REPORT ON DIGITAL SIGN BRIGHTNESS

Prepared for the Nevada State Department of Transportation, Washoe County, City of Reno and City of Sparks

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November 2014

Table of Contents

PART 1 3

Introduction. 3

Background. 3

Key Terms and Definitions. 4

Luminance. 4
Illuminance. 5
Reflected Light vs. Emitted Light (Traditional Signs vs. Electronic Signs). 5

Measuring Luminance and Illuminance 6

Measuring Luminance. 6
Measuring Illuminance. 8
Pros and Cons of Measuring Luminance vs. Illuminance 9
Equipment Cost. *9*
Calibration. *10*
Procedures that must be followed in the Field. *11*

Setting a Standard for Limits on Brightness– What Criteria Should be Used? 14

Other Issues for Regulation. 19

Daytime Luminance Limits. 19
Malfunctions. 19

How Bright are Current Roadside Commercial Signs? 20

Conclusions and Recommendations 21

References 23

PART 2 26

Proposed Language for Billboard Brightness Standards 26

Appendix 1: Field Measurements of Luminance Values of Existing Outdoor Signs (Digital and Traditional; On- and Off-Premise) 31

Part 1. Measured Luminance Values of *Traditional* Billboards in Washoe County, Nevada 31
Part 2. Measured Luminance Values of *Digital* Signs (on- and off-premise) in Washoe County, Nevada 34

Appendix 2: Field Data for All Signs Measured 36

Part 1. September 22, 2014 36
Part 2. October 18, 2014 59

PART 1

Introduction.

The purpose of this report is to develop and provide support for recommendations for state regulations and city and county ordinances to address the "brightness" of digital advertising signs, both on- and off-premise. The report consists of two parts. Part 1 provides background and support information, including: definitions of key terms, differences in measurement approaches and why one is considered by experts to be more appropriate than the other, luminance levels of existing digital and traditional signs in Washoe County and the cities of Reno and Sparks, other issues of relevance that should be addressed in an ordinance, and references cited in support of the discussion. Part 2 provides proposed ordinance language based on the information provided in Part 1. This work was performed at the request of Scenic Nevada, which had no role in the performance of the project other than providing maps of sign locations for our site visit.

Background.

As digital technology becomes more widespread for use in advertising signs, the public's reaction, when offered spontaneously or surveyed objectively, is most negative regarding the frequency with which the message changes (known as *dwell time* in the industry), and the perceived brightness of these signs[1]. This document addresses only the latter issue.

The words "bright" or "brightness" are commonly used to describe the visibility of an object. We may say: *the sun is very bright today,* or, *that light (or sign, or painted surface, etc.) is too bright for my taste.* But "brightness" is not a term of science, and cannot be measured objectively. When discussing the "brightness" of objects, lighting and visibility experts use the terms *luminance* and *illuminance,* with the former generally agreed to represent scientifically, that which is commonly called brightness. Unfortunately for the layperson, these two terms, which appear so similar, actually refer to very different characteristics of light and its measurement. Before we can develop and define appropriate language for an ordinance to regulate the brightness of outdoor advertising signs (especially at night), we must define these terms, understand how different they are and explore why there is not unanimity among experts as to the most appropriate measurement for use in a given circumstance. We must then defend our choice with evidence-based documentation, and demonstrate how the measure should be used in the development and implementation of the lighting section of a sign code.

Key Terms and Definitions.

Many experts have developed definitions of the terms luminance and illuminance in language meant to be understood by laypersons. In this section we will provide such definitions and place them into a meaningful context.

Luminance.

Lewin, in a report prepared for the Outdoor Advertising Association of America[2], defines luminance as follows:

> Also known as photometric brightness, this is the "brightness" of the billboard as seen from a particular angle of view. It is measured in candelas per sq. meter, also termed "nits."

While this is technically correct, it is not sufficient to assist a layperson in a full understanding of the term or how it is applied to signage. More communicative, albeit simplistic, definitions have been provided by others. For example, Clarion Associates and Clanton Associates[3] offer the following definition:

> Luminance (is a) measurement of the brightness of the sign face.

And an Illinois organization known as IROL[4] states:

> Luminance is a measure of the perceived brightness of a surface.

Most clearly, Garvey, et al,[19] working on behalf of the on-premise sign industry, describe luminance as:

> The photometric that most closely depicts the psychological experience of "brightness." Luminance can refer to either the light that is emitted by or reflected from a surface, and is an expression of luminous intensity (cd) over an extended area (m2). Like luminous intensity, *a source's luminance is constant regardless of distance* (italics added). (p. 3).

The bottom line is that luminance refers to the amount of light that is coming from the sign. This may be light reflected off the sign by the sun in daylight and by floodlights at night (in case of a traditional static billboard), or light that is actually emitted by the sign itself (in the case of a digital sign). Regardless of whether the light is reflected or emitted, luminance is measured in units called *candela per square meter,* written as cd/m^2. Luminance is often unofficially called *nits*. In measurement, 1 nit = 1 cd/m^2. In the literature, lighting professionals will typically use the term cd/m^2 and laypersons will use nits. But they are equivalent. The instrument used to measure luminance is simply called a luminance meter or photometer. (The outdoor advertising industry calls it a "nit gun"). When we think of how the human eye and brain perceive "brightness," it is the measure of luminance that quantifies this perception.

Illuminance.

Illuminance, conversely, is the measurement of light landing or falling on, a surface. For billboards (digital or traditional) the "surface" of interest is the eye of the driver (or pedestrian). The terms typically used to describe illuminance are *footcandles* (fc) or *lux* (lx). The instrument used to measure illuminance is called a lux meter.

Reflected Light vs. Emitted Light (Traditional Signs vs. Electronic Signs).

