SECTION 6.

RECOMMENDATONS FOR GUIDELINES

Based on the knowledge gained from the research reviewed in this project, as well as research conducted earlier and reviewed previously, good human factors practice, and guidelines or regulations developed or under consideration in jurisdictions throughout the US and world-wide, we have prepared a set of recommendations that State and local government agencies as well as private roadway operating authorities may wish to consider for use. We recognize that there are not yet comprehensive research-based answers to fully inform such guidance or regulation, and, given the complexity of the issue and the number of factors involved, it may be years before such results are available. Nonetheless, we have found, through the work undertaken for this project, that the research conducted within roughly the past ten years has quite consistently demonstrated empirical concern about driver distraction from roadside billboards, and has identified a number of DBB location and operational characteristics that seem to exacerbate the risk and/or consequences of such distraction, that the need for guidelines and/or regulations can be met within our current degree of knowledge. Indeed, of those research studies that have addressed driver distraction and roadside billboards, nearly every empirical study undertaken since 1995, including that by Lee et al., and sponsored by the outdoor advertising industry, have demonstrated that there is an adverse relationship between distraction and digital billboards.

MINIMUM MESSAGE DISPLAY DURATION (MESSAGE ON-TIME).

Perhaps the most contentious issue to be addressed in guidelines or regulations can be found in debates about the minimum duration of a message displayed on a DBB. For it is here that the goals of the DBB owner and those of the highway safety specialist are most at odds. Since roadside outdoor advertising is sold, to a large extent, on the number of drivers that pass the sign on a daily or hourly basis, and since certain times of day (e.g. rush hour) provide a larger audience, it is clearly to the sign operator's benefit to minimize the time for which any given message is presented so as to be able to offer more messages per unit time. There is, perhaps, a minimum display time below which both advertisers and regulators may agree that message display is unreasonable – for the advertiser because the time interval is too brief for a message to be read; for the traffic safety expert because the display obviously appears to "flash," and flashing signs are almost universally prohibited.

We are not aware of any research that has been conducted on the effects on distraction of the duration of time that a message on a DBB remains visible before changing to the next message. The OAAA (Undated a) has, periodically, issued guidance to its members on minimum display duration. It recommends 4 s. The FHWA (Shepherd, 2007) has recommended a minimum 8 s duration, and the OAAA (Undated b) reports that 41 States have enacted message display minima, ranging from 4 to 10 s. To our knowledge there is no empirical basis for any of these recommended or required display intervals. Indeed, as discussed below, good human factors practice would suggest that minimum display duration should differ with sight distance, prevailing speeds, and other factors.

Without the benefit of research, we must rely on human factors principles when attempting to develop a meaningful standard for minimum message duration. There are two human factors concerns that help to inform the analysis for this issue. First, it is widely understood that bright lights and visual change can draw the eye to a stimulus that is brighter than the surroundings, and/or exhibits movement or apparent movement. DBBs possess these properties, particularly at night and when they can be seen from considerable distances. In addition, the Zeigarnik Effect suggests that drivers will be attracted to attend longer to a display whose message changes as they approach it, in an effort to "complete" the viewing experience; in other words, to be able to look at a changeable message sign until he or she has seen the "complete" message. The simple way to minimize both of these potentially distracting effects of DBBs is to reduce to a minimum the likelihood that any given driver will observe an actual message change or to see more than a single displayed image. Given that any driver may come upon a given DBB at the moment of message change, regardless of the message duration, this objective cannot be met. However, it is not unreasonable to place a lower limit on message display duration to ensure that it is highly likely that motorists will be unable to see more than two successive messages (which would, by definition, include one message change). This can be accomplished by determining the sight distance and the prevailing speed (or the posted speed limit) for a road on which such a DBB appears, calculating the time for which a given DBB will be within the view of approaching drivers, and setting the minimum message duration at that interval or greater. Several jurisdictions have adopted this approach (see, for example, TEC, 1989; TERS, 2007). This is also the approach that was followed by the New York State Department of Transportation during the development of its draft regulations (NYSDOT, 2008a). The result of this analysis in New York was a proposed requirement for a minimum message display time of 61 s. (This proposed requirement was substantially reduced after a public comment period [NYSDOT, 2008b]). Of course, for different sight distances and different prevailing speeds, this minimum message duration would be different. Although a case-by-case process of setting minimum display durations would be optimum for traffic safety, it is likely that for both regulatory and enforcement purposes and for the ability of sign owners to establish standardized display intervals (and, hence, standardized advertising rates), it would be more practical for a road authority to establish only a small number of display duration minima, based on roads within their jurisdiction that operate with different speed limits and traffic characteristics.

