is viewing the EMC, and to develop a standard light level testing procedure.

Establishment of these appropriate lighting levels based on research is a critical component of achieving EMC sign visibility and legibility. If an on-premise EMC is not set at the appropriate light level for the given general ambient brightness (e.g., daytime, nighttime, dusk, or dawn), it will either be too dim, in which case it will not be optimally detectable or legible, or it will be too bright, reducing sign legibility because of overglow or blooming of the sign copy. The goal of this research was to develop appropriate EMC brightness and nighttime lighting level standards through said research.

Task 1: Development of a Standard On-premise EMC Light Level Measurement

Overview

The objective of this task was to develop a consistent, accurate, and easy-to-follow method to field-measure light levels emitted by on-premise EMCs. These measurement techniques were based on the findings of Garvey (2015), which concluded that while it is true that illuminance meters are less expensive than luminance meters, the latter have several advantages over the former:

1. Luminance is independent of sign size and viewing distance, so, unlike with illuminance, it is not necessary to know the sign area or establish “somewhat arbitrary” measurement distances (Lewin, 2009) when taking field measurements.
2. Luminance, not illuminance, is the photometric equivalent of brightness and therefore is the metric associated with sign visibility. According to the 3M Corporation: “luminance is the best measure available to judge relative sign brightness” (Wachtel, 2009).
3. Luminance meters are not influenced by changing ambient light levels such as vehicle headlamps, while illuminance meters are.
4. Depending on the level of ambient light, illuminance meters may not be sensitive enough to distinguish between measurements taken with the “sign on” and the “sign off,” which is necessary when using illuminance meters to measure sign output.

5. Luminance is the de facto standard used by EMC manufacturers in specifying sign lighting levels.
6. Both the Illuminating Engineering Society of North America (IESNA) and the International Commission on Illumination (Commission internationale de l'éclairage, or CIE) specify road sign lighting in terms of luminance values (Wachtel, 2009).

Procedure

Based on the above considerations, luminance was selected as the measurement metric. A Minolta LS-110 luminance meter was used to measure EMC luminance. NEMA (2005) recommended that when taking luminance readings of an LED sign, "the whole of the optical test area must be fully populated with elements, must be a minimum size of 100 x 100 mm, and must contain at least 5x5 = 25 elements" (NEMA, 2005, illustrated in Figure 1). This is the same technique used by Garvey and Mace (1996) for the measurement of highway Changeable Message Signs for the Federal Highway Administration and by Garvey (2005) to study the possibility of on-premise signs' impact on light pollution.

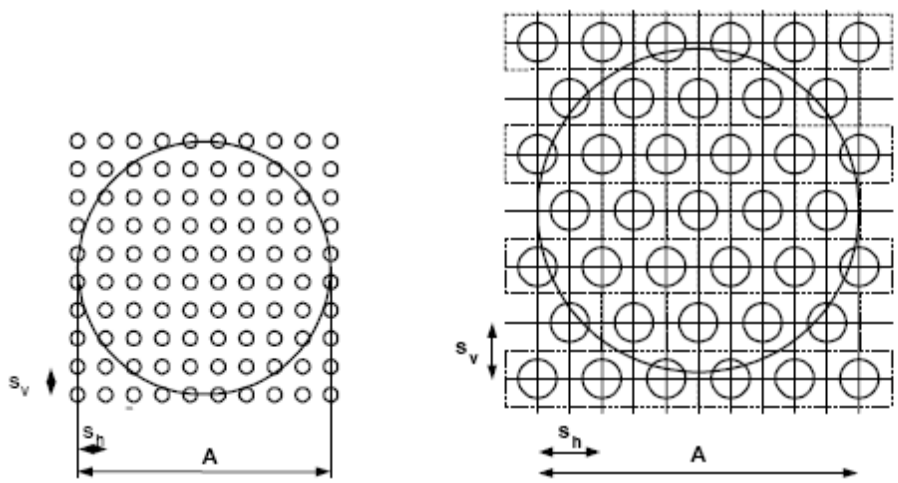


Figure 1. Positioning of the test area for EMC luminance measurement (NEMA, 2005).