Perhaps the most straightforward way to understand how digital signs differ from conventional or traditional signs is to study how they provide sufficient light for motorists to be able to read their message.

A traditional sign uses printed characters on a white (or other colored) background. The background may be the actual side of a building, or paper or vinyl sheeting attached to a sign surface. This same technology has been used for hundreds of years to print books, magazines, newspapers, and posters. These signs provide no light of their own. They can only be seen (and, therefore, read) by the light that shines onto, and reflects off, their surface. Traditional outdoor signs use the light from the sun and the sky to provide this reflection during daylight hours. At night, in order to be seen, these signs are commonly equipped with a number (typically 2-4) of powerful floodlights that shine onto the sign from above or below, providing sufficient reflectance so that they can be read. If you take a traditional book with you to the beach, you might find it *so* bright, and *so* reflective, that it is difficult to read without sunglasses, or without moving under the shade of an umbrella. Conversely, to read the same book at night, you need to have a reading light of some sort to provide sufficient reflectance (called luminous contrast) to be able to read it. Traditional signs work the same way.

But a digital sign is totally different. It generates its own internal source of light, and *emits* that light to make its message visible and readable. Today, digital devices of all types are in our lives everyday – televisions, mobile phones, computers, tablets, and e-readers. The vast majority of these digital devices are made readable by emitting light from within. The more light they emit, the brighter their display appears. In many ways, this technology leads to the opposite readability situation from traditional signs. In contrast to a traditional book or newspaper, which may be too bright or reflective to comfortably read under direct sunlight, an electronic book (or computer, cell phone, or digital advertising sign) must be turned on, and turned up to high power/brightness levels in order to be visible and readable in bright sunlight. If you take your e-reader to the beach, and don't power it up high – you will be staring at a blank screen. Conversely, when indoors, or at night, where a traditional book can't be read without supplemental (external) light, the digital version of that book needs only low power from its internal light source to be readable – and, if the digital book is turned up too high, it may be difficult to read because it is so bright and causes glare to the human reader. The same is true for digital signs.

This is summarized in the table below:

	Type of lighting required for reading in daylight	Type of lighting required for reading indoors or at night
Type of Device		
Traditional book, magazine, newspaper	Light reflected off the page by the sun or sky	Separate reading light
Traditional billboard or on-premise sign	Light reflected off the sign by the sun or sky	Floodlights mounted on the sign structure
Digital book, magazine, newspaper, cell phone, computer, tablet, e-reader	Emitted light from the device itself – with high power for bright conditions	Emitted light from the device itself- dialed down to reduce brightness and glare
Digital billboard or on-premise sign	Emitted light from the device itself – with high power for bright conditions	Emitted light from the device itself- dialed down to reduce brightness and glare

Measuring Luminance and Illuminance

As reflects their different technologies, luminance and illuminance are measured differently. In the case of digital billboards, this measurement difference divides the billboard industry (which recommends illuminance) from researchers and the academic community (which recommends luminance). Further, whereas those State and local Departments of Transportation that consult with the billboard industry favor the use of illuminance, whereas those Departments (and the research arm of the Federal Highway Administration) that have developed standards based on empirical research favor the use of luminance.

Measuring Luminance.

To understand luminance and how it is measured, pretend that our digital sign is like a flashlight shining its beam toward us within a dark room. If we want to measure the luminance of the flashlight, i.e. how much light it is emitting, or how “bright” it is, we use a *photometer* that we aim directly at the flashlight. The photometer acts something like a high performance digital camera with a telephoto lens. The operator points the meter at the flashlight, looks through the viewfinder, and pulls the trigger to capture an instantaneous reading. Within the viewfinder there is a small circle in the center of the field of view that is superimposed on the scene being viewed. This circle represents the area of light that the meter will measure. (It is typically 1° or less). As long as this central circle “captures” light only from the flashlight beam and not the surrounding dark room, the meter will provide an accurate reading of the flashlight’s luminance. It does not matter how far away the meter is, or from what angle the reading is made – the only requirement that must be satisfied is that the central circle (the “acceptance” angle of the meter) reads only the flashlight beam and nothing beyond it. The reading provided will be specified in *candela per square meter,* or cd/m^2.

Figure 1 – A Typical Photometer
(Shown reading 113.4 cd/m^2)

When applying this technique to the measurement of luminance of digital billboards or digital on-premise signs, the photometer is the same; we simply substitute the digital sign for the flashlight. And, instead of the dark room, we take our measurement in whatever outdoor setting the sign is located. In this “real world” setting, it does not matter how large or small the sign is, how high off the ground or how far from the roadway it is located, or whether it is viewed against a bright urban or dark rural background. As long as our photometer's sensor reads *only* the sign (or a selected portion of the sign – see below) of interest, all we need to do is point our photometer at the sign and read the resultant luminance value on the meter. We may think of the photometer like a telephoto lens in photography – it reaches out to capture small objects (in this case, light emitting diodes, or LEDs) in the distance. In short, it captures the light being emitted by or projected from, the sign itself.

Of course, in the real world, digital signs often present images with several colors simultaneously. In addition, such signs change their display, and consequently their colors, every several seconds (or minutes). And, for a given amount of power that is applied to the sign, certain colors will appear brighter (i.e. produce higher luminance) than others. Typically, colors such as white, yellow, and orange will appear brighter than colors such as red, blue, or green. Thus, if we want to know what the "average" or "overall" luminance of a digital sign is at any given moment, and if our photometer has a small sensor size, we will either need to take separate meter readings of each area of color and then find their average, or else move sufficiently far away from the sign that our photometer captures the luminance of the multiple areas of color all at the same time.