Recommendation.

It is recommended that the following formula be used for calculating a minimum acceptable DBB display duration:

Sight distance to the DBB (ft) / Speed Limit (ft/sec) = Minimum display duration (sec).

INTERVAL BETWEEN SUCCESSIVE DISPLAYS.

There is little disagreement between those roadway authorities which have promulgated guidance or regulations concerning the interval between successive displays. It is clear and consistent that this time interval should be as close to zero as possible. Some jurisdictions define the change interval as “instantaneous,” others describe it as 0.1 s or less. The reason for this position is simple. Given that it is a combination of brightness and motion (real or apparent) that attracts a viewer’s gaze to a DBB, a perceptible dark or blank interval between successive displays will increase the sense of apparent motion (i.e. bright-dark-bright is more visually compelling than bright-bright).

Recommendation:

Regardless of how it is operationally defined, the interval between successive displays should be essentially zero, such that an approaching driver cannot perceive any blanking of the display screen.

VISUAL EFFECTS BETWEEN SUCCESSIVE DISPLAYS.

Even more so than the case for the display interval, regulatory authorities are in complete agreement that there should be no visual “special effects” of any kind during the transition between successive messages. It is clear that the screen should transition from one message to the next with no perceptible dimming or blanking of the display, and with no visible effects such as fade, dissolve, or animation. Different jurisdictions have described such prohibited effects differently, but the purpose is the same – a seamless, imperceptible transition from one image to the next.

Recommendation.

No special visual effects of any kind should be permitted to accompany the transition between any two successive messages. (Of course, it is assumed that no special visual effects are permitted during the time that any message is displayed on the screen).

MESSAGE SEQUENCING.

Message sequencing is a term used to describe a single thought, idea, concept, message, or advertisement for a product or service that is divided into segments and presented over two or more successive display phases of a single DBB or across two or more individual DBBs. Like the old “Burma Shave” signs that lined the country’s roadways beginning in the 1920s (Vossler, 1997), the use of roadside advertising signs to communicate a message in segments is based on the premise of capturing and holding the driver’s attention throughout the time or distance chosen to present the complete message. This premise is, in turn, based on the understanding of the Zeigarnik Effect; or, as described in the Wikipedia entry, the signs were effective for “drawing the attention (of) passers-by who were curious to discover the punchline” (Wikipedia contributors, 2009).

We believe that sequencing should be prohibited, whether on a single sign or multiple signs. This can be effectively accomplished by establishing minimum longitudinal distances between DBBs, or by ensuring that the minimum message display time is sufficiently long that a driver cannot view more than two such messages on a given passage, or by a combination of both. Even more simply, restrictions can follow those promulgated by SANRAL, which state: succinctly: "no message may be spread across more than one advertisement" (SANRAL, 2000).

Recommendation.

Message sequencing should be prohibited.

AMOUNT OF INFORMATION DISPLAYED.

Other factors held constant, the more information that is presented on a DBB, the longer it will take an observer to read the message, and as shown in studies of official CMS, the more likely it will be that drivers will slow to read the message, adversely affecting traffic flow and safety. This concern is exacerbated in situations when a driver might want to memorize or memorialize part or all of a message displayed on a DBB. Dudek (2008), in discussing official CMSs using the latest LED technology, reports that about 85% of drivers can begin reading a message about 800 ft upstream of the sign if the sign uses character heights of 18 in. At a reading speed of one word per second (demonstrated in numerous studies), this translates to maximum message lengths of eight words at 55 mph, seven at 65 mph, and six at 70 mph (p. 9). One must keep in mind, however, that these message lengths assume a message optimized for legibility and readability. To the extent that message fonts, typefaces, colors, color contrast, and other factors detract from readability, these message lengths must be reduced.

To our knowledge, no US jurisdiction places restrictions on the amount of information that may be presented on billboards, including DBBs. As stated above, the amount of information on official traffic signs is controlled as a result of years of human factors research. Both the outdoor (OAAA) and on-premise sign industries (International Sign Association [ISA]) have, from time to time, provided guidance to their members about the relationship between the effectiveness of a sign and the amount of information presented on it.