With the assistance of the USSC and its members, three full-color EMCs designed for on-premise use were obtained for testing purposes, two were purchased from Innovision, and a third was donated by Daktronix (there were unresolvable technical problems with the Daktronix sign early in the research, so the results from that sign are not reported here). The two remaining signs used an RGB design to provide full-color (i.e., each "pixel" consisted of a cluster of three LEDs: one red, one green, and one blue). The signs were 54.25 inches tall by 67.00 inches wide. One sign had 16 mm inter-pixel spacing and the other 20 mm. Access to the signs' controllers allowed them to be changed to display an all-white image, recommended in several proposed light measurement methods (Garvey, 2015), and for the signs to be

turned on and off and varied in brightness. The signs were mounted on a straight, flat section perpendicular to the roadway at the Larson Institute's full-scale test track facility (Figure 2).

Figure 2. Placement of signs at the Larson Institute's full-scale test track facility.

Results

The luminance meter was set at a distance of 360 ft in front of each sign at the height of the signs' centers and aligned with the signs. The signs were measured with all the LEDs illuminated under a "white sign" condition. All measurements were taken at night in a dark setting. Multiple luminance measurements were taken across the sign faces under various manufacturer-set, sign-brightness percentage levels ranging from 1 to 100 (Table 1).

Table 1. Sign luminance (cd/m2) – Levels selected for testing are highlighted in yellow.

Percentage	**16 mm**	**20 mm**
100	6700	3770
95	6380	3570
90	6000	3400
85	5700	3200
80	5400	3000
75	5000	2820
70	4700	2620
65	4400	2450
60	4050	2260
55	3700	2065
50	3400	1890
45	3070	1700
40	2750	1500
35	2400	1320
30	2050	1125
25	1750	950
20	1380	760
15	1035	560
10	710	390
9	625	340
8	550	300
7	500	270
6	410	225
5	350	195
4	285	150
3	240	120
2	150	75
1	100	45

Task 2: Human Factors Study

Overview

The objective of this study was to develop EMC lighting levels that optimize sign lighting from the perspective of a motorist who is viewing the EMC. Specifically, licensed drivers were recruited to view two EMCs under nighttime conditions at the Larson Institute's test track and to rate the signs' brightness levels on a scale ranging from Too Dim to Too Bright (Appendix A).

Test Site and Apparatus

The test site was the Larson Institute's Bus Research and Testing Facility. The 5,042-foot-long, oval track is located four miles from the Larson Institute's offices. The observation vehicle was a 2006 Dodge Stratus. The two signs and their mounting were described above.

Subjects

The subjects ranged in age to represent the U.S. driving population. An equal number of males and females were recruited. Forty-eight subjects participated in the research.

Procedure

The subjects were tested in pairs. They were seated in the rear of the test vehicle and driven to a point 360 ft in front of the signs, where they then moved to the front seats of the car to view the signs. The subjects were then shown a series of eight sign-color conditions (four per sign). The conditions were the same for both signs (Figure 3), containing two mixed-case words with 12-inch capital letter heights, using the Arial Bold font. The words on the signs were there to aid the subjects in their subjective impressions of sign brightness; they were not required to read the words, as this was not a sign legibility task.

Figure 3. Sign color combinations.