On the other hand, if our goal is to identify how bright the sign can possibly be – something we would want to know if we are developing a guideline, ordinance or regulation that identifies a maximum allowable luminance, then we need to measure the luminance with the sign set at its maximum power, and we need to read a white area of the display with our photometer. (Note that, unlike the measure of illuminance, it is not necessary to have the entire sign display white. As long as any portion is white, we can use the photometer to measure only that portion).

Measuring Illuminance.

Let us now take the same example of the flashlight in the dark room. To measure its *illuminance* we will use an illuminance meter (typically called a *footcandle* (or fc) or *lux* (lx) meter, and we will measure the brightness of the flashlight's beam when that light is aimed onto a surface. In our measurement case, that surface is the meter itself, as it will substitute for the eye of a motorist or other road user. Moving out to the real world from the flashlight example, we will find that our fc meter is like a camera with a wide-angle lens, measuring light from a wide variety of sources, angles and distances simultaneously. It gives us a big picture view, but because it has no viewfinder, we cannot know exactly what we are measuring. The front (the sensor) of a footcandle meter looks like a Ping-Pong ball that has been sliced in half. The white, translucent, half-sphere that forms the sensor captures light from everything in front of it. Moving the meter in any direction (up/down, left/right, nearer/farther) will change the measurement because every such movement causes the meter to capture more or fewer light sources, and because the meter has gotten closer to some and farther from others, etc.

Because the fc meter captures light from everything in the scene in front of it, it is not possible, using the illuminance method, to measure the brightness of the billboard alone; we can only measure it within the context of every other source of light in the surrounding environment. This raises several concerns, discussed further in the next section of this report.

Figure 2: Two Typical Illuminance Meters
Each displays a reading in Lux (lx)
(Note the white “dome” that collects light, and the lack of a viewfinder)

Pros and Cons of Measuring Luminance vs. Illuminance.

Expert opinion about whether to use luminance or illuminance to develop standards for digital billboard brightness is divided. There are two different schools of thought on the subject. The billboard industry, their contractors, and those Government agencies that have accepted industry arguments, believe in measuring illuminance. Universities, independent research institutions, and Governmental organizations whose codes and ordinances were based on empirical research, favor using luminance. It is interesting to note that the Federal Highway Administration has taken no official position on this issue, although it uses luminance in its own research[5].

The key issues in this debate are discussed below.

Equipment Cost.

Advocates of the use of Illuminance explain that the differences in cost between luminance and illuminance meters are dramatic. It is true that a good luminance meter may cost $3000, whereas illuminance meters can be purchased for 10% of that price. This is, however, a misleading comparison, for several reasons, including:

- Labor (usage) costs are higher with illuminance meters because more time must be spent on site, since measurements must be taken with each sign fully lit as well as turned off.
- If the procedure recommended by the Outdoor Advertising Association of America (OAAA) is used (see footnote below), then two persons are needed when using an illuminance meter, whereas a luminance measurement can be completed by a single individual.
- Specialized equipment, such as a bucket truck, may be required to measure illuminance because meter readings must be taken from precisely specified distances, and there may be no accessible or safe locations at which the crew needs to stand on or near the roadway surface.
- Since such meter readings need not be taken frequently, it is possible for the responsible agency to rent a meter only for the time needed, thus eliminating purchase costs for a luminance meter.
- It is possible for an agency to own only a single luminance meter, and to make it available to all departments as needed; or multiple agencies can share the same meter as required.
- A system that has worked well in other Government applications could work well here. Simply put, as part of a sign permit application process, the sign owner or operator would certify to the cognizant Government agency that the sign in question complies with all luminance (or illuminance) requirements. This removes the requirement that the Agency field check all signs for compliance. On a complaint-driven basis, the Agency may perform such field tests with a rented or borrowed meter.

Calibration.

If Government agencies are to impose enforceable regulations on digital sign brightness, it is important that the equipment used to measure such brightness levels for compliance provides readings that are valid and reliable. With photometers, this assurance is predicated on the use of periodic, third party calibration and certification. Inexpensive illuminance meters are unlikely to offer a guarantee of the precision of their meter readings sufficient to support such calibration/certification.

Luminance meters, which are generally more expensive than illuminance meters, are typically calibrated at the factory and sold with documentation of their precision, and thus are amenable to such periodic recalibration. It is suggested that a Government agency investigate, in advance, the feasibility of calibration for any meter that might be considered for use (including rental equipment).

Procedures that must be followed in the Field.

There are large differences between luminance and illuminance measurements that must be followed when preparing for, and making, field measurements. These are outlined below.

Meter Placement.

Luminance. To take a luminance reading of a billboard or on-premise sign, the individual performing the measurement simply aims the meter at the sign, being sure that the central reading circle in the meter's viewfinder covers only the area of the sign that is of interest. The meter can be used at any safe and convenient distance from the sign, at any height, and at any angle to the sign.

Illuminance. According to Lewin, who developed this approach on behalf of the OAAA, and which the OAAA and many of its member billboard companies now endorse, the illuminance meter must be placed at a precise distance from the sign being measured, a distance determined by the size of the sign, and this same distance must be used when measuring any and all signs of a given size. According to Lewin, the following meter placement distances are reqired[2]:

Billboard Size (ft.)	Meter Reading Distance (ft.)
11x22	150
10.5x36	200
14x48	250
20x60	350

Lewin further notes that these measurements are to be taken with the meter facing the sign perpendicularly, and held five feet (5') above grade. This selected elevation value was chosen because it represents "approximately eye level." Although this may represent the eye height of a standing person, the assumed eye height of the average driver (as determined by regulatory and standards setting bodies, is 3.5 feet).

There are many instances where it would be impossible for an individual to use an illuminance meter at the height and distance specified by Lewin and the OAAA, thus rendering this method infeasible in such circumstances. Figure 3 shows an urban digital billboard in a not atypical setting (on a tall pole so that the sign is at eye level of drivers on an elevated roadway) where illuminance measurements following the recommended practice could not be made.