Several government agencies outside the US have promulgated regulations or guidance that addresses this issue from the perspective of driver workload. Some limit the number of words or characters permitted on a sign; others restrict the number of bits of information that a sign may contain. Lengthy strings of numbers and/or letters, such as telephone or license plates numbers, or internet addresses, have come under scrutiny in a number of jurisdictions because of the demands that they may place on the driver.

There remains, however, a clear distinction between the efforts of highway and traffic safety experts on the one hand and the creators of outdoor advertising sign content on the other, in the approach that they have followed to the design of messages meant to be read by drivers. The MUTCD and the research on which it relies recognize that road signs are something of a “necessary evil.” They are required to communicate warnings, regulations, guidance and other information to road users. But, because even official signs draw the driver’s eyes away from the principal task, such signs are designed communicate their message quickly, clearly, and consistently. Advertisers, on the other hand, have demonstrated little predilection to follow these principles; rather, their goal is to attract the driver’s attention, and hold it long enough to communicate their message. For this reason, as well as others including brand identification and the need to compete with other signs for attention, billboards, including DBBs, tend to rely on bright colors, bold graphics, attention-getting images, and clever phrases to perform their job. Words and phrases may be presented anywhere on the sign face, including sideways and upside down, depicted in multiple fonts and typefaces that may be difficult and time-consuming to read. Color and contrast may draw attention to the sign and yet prove to be a challenge to the driver to read the message in the time available for it to be seen.

While it is not be within the power of any government agency or road operating authority in the US to dictate the type or nature of display content or presentation, we believe that it is reasonable for such authorities to impose limits on the amount of information that can be presented. Precedent for guidelines on information content can be found in the work of duToit and Coetzee (2001) in South Africa, Martens (2009) in The Netherlands, and Dudek (2008) in the US. The basis for such control as used on official signs is presented in the MUTCD (2003) at Section 2E.21 (p. 2E-20).

Recommendations.

Specific upper limits on the amount of information that might be permitted on DBBs should differ depending upon sight distance, speed limits (or prevailing speeds), and driver task demands imposed by the design and operation of the roadway. Without specific research it would be premature to recommend such limits in this report. However, reasonable guidance based on relevant human factors research, as discussed in Section 5 of the present report, has been developed by SANRAL (2000) and for the highway authorities in The Netherlands (Martens, 2009), and might prove to be a useful starting point for interested agencies. Further, the work by Dudek (2008) and his colleagues provides valuable insights, although this research is targeted at official CMS.

It should be noted that the use of telephone numbers, internet addresses, text message instructions, etc., is potentially harmful to traffic safety because drivers may slow to read, record, or even copy such information while in traffic. Evidence of such traffic slowing has been shown by Dudek, et al. (2007) with regard to AMBER Alert messages on official changeable message signs. Figure 6 shows a DBB displaying a commercial message that includes a number of these elements.

Figure 6. A DBB adjacent to an interstate highway in California. The sign includes an internet address, text messaging instructions, characters in multiple colors, sizes and typefaces, poor figure-ground contrast, and several graphic elements too small to read.

INFORMATION PRESENTATION.

As discussed immediately above, considerable research in both the US and abroad has produced clear and consistent recommendations for display presentation characteristics that facilitate speed and ease of reading and rapid, unambiguous message interpretation. These recommendations, through years of development and constant refinement have resulted in uniform standards for official signs. The lessons learned from this research, and the adoption of the spirit of such standards by the outdoor advertising industry could produce DBBs that facilitate rapid, error-free reading of roadside advertisements with lower levels of driver attentional demand and distraction. Typeface, font, color and contrast of figure and background, character size, etc., all play a role in the legibility and readability of a display. Figure 6, above, shows the potential difficulty of reading a message presented on a DBB with several display features that are less than optimum for readability by approaching drivers.

Recommendations.

Specific recommendations for the design of DBB advertisements are beyond the scope of this report, and, possibly, outside the authority of regulators. This is an area, however, where considerable guidance is available to advertisers and DBB owners from sources inside the outdoor advertising industry as well as human factors and traffic safety experts, and the MUTCD itself. Stronger industry guidance and self-regulation regarding the design of information presentation on DBBs could go a long way toward reducing their potential for driver distraction.

DBB Size.