The signs were varied in luminance from low to high or from high to low (Table 2). The subjects were told that the goal of the study was to try to find the best lighting level for storefront electronic (or LED) signs. All subjects were shown a practice sign to familiarize them with the task. Once the subject was exposed to a sign at a certain brightness level, they were asked to mark on their answer sheets their impression of the brightness. There were scales on the answer sheets that ranged from Too Dim to Too Bright, with Just Right in the middle. The participants were told to place an “X” where they thought a particular sign seemed to them. They were told that while they might be able to read a very bright sign, if it seems glary, or is in any way annoying because it seemed too bright to them, they should mark it as Too Bright. On the other hand, while they might be able to read a very dim sign, if it was a bit of a struggle or if they thought that being brighter might help them find or read the sign, then they should mark it as Too Dim. Because there were two people doing the same task at the same time, they were instructed to make sure that their responses were their own and that they did not influence the other subject by making any oral comments or any kind of remark aloud, but rather to silently place an “X” on the scale. The session lasted approximately one hour for which the subjects were paid $50.00.

Table 2. Sign luminance test conditions (cd/m2).

16 mm	20 mm
1380	1320
1035	1125
710	760
350	340
100	45

Results

Statistical Analysis

The Pearson chi-square test was used to determine if there were statistically significant differences between the two signs under the five brightness levels and four color conditions. The null hypothesis of the chi-square test is that there is no relationship between the two signs. If the null hypothesis is not accepted, then there is a statistically significant relationship between the two signs. For the purposes of analysis, the scale (Appendix A) was divided into three equal segments, with subject X-marks falling into one of three categories: Too Dim, Just Right, and Too Bright, the values were defined as ordinal variables. The software SPSS 22 was applied in this analysis.

Overall Comparison of Sign Brightness

With the Pearson chi-square X^2= 5.392 and the two-sided probability associated with Pearson chi-square (p-value) = 0.067, the null hypothesis that there is no relationship between the two variables could not be rejected. (A significant p-value of 0.05 was selected for all analyses, 0.067 is larger than 0.05.) Therefore, the distribution of brightness for the two signs is not different; that is to say, the two signs produced the same subject response as a function of sign brightness.

Overall Comparison of Color Combinations

With the Pearson chi-square X^2= 222.086 and the two-sided probability associated with Pearson chi-square (p-value) < 0.001, the null hypothesis that there is no relationship between the two variables was rejected. That is to say, the sign luminance levels that the subjects thought were Too Dim, Just Right, and Too Bright varied depending on color combination. This was true for both signs.

Individual Comparisons of Sign Brightness and Color Combinations

Because the results differed as a function of sign color, additional analyses were conducted to determine the optimal luminance level for each sign and each color combination condition (a total of eight analyses). Optimal luminance was defined as the level that produced a combination of the highest

percent of Just Right responses and the lowest percentage of Too Bright and Too Dim. Where there were conflicts, or where there were non-significant differences between luminance levels with the highest percentage of Just Right responses, the lowest level of Too Bright was given greater weight. This is because while Too Dim might result in an observer not being able to read a sign, Too Bright might result in the more serious conditions of either disability or discomfort glare, where the brightness of a sign might make it more difficult to see other objects or would be uncomfortable to view, respectively.

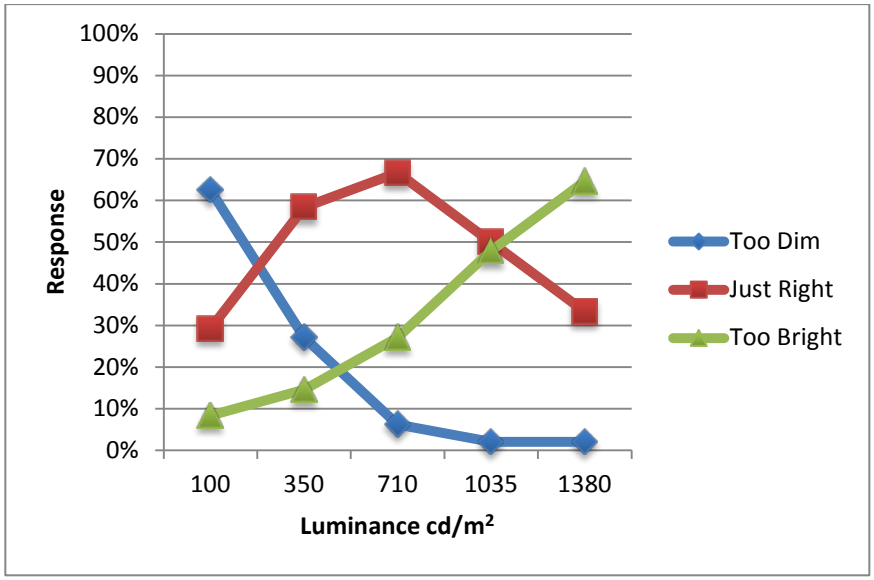
Condition One - White (illuminated) background with Black (non-illuminated) words:

The results of the statistical analyses showed that 100 and 45 cd/m^2 were significantly too dim and 1,380 and 1,320 cd/m^2 were significantly too bright, with p-values less than 0.001. Although there was no significant difference between the 350 and 710 cd/m^2 and the 340 and 760 cd/m^2 reading results, as the 350 and 340 cd/m^2 levels resulted in significantly fewer Too Bright responses, they were deemed to be the optimal level for the Condition One color scheme (see Figure 4).

Condition Two - Black (non-illuminated) background with White (illuminated) words:

The results of the statistical analyses showed that 100 and 45 cd/m^2 were significantly Too Dim with p-values < 0.001, and 1380 and 1320 cd/m^2 were significantly Too Bright with p-value < 0.002. Again, as in Condition One, there was not a significant difference between the 350 and 710 cd/m^2 and the 340 and 760 cd/m^2 results, but the 710 and 760 cd/m2 levels resulted in the highest percentage of Just Right responses; therefore, these reading results were deemed to be the optimal level for the Condition Two color scheme.

Helena Forgan



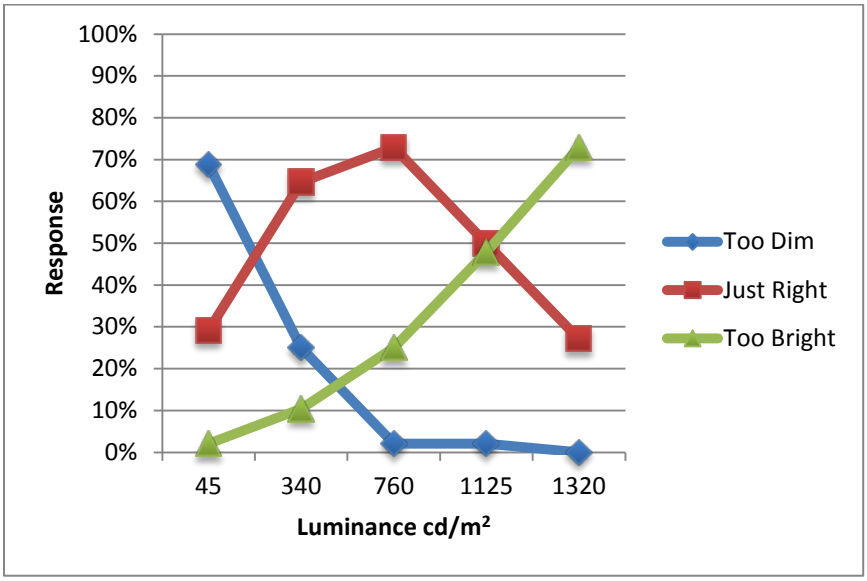
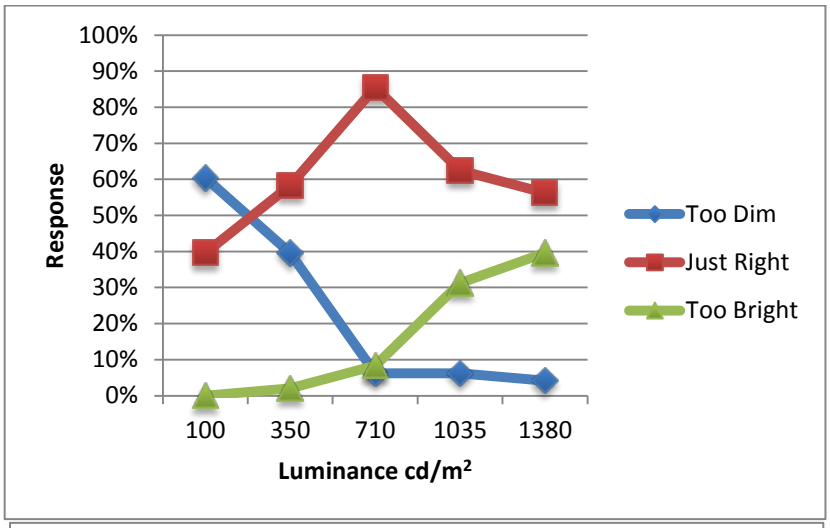