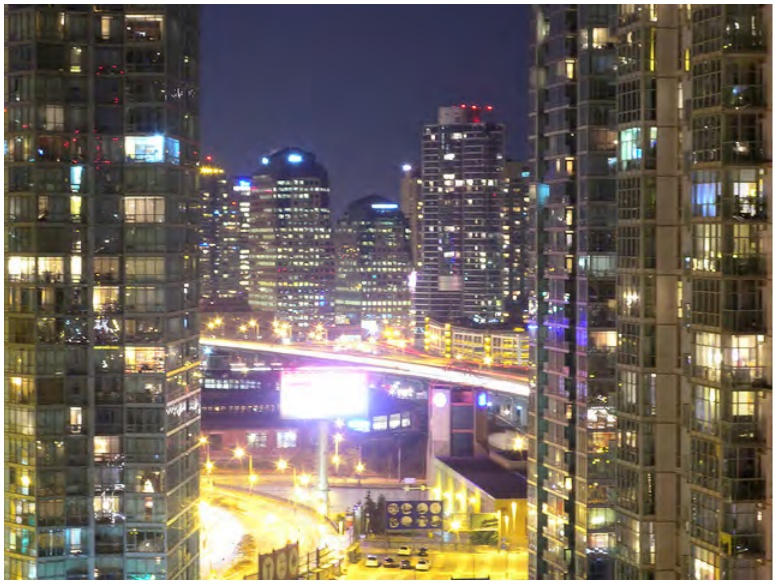

Figure 3. A Digital Billboard in a Major North American City

Time of Day for Brightness Measurement.

Luminance. The luminance meter reading can be made at any time of day or night, although nighttime readings are recommended to ensure that they represent actual sign output.

Illuminance. Nighttime readings are required, and are further constrained by the operating hours of nearby businesses and street and highway lighting. Because meter readings must be taken with the billboard off, and again at its maximum bright white setting, the illuminance that can be attributed to the billboard can only be calculated by subtracting the meter reading with the billboard off from that with the billboard on as described above. Thus, it is critical that environmental lighting in the vicinity of the billboard (street lights, lights from other nearby businesses or billboards, window lights from commercial or residential structures, etc.) be on for both meter readings. Accordingly, the two readings must be taken in close temporal proximity, and it must be assured that such nearby lighting does not differ between the two readings. (It should be noted that sky brightness and moon conditions must also remain the same for each of the two readings).

Recently the OAAA proposed an illuminance-based measurement method that, it said, would not require the billboard to be turned off[6]. Simply stated, the OAAA suggested that: "A helper should position themselves (sic) about 7' to 10' in front of the light meter and hold up an opaque black sheet of material that is roughly 12" high by 40" wide. … The sheet should be positioned so it blocks all light from the digital billboard but still allows the remaining ambient light to register on the foot candle meter." Unfortunately, this recommendation demonstrates a lack of understanding about how illuminance is measured or the difficulties of making such measurements in the field. Three examples illustrate our concern with this OAAA recommendation. First, since, as discussed above, there is no viewfinder on the typical illuminance meter, there is no way for the meter reading personnel to know where to position the black sheet. Second, if, as is likely, there are other light sources (street lights, other signs, traffic signals, etc.) in close proximity to the digital billboard being measured, then holding the black sheet such that it blocks the light emitted from the billboard will also block the light from these other sources, thus rendering the entire measurement erroneous. In addition, since the half-dome photocell accepts light from every direction regardless of source or intensity, it is highly likely that placement of the black sheet will also block some such sources, including those not near the billboard being measured but nonetheless important for the overall ambient measurement; this too will cause an erroneous reading. Third, as Lewin has suggested, and the OAAA has accepted, the meter must be placed at different distances depending upon the sign of the billboard being measured. Thus, it would be necessary for the black cloth to change in size and/or distance as well, yet OAAA proposes a single size and distance. It is also noted that there seems to be no recognition or endorsement by Dr. Lewin of the proposed OAAA approach.

Even if the OAAA's method could work, it requires the participation of a second person, thus increasing costs to the agency performing the measurement.

It is interesting to note that the on-premise sign industry, represented by the United States Sign Council (USSC) disagrees with the OAAA regarding such measurement[13]. The USSC endorses the luminance measurement methodology recommended by the experts cited above. In its "Model On-Premise Sign Code," USSC states:

> The USSC standard for the measurement of on-premise sign illumination is Luminance. Luminance measures light output at its source, does not vary with ambient light conditions, and further can be objectively measured both during the sign fabrication process and after installation in the field to ensure adherence to the illumination requirements of this model (p. 3).

The USSC report continues:

> This Model Code strongly recommends that other light measurement methods be avoided in regard to on-premise signs (for instance, an illuminance standard, or including ambient lighting conditions as a part of a complicated formula), because these methods do not account for true sign brightness which, in regard to traffic safety, is the primary determinant as to whether a sign is visible and legible to the motorist (p. 49).

Converting Illuminance to Luminance.

Ironically, after explaining the benefits of measuring illuminance, Lewin ultimately recommends the conversion of the obtained illuminance readings into luminance values, thus begging the question of why the far simpler and more direct method of measuring luminance was not followed in the first place. In a section of his report[2] titled "Allowable Average Luminance and Billboard Size," Lewin states: "For any given billboard size, formula 1 can be used to compute the allowable average luminance (note that he does not refer to allowable *maximum* luminance, which is the proper purview of an ordinance) by incorporating the suggested distance value from Table 2. The results for the standard dimension billboards are provided in Table 3." We have reproduced his table below:

Billboard Dimensions (ft.)	Distance (ft.)	Luminance (cd/m^2)
11x22	150	300
10.5x36	200	342
14x48	250	300
20x60	350	330

As will be seen below, we consider these luminance values to be 2-3 times greater than necessary for *maximum* luminance needs (and recall that Lewin's values represent *average* luminance values). Nonetheless, it is interesting that Lewin's elaborate and difficult to employ methods ultimately lead to luminance, not illuminance, recommendations.