The larger the size of the DBB, the larger the images and characters that can be displayed on it, the brighter it can appear to be, and the greater the distance from which it can be seen and read.

In the US, the majority of DBBs erected to date, and, to the best of our knowledge, the majority of those contemplated in the near term, are one-to-one replacements for, or the same size as, existing conventional billboards. The most common size for such billboards adjacent to roadways is 14 ft by 48 ft in a horizontal format.

Regulations governing DBB size may be based on factors other than sight distance or legibility, such as zoning, land use, structural constraints, etc., and are beyond the scope of this report.

On-premise and vehicle-mounted digital (and video) signs, do not necessarily conform to these standards. The issue of DBB size is this context is briefly discussed in Section 6.

Recommendations.

Since the principal focus of this report is off-premise DBBs, recommendations for maximum sign sizes are inappropriate.

BRIGHTNESS, LUMINANCE AND ILLUMINANCE.

The issue of brightness, luminance, and illuminance is at once the most contentious, the most important, the most "public," and the least well understood aspect of DBB operation and its potential for adverse impacts on approaching drivers. And yet, it is the issue that may be the most amendable to a solution that is satisfactory to DBB owners and operators, traffic safety experts and regulators, and the traveling public.

Brightness is a measure of the *perceived* intensity of a source of light. As described by Halsted (1993), "brightness is a subjective attribute of light to which humans assign a label between very dim and very bright (brilliant). Brightness is perceived, not measured… The response is non-linear and complex. The sensitivity of the eye decreases as the magnitude of the light increases" (p. 2). A DBB is constructed of thousands of Light Emitting Diodes (LEDs) that operate together to produce the myriad colors and levels of light that we see when we view such a sign. Thus, we may consider a DBB to be a source of light, although, in actuality, it is built of many individual sources. If we were to set a DBB to its maximum output and observe the sign in full sunlight, it would appear less bright to the human observer than it would if we viewed the same sign, at the same setting, at night. Similarly, if we viewed the sign at the same setting at night in a bright urban landscape it would appear less bright than if we viewed it in a dark rural environment. Accordingly, when trying to develop guidelines or requirements for the "brightness" of DBBs, what we really mean is that we need to establish objective, measurable limits on the amount of light that such billboards actually emit, and set different upper bounds for different environmental and ambient conditions. Such conditions might include daylight in sun or clouds, dusk and dawn, adverse weather such as rain or fog, and nighttime conditions in urban, suburban, or rural settings. In short, "brightness" cannot be used as a criterion to regulate or provide guidance for the output of DBBs.

Whereas brightness measures the subjective, human perception of the DBB's intensity, two objective measures are available for the actual measurement and establishment of limits. *Illuminance* describes the amount of light coming from a light source that lands on a surface. Horizontal illuminance describes the amount of light landing on a horizontal surface, such as the light reaching the surface of a desk or table from a lighting fixture mounted overhead. Vertical illuminance describes the amount of light landing on a vertical surface. For example, a light shining on a wall, or a vehicle's headlights shining on a non-illuminated road sign. Illuminance is measured in *footcandles (fc)* or *lux (lx)*. *Luminance* describes the amount of light leaving a surface in a particular direction, or reflected off that surface, and can be thought of as the measured brightness of a surface as seen by the eye. Luminance is measured in *candelas per square meter* (cd/m^2), also referred to as the *nits* (one nit = one candela per square meter). A typical LCD computer monitor, for example, has a luminance of 300 nits or higher.

We might think of illuminance as the lighting *of* an object, and luminance as the light coming *from* an object. In the case of a traditional, static billboard that is illuminated at night by floodlights, as well as in the case of a DBB which uses LED technology that is often described as "self-luminous," we are concerned with luminance, the light being emitted from the billboard rather than illuminance. Through a simple example, we can demonstrate how these two different measurement principles work, and why luminance is preferred for our application. If we shine a light onto a white wall, and shine the same light onto a dark grey wall from the same distance, the illuminance (the light falling on the wall) will be identical, but the luminance will be much lower for the grey wall, because it reflects back to the observer's eye much less of the light striking it.

Both the Illuminating Engineering Society of North America (IESNA) in its standard RP-19-01, and the Commission Internationale de L'Eclairage (CIE), in its publication 111-1994 (both cited in Andersen, 2008a), discuss luminance values for road signs – externally and internally lighted signs in the first case, and changeable message signs in the second. In its discussion of sign brightness, the 3M Corporation says: "luminance is the best measure available to judge relative sign brightness" (3M, 2005).