Figure 4. Condition One results.



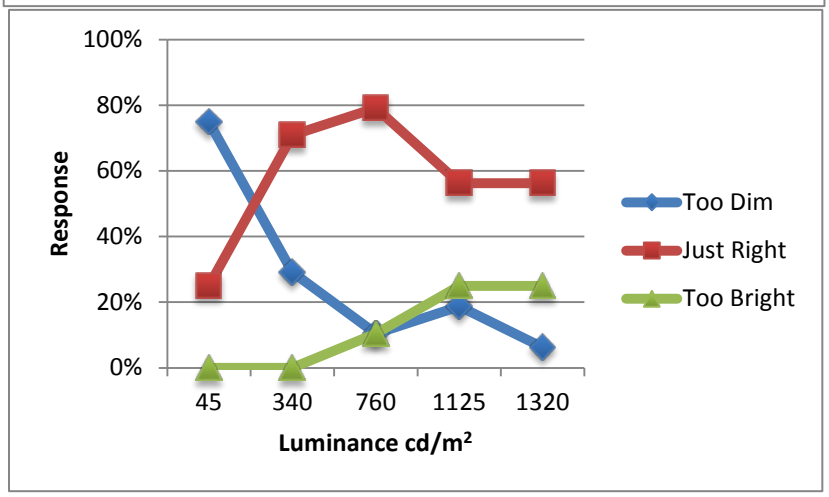


Figure 5. Condition Two results.

Condition Three - Black (non-illuminated) background with Red (illuminated) words:

The results of the statistical analyses showed that 100 and 45 cd/m^2 were significantly Too Dim with p-value less than 0.001. A majority of test subjects found a broad range of lighting levels Just Right in Condition Three, including the upper lighting levels of 1035/1125 cd/m^2 and 1380/1320 cd/m^2. Because the 350 and 340 cd/m^2 levels had a high level of Just Right responses coupled with some of the lowest levels of Too Bright responses in Condition Three, the 350 and 340 cd/m2 reading results were deemed to be the optimal level for the Condition Three color scheme, by a narrow margin.