Setting a Standard for Limits on Brightness– What Criteria Should be Used?

It goes without saying that digital signs should operate with sufficient luminous intensity both during the day and at night that they can be comfortably seen and easily read by approaching motorists and other road users. Reasonable luminance values associated with this legibility criterion are well understood based on extensive research, and are discussed below.

There are, however, other criteria that might reasonably be employed in any consideration of roadside digital signage brightness, and the proper criterion to use must be determined by the Agency's objective for setting limits.

For example, astronomers and environmentalists are concerned about the darkness of the night sky, and the possible adverse effects of billboard brightness on this objective. This phenomenon is known as "light trespass." This term refers basically to the light of a digital sign that spreads beyond the sign itself, and brightens what would otherwise be a dark sky. Closely related to this criterion is the spread of light from a sign into the windows of nearby buildings, particularly residences. This is also a form of light trespass, but the concern here is primarily with horizontal trespass, whereas dark sky concerns reflect vertical trespass. It is interesting to note that Lewin's methodology and his resultant recommendations are, in fact, based on a standard for light trespass rather than a standard relevant to roadways and driving[2,4] . Although the use of a light trespass standard is of interest to dark sky advocates and to those concerned about light and glare from billboards entering residential windows at night, it is the wrong standard to use when developing brightness criteria for signs to be viewed by road users. The standard that Lewin applied was based essentially on a Technical Memorandum from the Illuminating Engineering Society of North America (IESNA) titled: "Light Trespass: Research, Results and Recommendations"[15]. But, as Luginbuhl points out, the IESNA already had in place a standard that was directly applicable to billboards, titled: "Recommended Luminances for Poster Panels, Painted Bulletins, and Other Advertising Signs"[16] and this standard recommended illuminance levels for billboards that are "consistent with luminances of 45-111 nits." Conversely, following the standard cited by Lewin, billboards could reasonably be expected to achieve luminance levels of 300-350 nits, a level some 3-6 times higher than is necessary or desirable for roadside advertising signs.

Of all of the complaints that motorists express about digital signs, excessive sign brightness is one of the two issues that cause the greatest concern[1]. (The other is the distracting nature of a rapid change of message, but that is outside the scope of this paper). Interestingly, and of direct relevance to the brightness issue, this level of motorist annoyance with digital signs does not extend to traditional fixed billboards. Traditional signs, illuminated at night by one or more floodlights, have never to our knowledge been the subject of motorist complaints, and yet such signs are highly readable, even at highway speeds. In short, as discussed below, motorist complaints about digital billboard brightness levels stems not from the technology used, but rather for the simple reason that digital billboards (and many on-premise signs) are typically set at luminance levels that are far too high at night – and these excessive levels not only cause driver discomfort, but also make the billboards more difficult to read, an issue that, at first, seems to be counterintuitive.

Given the primary concern for driver and traffic safety, we must address the potential consequences of light emitted from the sign that can cause several adverse impacts on road user behavior and performance. Excess sign luminance can lead to any (or all) of the following impacts:

- Beyond certain luminance levels, brighter signs become more difficult to see and to read, thus defeating the advertiser's specific purpose (if the motorist chooses to ignore the sign), or contributing to potentially dangerous levels of distraction (if the motorist expends greater time and effort to read it). Although it might seem counterintuitive that brighter is not necessarily better, this has been demonstrated over decades of research, conducted primarily to ensure optimum legibility of official highway signs[7,8].

- Signs that are substantially brighter than other objects in the driver's field of view tend to attract the driver's gaze at the expense of, not only other advertising signs that may be within view, but every other object in the field of view including objects critical to safe driving such as traffic signals, and the taillights, turn signals, or brake lights of other vehicles.

- Signs that are excessively bright can cause "discomfort glare" or "disability glare," terms of science that describe a person's resultant temporary inability to recognize and respond to important objects in the field of view.

As described by Allen, et al[14], nearly 50 years ago, "… the data suggested that high-luminance signs can change the adaptation level of the eye (or the pupil size, or both). This finding suggests that the driver's vision would be impaired for other tasks requiring dark adaptation. It seems unwise to install unnecessarily bright signs that are unpleasant to the driver and may impair his vision" (p. 33).

Of course, more recent research has also addressed this question. For example:

- The State of Queensland, Australia, in promulgating its outdoor advertising regulations, stated: "Research has indicated that brightness from illuminated Advertising Devices directed at road traffic should be minimized under all conditions" (p. D-2)[17].

- Austroads, the Association of Australian and New Zealand Road Transport and Traffic Authorities, in a comprehensive recent study,[18] stated: "Signs that have luminance levels that are high relative to other objects in the environment are likely to gain preferential attention and be particularly good at capturing attention when they change. As a result, digital signs should have luminance levels no greater than any other sign and preferably lower than non-changeable signs" (p. 18).

- Clarion Associates and Clanton Associates[3], reviewed "national studies by the Federal Highway Administration (FHWA) and a review of recent EAS (the city of Pittsburgh's term for digital billboards) ordinances in other communities." As a result, they recommended that the city adopt a "day/night brightness restriction of 1000 nits/100 nits maximum from any element on the sign" (p. 6).