With an important exception discussed below, the luminance of a DBB is relatively unimportant during a sunny day. However, it is precisely because a DBB must have a very high luminance capability to be visible in bright sunlight, that its output must be reduced at night, at dawn or dusk, or in inclement weather.

Through what some have called the "moth effect" (see, for example, Green, 2006) but may be more appropriately seen as a variant of the physiological mechanisms of phototropism or phototaxis, the eye is drawn to the brightest objects in the field of view.

Thus, other things equal, a brighter billboard will attract a driver's gaze earlier and, potentially, longer, than other visual stimuli in the environment that appear less bright.

At night, dawn or dusk, or in inclement weather such as rain or fog, where visibility conditions are poorer than in daylight, a bright sign can draw attention away from the road, official TCDs, and other vehicles, and can render signs lighted to a lesser degree more difficult to discern, particularly when the billboard and the official signs must be viewed at the same time. Similarly, vehicle rear lighting can become more difficult to see, and less conspicuous, if it is to be viewed at the same time, and within the same field of view, as a brightly lit DBB.

There is no single luminance level that can be established as a reasonable criterion because brightness (although not actual luminance) is dependent upon the surrounding environment in the context of which a particular DBB is viewed. Thus, for example, a DBB of the same size and luminance will appear to the driver to be much brighter if it is located in a rural area or along an unlit roadway, than it would if it was in a brightly lit urban environment or adjacent to a illuminated freeway.

All of the research identified in this report, and all of the identified regulatory authorities that have imposed billboard, including DBB, brightness limits, use luminance as their measurement approach. On the other hand, the OAAA uses illuminance. The discussion below highlights these differences and explains the implications of them for the setting of regulations or guidance.

On behalf of the New York State Department of Transportation, the Lighting Research Center of the Rensselaer Polytechnic Institute (Bullough and Skinner, 2008) prepared a document titled: "Technical Memorandum: Evaluation of Billboard Sign Luminance." The principal purpose of RPI's work was to provide NYSDOT with estimates of the luminance levels of existing, static, externally-illuminated billboards adjacent to State highways so that the State could make an informed decision about maximum luminance levels that might be permitted for DBBs using "self-luminous light sources such as light-emitting diodes (LEDs)" (p. 1). The work consisted of three steps – a review of recommendations and methods to calculate luminances from IESNA and industry sources; field measurements of the luminances of several billboards in situ; and a computer simulation of a billboard lighting installation based on industry recommendations.

The report describes the IESNA recommendations (Rea, 2000) for "illuminated billboard signs and other large advertising panels" (i.e. the dedicated, fixed lighting shining on the billboard to illuminate it at night) and identifies two factors that must be considered when applying these values. The first is the degree of reflectivity of the billboard itself – a dark-colored sign will reflect less light than will a light-colored sign (assuming that the lighting sources are equal). The second is the surrounding location – whether the billboard is located in a bright, typically urban, setting, or in a dark, typically rural setting. The IESNA values for billboards in bright surroundings is 1000 lux (abbreviated lx), and for dark surroundings, 500 lx. Assuming that a billboard had a white sign face with a reflectance of 0.8, the luminance (L) of such a billboard (the amount of light reflected back from the sign) would be 250 candela per square meter (cd/m^2) in the bright environment, and 130 cd/m^2 in the dark setting. The authors then reviewed product information supplied by two billboard manufacturers and concluded that industry recommendations were in close accord with those recommended by the IESNA.

The researchers then recorded the luminance values for six conventional billboard faces and four LED billboard faces using a Minolta LS-100 luminance meter. Their measurement methods are well described in their report and won't be repeated here. They found that the LED billboards ranged from 160-320 cd/m^2 at night, with a mean value of 225 cd/m^2. The conventional billboards (excluding two faces that were apparently not illuminated) ranged from 150-240 cd/m^2 with a mean of 182.5 cd/m^2.

Bullough and Skinner next created a computer simulation model to determine whether they could reproduce their field measurements. Their model consisted of a 14 ft. by 48 ft. fixed, illuminated billboard with a white (0.8 reflectance) sign face and a 40 ft. tall mounting pole with reflectance of 0.25. Their virtual billboard installation was created in a simulated dark nighttime setting. They found that the luminance values of the billboard signs were generally consistent across their three tests, and they concluded that "it is probably reasonable to expect that the luminance of a conventional billboard would not be likely to exceed about 280 cd/m^2 during the nighttime" (p. 4).