Larned Harney

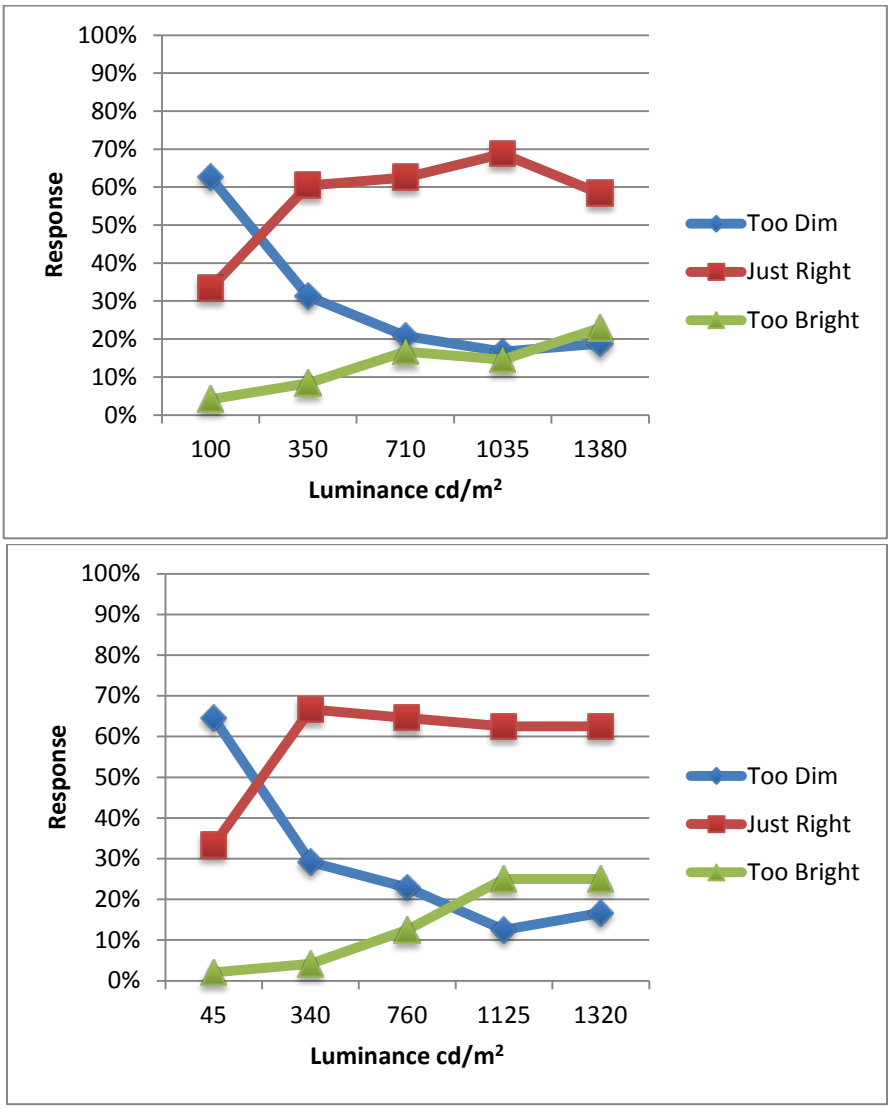


Figure 6. Condition Three results.

Condition Four - Red (illuminated) background with Yellow (illuminated) words:

The analyses showed that 100 and 45 cd/m^2 were significantly Too Dim with p-value less than 0.001, and that 1380 and 1320 cd/m^2 were significantly Too Bright with p-value also less than 0.001. Because of the unusual sign attributes (multi-color combination), the number of subjects who found this sign to be Just Right never rose above 50 percent at any luminance level. However, based on the adjusted residual result, it was found that significantly more subjects rated level 350 cd/m^2 and 340 cd/m^2 to be Just Right; therefore, these levels were deemed to be optimal for Condition Four (see Figure 7).