- These same authors cited a FHWA study "of the potential safety impacts of electronic billboards" which concluded that: "a brightness of 30 nits was sufficient to view the message on an electronic billboard at 650 feet at night and 1000 nits was sufficient during the day" (p. 13).

- Luginbuhl, et al[7] performed a review of Lewin's work, measured brightness levels of existing billboards in Arizona, and examined IESNA (Illuminating Engineering Society of North America Standards), and reached the following conclusions: "Unlike previous technologies, these signs (digital LED billboards) are designed to produce lighting levels that are visible during the daytime; should too large a fraction of this brightness be used at night, serious consequences for driver visibility and safety are possible. A review of the lighting professional literature indicates that drivers should be subjected to brightness levels of no greater than 10 to 40 times the brightness level to which their eyes are adapted for the critical driving task. As roadway lighting and automobile headlights provide lighting levels of about one nit, this implies signage should appear no brighter than about 40 nits. Standard industry practice with previous technologies for floodlit billboards averages less than 60 nits, and rarely exceeds 100 nits. It is recommended that the new technologies should not exceed 100 nits."

- Carhart[4] concluded: "All self-luminous outdoor signs should be subject to surface luminosity limits both during the daytime and nighttime hours. During the daytime, based on normal daylight illumination, a maximum of 5,000 nits will keep luminous signage balanced with the surrounding landscape. During the nighttime hours, a luminosity limit of 150 nits will provide a surface brightness for digital signs which is comparable to the nighttime signage which is widespread across this nation, and is in line with the sign illumination level recommendations of the Illuminating Engineering Society of North America (IESNA). If the nighttime luminance setting and limit is based on the sign in question being set to a display full white, full brightness field, a limit as high as 200 nits for this method of calibration and testing is suitable. Incremental luminance limits between the nighttime limit and the full sunlight limit may also be specified for overcast or foggy days, or for dusk; or regulations may require an automatic control of sign luminance based on the ambient lighting condition, to throttle the sign luminance between the sunny-day and night maximums" (p. 10).

- Freyssinier, et al[8] studied "the preferred luminance of simulated outdoor signage for legibility and acceptability under nighttime viewing conditions," and concluded that sign luminances of no more than 100 cd/m^2 were found to optimize legibility and acceptability, even when competing signs were present" (p. 6).

- Bullough and Skinner[9] reviewed the *IESNA Lighting Handbook* that "contains recommendations for illuminating billboard signs and other large advertising panels. These recommendations are based on two factors: the surrounding location (bright versus dark surroundings, as might be found in urban and rural settings, respectively), and the average reflectance of the information on the billboard." The authors state that use of the latter factor is impractical, because information on digital billboards is constantly changed, and a message that is dark in color at one moment could be replaced with one that is light in color the next. Because these IESNA recommendations are based on the sign achieving "sufficient conspicuity," and since the power supplied to the billboard is unlikely to be changed based on the color of the message being displayed at any given time, the authors believe that it is reasonable to expect that "many billboard exterior lighting systems (will) provide the higher illuminance recommended by IESNA." Employing an equation to convert IESNA's illuminance recommendations to luminance values, the authors conclude that, for bright surroundings and an all-white sign face with reflectance of 0.8, the upper limit for luminance would be 250 cd/m^2, and for dark surroundings, the same all white sign face would have an upper limit of 130 cd/m^2. Reviewing the marketing literature from two manufacturers, the authors found that one cited the IESNA recommendations verbatim, whereas the other chose an upper limit roughly mid-way between the two values – the equivalent of 200 cd/m^2. The authors suggested that several caveats should apply to measurement of digital billboard luminance in the field. These are: (1) Because LED output is related to ambient temperature (lower temperatures result in higher light output), measurements should be made at night if maximum luminance levels are being measured, e.g. for code compliance; (2) for the same reason, digital signs should be measured when the sign display is mostly white. Two potential issues that proved to be of no concern were: (1) In all but the brightest urban environments, ambient light in proximity to the sign being measured would not add significantly to billboard luminance; and (2) It is reasonable to expect that the luminance of the sign when measured directly in front of it is similar to its luminance at the angles from which it is expected to be seen (and possibly measured) from the roadway.

- In a study for the United States Sign Council (an organization of the on-premise sign industry), Garvey, et al[19] wrote: "Based on a review of the literature, Sivak and Olson (1983) suggested an optimal nighttime sign legend luminance of 75 cd/m^2 and a minimum of 2.4 cd/m^2 for black on light (negative contrast) signs. With light-on-dark (positive contrast) signs, Garvey and Mace (in press) found 30 cd/m^2 to provide maximum nighttime legibility distance (p. 26).

- The same authors[12] developed what they called "model guidelines for visibility of on-premise advertisement signs." Citing a number of different sources, the authors reported that, for black characters on a light background ("negative contrast") signs, the optimum nighttime legend luminance level was 75 cd/m^2 with a minimum of 2.4 cd/m^2, and for light on dark ("positive contrast") signs, the maximum legibility distance was achieved at 30 cd/m^2. At the end of their report, in a section in which they specified their visibility guidelines, they wrote:

> **Nighttime Sign Luminance is Between 30 and 75 cd/m^2**
> Nighttime sign luminance refers to message brightness with positive-contrast signs and background brightness with negative contrast signs**.** As with daytime internal contrast, and for the same reasons, falling below or *exceeding recommended nighttime luminance values will result in a loss in legibility distance* (italics added).

It is interesting to note, however, that despite the Kuhn, et al work on behalf of the USSC, the sign council continues to recommend a nighttime maximum luminance level of 750 cd/m^2, a value more than ten times greater than their own consultants recommended[13].

Other Issues for Regulation.

Daytime Luminance Limits.

Whereas traditional outdoor advertising signs obtain their daytime luminance from natural light from the sun and sky, digital (LED) signs must receive high power in order to be visible in daylight. Nonetheless, too much power will render such signs excessively bright, and could cause temporary vision difficulties due to glare. The sun in daylight is considered to have a brightness of approximately 6500 nits, and outdoor advertising signs with luminance values in the range of 5000-7000 nits are acceptable. However, there is no need for signs to achieve such luminance levels in order to be visible and legible to motorists. In our measurements of signs in Washoe County, we measured one internally illuminated sign with daytime luminance averaging 1527 cd/m2, and it was highly visible. And researchers at Pennsylvania State University[19], working for the on-premise sign industry, reported on an earlier study that found that "daytime legibility distance continued to improve with increases in luminance up to 850 cd/m^2, after which performance leveled off" (p. 26). Finally, several manufacturers of digital signs promote the fact that their signs can achieve luminance levels of 11,000 nits or higher, far too bright for even a cloudless day. Since the power demands and cooling requirements for digital signs increase with the amount of light that they must produce, there is nothing to be gained from powering these signs to higher levels than necessary during daylight hours.

Malfunctions.

All digital signs, particularly those that are controlled remotely and wirelessly, are at risk for malfunctions or temporary failures that can affect that integrity of the display. Such malfunctions may be manifested in display segments that appear to flash or scintillate, and this can increase the risk of driver distraction because of excessive brightness, or the flashing appearance of the display. Accordingly, it is imperative that any malfunctions or failures of any software, hardware, firmware, or communications component of the display result in a "fail-safe" condition – one in which the display turns off (or fully dark) until the malfunction is repaired.

How Bright are Current Roadside Commercial Signs?

The nighttime luminance of outdoor advertising signs, both on- and off-premise, and both digital and traditional, have been measured by independent experts in Arizona, New York, Pennsylvania, Delaware, California, and Nevada. All such measurements were made using cd/m^2 as the measurement criterion, and all who reported the equipment used specified the use of a Konica/Minolta LS-100 or LS-110 digital luminance photometer. A summary of these measurements is provided here:

- In Illinois, three traditional billboards averaged 63.3; the range was 46-76.
- In Arizona, 55 traditional billboards averaged 53.3; the range was 6-235.
- In New York, six traditional billboards averaged 123.6; the range was 4-240.
- In New York, four LED billboards averaged 225; the range was 160-320.
- In Washoe County, Nevada, on September 22, 2014, 16 traditional billboards averaged 59.8; the range was 2.2-291.
- In Washoe County, Nevada, on September 22, 2014, seven LED billboards averaged 1,291; the range was 107-5,390.
- In Washoe County, Nevada, on October 18, 2014, 11 traditional billboards averaged 51.1; the range was 2.1-240.
- In Washoe County, Nevada, on October 18, 2014, eight LED billboards averaged 1,318.2; the range was 44-4,440.
- In Washoe County, Nevada, on October 18, 2014, three fixed, internally illuminated signs averaged 191.3; the range was 5.3-523.
- In Washoe County, Nevada, during daylight on October 19, 2014, one fixed, internally illuminated sign measured 1527; the range (depending on cloud cover) was 1391-1776.
- In Washoe County, Nevada, during daylight on October 19, 2014, one digital sign averaged 4442.3; the range was 4072-4888.

There are several insights that can be drawn from this array of measurements. These include:

- Traditional billboards in Washoe County present luminance values within the average range of similar signs in other states.
- None of the traditional billboards measured in Washoe County presented any visibility or legibility concerns, even though several of these signs had luminance values below 5 cd/m^2.
- Digital signs in Washoe County, however, exceed similar digital signs in New York State (the only other jurisdiction in which such measurements have been taken) by 5-6 times.
- One digital billboard in Washoe County measured only 44 cd/m^2. Yet, there was no difficulty seeing or reading this sign.
- In both site visits to Washoe County, the digital signs (billboards and on-premise signs) averaged 12-13 times the level recommended by the many experts cited in this report. These signs are no easier to view or read because of their extreme luminance values, and they risk unsafe levels of driver distraction, discomfort or disability glare, and unnecessary levels of light trespass.

Conclusions and Recommendations

The conclusions of this paper are based on a review of the technical and professional literature in the field, the measurement (our own and others') of existing luminance values for outdoor advertising signs in six states, good human factors practice regarding driver attention and distraction, susceptibility to glare, and demands of the driving task, and a review of applicable standards documents.

Our conclusions are clear, objective, and defensible, and they are in close accordance with all other experts except those involved with or employed by the outdoor advertising industry.

It is clear from our review, and from the work of other researchers cited herein, that the typical range of nighttime luminance values for traditional (floodlit) billboards is dramatically lower than that of digitals; in Washoe County, including the cities of Reno and Sparks, the average luminance of digital signs (both on- and off-premise) measured was more than 22 times greater than those traditional billboards measured. In Arizona, where 55 traditional billboards were measured, the average luminance value was 53.3, remarkably close to those in Washoe County. Although no measurements were taken of digital signs in Arizona, we would expect the multiplier to be similar to that in Nevada. And yet, we are aware of no complaints about the luminance levels of traditional billboards, either, on the one hand, that they are too bright; and on the other that they are too dim to be read. For this, and other reasons described in this report, we see no reason why the luminance of digital billboards needs to exceed 100 nits in rural areas, and 150 nits in brightly lit urban areas.

In Part 2 of this report, we have taken these conclusions and recommendations and written them in the language of a potential ordinance for consideration by government staff preparing sign codes or regulations.

Below, we have summarized, in bullet form, the crux of these recommendations.

- Billboard brightness measurements should be made using luminance, not illuminance meters. Luminance meters used should have a viewfinder and an acceptance angle of one degree (1°) or less.