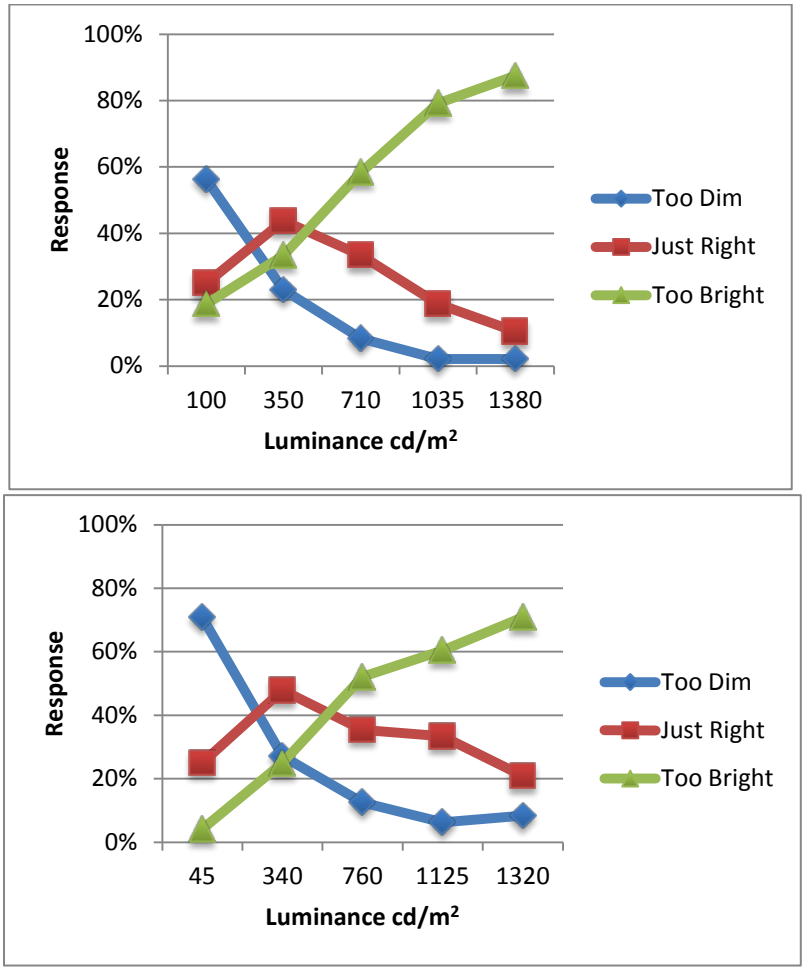


Figure 7. Condition Four results.

Conclusions

Task 1: Development of a Standard On-premise EMC Light Level Measurement

Based on considerations from the results and recommendations of Garvey (2015), it was determined that luminance should be the metric used to measure and describe on-premise EMC brightness levels. The measurements taken of the two signs in the testing varied significantly, with the higher resolution 16 mm sign luminance ranging from 100 to 6,700 cd/m^2 and the lower resolution 20 mm sign luminance ranging from 45 to 3,770 cd/m^2.

Task 2: Human Factors Study

Summary

A. The range of luminance levels evaluated in this study was selected on the basis of pilot testing and the results of previous research. The goal was to include luminance levels that would result in a substantial percentage of participants finding one of the levels to be Just Right, at least one to be Too Dim, and at least one to be Too Bright. The levels for the two signs were also selected to obtain steps that were as close as possible to one another.

B. When discussing the dimming of signs from daylight brightness levels to nighttime levels, a percentage is often mentioned; for example, that the signs should be dimmed by 50 percent or taken to 10 percent of maximum sign brightness. From Table 1 it can be seen that the luminance level of a given percentage of brightness (provided by the manufacturer) can vary greatly between sign models, even within a single sign manufacturer. It is clear, therefore, that a metric such as luminance is needed to set appropriate nighttime brightness levels so that a standard can be applied across the broad spectrum of EMC sign designs (variables such as resolution, number of pixels installed, and so forth) and manufacturers.

C. Also of note: there was no significant difference in subject response to the two signs tested, even though they had very different pixel resolution (16 mm versus 20 mm).

D. Across all the scenarios tested, very low lighting levels (100 and 45 cd/m^2) were judged to be Too Dim, and were never found to be Just Right. Across all the scenarios tested, upper end lighting levels (1,380 and 1,320 cd/m^2) were never judged to be Too Dim. In two of the four conditions, the upper levels did gain a majority of responses as Just Right, but were never found to be the optimal lighting level for any condition. The research suggests, therefore, that these lower and upper thresholds for EMC lighting levels at night are to be avoided in any regulatory setting.