- Any meter to be used for brightness measurement should be tested and calibrated by an independent testing organization, and such calibration should be current when the meter is used.

- The measurement method can and should be applied to any outdoor signage, whether a billboard or on-premise sign, and whether digital or traditional.

- Measurements for daytime luminance should be made between two hours after morning civil twilight and two hours before evening civil twilight[*].

- Measurements for nighttime luminance should be made after the end of evening civil twilight and before the beginning of morning civil twilight*.

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[*] Civil Twilight is defined to begin in the morning, and end in the evening when the center of the Sun is geometrically 6 degrees below the horizon. This is the limit at which twilight illumination is sufficient, under good weather conditions, for terrestrial objects to be clearly distinguished; at the beginning of morning civil twilight, or end of evening civil twilight, the horizon is clearly defined and the brightest stars are visible under good atmospheric conditions in the absence of moonlight or other illumination. In the morning before the beginning of civil twilight and in the evening after the end of civil twilight, artificial illumination is normally required to carry on ordinary outdoor activities[10]. Civil twilight is the definition of twilight most widely used by the general public[11].

- Measurement of each sign should be made from a location that is as close to the sign as reasonably possible, although this is not mandatory.

- Measurement should be made with the meter's sensor filled with a section of the billboard displaying all white light.

- Any temporary failure or malfunction of any component of the display system that results in display segments that appear excessively bright or appear to flash or scintillate should result in an immediate conversion of the display to an "off" or all dark configuration, until such time as the malfunction is corrected.

- Daytime luminance values should not exceed 3,000 cd/m^2.

- Nighttime luminance values should not exceed 100 cd/m^2 in rural areas or 150 cd/m^2 in brightly lit urban areas.

- The sign's light sensitive control system should be able to account for reductions in daytime sky luminance caused by clouds or storms, and should automatically reduce sign luminance proportionally.

References

1. Wachtel, J. (2011). Public Attitude Toward Roadside Advertising Signs: Forty Years of Surveys, Interviews, and Unsolicited Opinions. Washington, DC: *90th Annual Meeting of the Transportation Research Board.*

2. Lewin, I. (Undated). Digital Billboard Recommendations and Comparisons to Conventional Billboards.

3. Clarion Associates & Clanton Associates (2010). Pittsburgh Electronic Sign Code Amendments - Evaluation – Preliminary Staff Draft.

4. Carhart, D. (2010). Digital Billboards: New Regulations for New Technology. (Illinois Coalition for Responsible Outdoor Lighting). Accessed from the web at: http://www.illinoisighting.org/billboards.html

5. Perez, WA, Bertola, MA, Kenned, JF, & Molino, JA. (2011). Driver Visual Behavior in the Presence of Commercial Electronic Variable Message Signs (CEVMS). *Report No. FHWA-HEP-11-014*. Washington, DC: Federal Highway Administration. Accessed from the web at: http://www.fhwa.dot.gov/real_estate/oac/visual_behavior_report/review/cevms2.pdf

6. OAAA (2014). Digital Billboard Lighting Measurement: How to Measure Foot Candles in the Field – Without Sign Company Knowledge. In *Reference Documents for Meeting on CDOT's Draft Outdoor Advertising Rules, August 28, 2014,* pp. 52-54.

7. Luginbuhl, CB, Israel, H., Scowen, P, Polakis, J & Polakis, T. (2010). Digital LED Billboard Luminance Recommendations – How Bright is Bright Enough? *Draft Report.*

8. Freyssinier, JP, Narendran, N, & Bullough, JD. (2006). Luminance requirements for lighted signage. *Proceedings of the Society of Photo-Optical Instrumentation Engineers, Volume 6337.* Bellingham, Washington. Society of Photo-Optical Instrumentation Engineers.

9. Bullough, JD, & Skinner, NP. (2011). Luminance Criteria and Measurement Considerations for Light-Emitting Diode Billboards*. 90th Annual Meeting of the Transportation Research Board.* Washington, DC: Transportation Research Board.

10. U.S. Naval Observatory. Accessed from the web at: http://aa.usno.navy.mil/faq/docs/RST_defs.php

11. National Weather Service Weather Forecast Office. Accessed from the web at: http://www.crh.noaa.gov/lmk/?n=twilight-types

12. Kuhn, BT., Garvey, PM, & Pietrucha, MT. (2007). Model Guidelines for Visibility of On-Premise Advertisement Signs. *Transportation Research Record 1605.* Washington, DC: Transportation Research Board.

13. Bertucci, AD, & Crawford, RB. (2009). Model On-Premise Sign Code. Bristol: PA. United States Sign Council (p, 48 ff).

14. Allen, TM, Smith, GM, Janson, MH, & Dyer, FN. (1966). Sign Brightness in Relation to Legibility. *Final Report on a Highway Planning and Research Study Conducted in Cooperation with the U.S. Department of Commerce—Bureau of Public Roads.* Lansing: Michigan State Highway Commission.

15. IESNA (2011). Light Trespass: Research, Results, and Recommendations." *TM-11-00* (Reaffirmed 2011). New York: Illuminating Engineering Society.

16. IESNA (2000). Lighting Handbook. New York: Illuminating Engineering Society.

17. Queensland Government (2002). Guide to the Management of Roadside Advertising. *TERS Product No. 80.500.* Brisbane, Queensland, Australia:

Queensland Government Department of Main Roads.

18. Roberts, P, Boddington, K, & Rodwell, L. (2013). Impact of Roadside Advertising on Road Safety. *Austroads Publication No. AP-R420-13.* Sydney, NSW: Austroads Ltd.

19. Garvey, PM, Thompson-Kuhn, B, & Pietrucha, M. (1996). Sign Visibility Research and Traffic Safety Overview. *A Research Project of the United States Sign Council.*