D. Three of the four color-conditions performed best at 345 cd/m^2 (averaging the two signs), with the white-on-black condition requiring more light (735 cd/m^2) to reach Just Right at night. The differences between the responses at the 350/340 cd/m^2 and 710/760 cd/m^2 lighting levels were nuanced and not

dramatic. These results are consistent with earlier research and recommendations for nighttime EMC brightness discussed in the introduction of this report.

E. Results (Optimal Levels)

- Condition One – Black on White: 350 and 340 cd/m^2.
- Condition Two – White on Black: 710 and 760 cd/m^2.
- Condition Three – Red on Black: 350 and 340 cd/m^2.
- Condition Four – Yellow on Red: 350 cd/m^2 and 340 cd/m^2.

Recommendations

EMC signs used under real-world conditions will display messages using color combinations not contemplated in this research, and motorists viewing EMC signs at night will do so under varying seasonal and climatic conditions, and those conditions can have the potential to degrade the ability of the motorist to detect and read the EMC sign at a particular optimal lighting level generated by the responses gathered under the controlled conditions of the Larson Institute test track. Recommendations should accommodate all viewing scenarios, to ensure that any particular EMC using this research as a benchmark yields a sign message that is both visible and legible for motorists using all possible/different color combinations that are available via LED EMC technology. In light of the research reported here, several recommendations can be reached:

- A single EMC lighting level at night covering all types of EMC models and manufacturers, and all color schemes, is not suggested by the findings.
- Optimal LED EMC lighting levels at nightfall within a range of 350/340 cd/m^2 to 710/760 cd/m^2, depending on color and contrast orientation (light on dark versus dark on light). This range is most likely to accommodate the widest range of EMC color combinations and provide optimal EMC visibility and legibility for motorists.
- Arbitrarily selecting one EMC lighting level at night, particularly one on the lower end of the lighting level range, will fail to account for all illumination and color combination scenarios and could therefore have motorist-related traffic safety implications.
- If an EMC lighting level regulation were to require a single number, the lighting levels in the 710/760 cd/m^2 range appear from this research to be most inclusive.

References

Garvey, P.M. (2005). On-premise commercial sign lighting and light pollution. *Leukos: The Journal of the Illuminating Society of North America*. Vol. 1(3), 7-18.

Garvey, P.M. (2015). On-premise Electronic Message Center (EMC) *Nighttime Dimming Research Review and State of the Practice Industry Survey*. Final Report for the United States Sign Council. 28 pgs.

Garvey, P.M., Pietrucha, M.T., and Cruzado, I. (2008). *The Effect of Internally Illuminated On-premise Sign Brightness on Nighttime Sign Visibility and Traffic Safety*. United States Sign Council (USSC) Research Project, Final Report.

Lewin, I. (2008). Digital billboard recommendations and comparisons to conventional billboards. Available at: http://www.ies.org/E-Newsletter/pdf/Billboards.pdf

Kuhn, B.T., Garvey, P.M., and Pietrucha, M.T. (1997). Model guidelines for visibility of on-premise advertisement signs. *Transportation Research Record*, No. 1605, 80-87. National Academy Press, Washington, DC.

Lewin, I. (2009). Electronic message center sign luminance. Available at: www.signs.org/LinkClick.aspx?fileticket=coM8vfbNNIg%3d&tabid=745.

NEMA (2005). Hardware standards for dynamic message signs (DMS) with NTCIP requirements. NEMA Standards Publication TS-2005.

NEMA (2008). Standardization policies and procedures of the National Electrical Manufacturers Association. Available at: http://www.nema.org/stds/aboutstds/upload/SPP-2008_final_updated.pdf.

Queensland Government (2009). Queensland Government roadside advertising guide: Edition 1.1. Available at: http://www.transportandmainroads.qld.gov.au

Appendix A – Brightness Rating Scale

SIGN __X___ Condition __Y___

Too Dim Just Right Too Bright

Too Dim Just Right Too Bright

Too Dim Just Right Too Bright

Too Dim Just Right Too Bright

Too Dim Just Right Too Bright

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