When discussing luminance measurements for DBBs, the authors make several recommendations:

- Luminance measurements should be made directly in front of a sign.

- Because LEDs have higher light output at lower temperatures, measurements should be made within predefined, and consistent ambient temperature ranges.

- A luminance meter aperture of 1 deg or less should be used.

- Because LED billboards are composed of arrays of LEDs, their surfaces are not uniform. If viewed from very close distances, they will appear as an array of bright points against a dark background. Thus, a viewing distance of approximately 50 ft is suggested, since a 1-deg meter aperture would subtend approximately 10 in at this distance, sufficient to ensure uniformity of the display.

- Since light from the ambient environment adds to the recorded luminance, measurements should not be taken at distances greater than that suggested above.

- Measurements should be made while the sign display is white to present the maximum luminance values.

In its draft regulations, the State recognized that DBBs at night, if excessively bright, could not only cause distraction, but also could compromise dark adaptation, particularly for older drivers. (The potential for discomfort or disability glare was not discussed in the State's proposal, but was briefly addressed in the RPI report). Based on RPI's work and as a result of the State's review of the billboard industry's own published literature, the State initially recommended a "maximum brightness" for DBBs at night of 280 cd/m^2. This upper limit remained in force when the State issued its final regulations.

On behalf of the government of Queensland, Australia, TERS (2002) also described a specific measurement technique using luminance, and identified specific constraints for nighttime luminance levels. Appendix D to their report cites, as a basis for their guidelines, the research results from Johnson and Cole (1976) that "brightness from illuminated Advertising Devices directed at road traffic should be minimized under all conditions" (p. 20).

Similar to the work by RPI for NYSDOT, these authors indicate that the surroundings in which the billboard is located is a major factor that affects its brightness, given a particular luminance level. They have defined three "Lighting Environment Zones"

The maximum recommended luminance levels for billboards of all sizes, measured in cd/m^2, are as shown below:

Lighting Environment Zone 1	Lighting Environment Zone 2	Lighting Environment Zone 3
500 cd/m^2	350 cd/m^2	300 cd/m^2

TERS describes its luminance measurement methodology as summarized below:

- Allow the billboard to "burn in" for at least 100 hours.

- Use a luminance meter with a field of view of 2 degrees.

- Ensure that no ambient background area or spurious light source beyond the billboard is included in the field of view of the luminance meter.

- Take the measurement with the operator standing at the edge of the traveled way, in a direct line, and at a longitudinal distance from the billboard determined by a formula shown as:

  $$x = 28a \text{ meters}$$

  where x is the longitudinal distance from the billboard and a is the short dimension of the billboard. Thus, for a billboard that measures 14 ft. (4.3 m) in its shortest dimension, the measurement would be made from 120.4 meters (395 ft.) away.

- If the longer axis of the billboard is greater than 1.5 times the shorter axis, take a series of measurements and average the results to determine a mean luminance level for the entire sign face.

Although the luminance measurement distance recommended by TERS is greater than that proposed by RTI, there is a simple explanation for this apparent discrepancy. First, the measurement technique presented by TERS is for use with conventional billboards, and recognizes that there may be wide variations in luminance at different positions across the sign face. Thus, their measurement technique places the luminance meter sufficiently far from the billboard to take in the overall sign face without also including nearby ambient lighting sources. If the TERS measurement methodology were to be applied to a DBB, and if the measurements were to be made with a uniform white sign face, as proposed by RPI, then it is likely that the proposed measurement distances would be closer, recognizing that TERS suggests a 2 deg field of view and RPI suggests 1 deg.

Recommendations.

The measurement of luminance is reasonably straightforward, and, although there are some technical disagreements on how this measurement should be made, these differences are minor. Both New York State (Bullough and Skinner, 2008) and the Queensland (Australia) government (TERS, 2002) use equivalent methods, which are similar to the approach recommended by an FHWA expert in this field (Andersen, 2008b).

These methods can be adopted for use by any jurisdiction, with two caveats. First, although Queensland has explicitly recognized the need for different maximum billboard luminance levels depending upon different roadway environments, such ambient lighting conditions in the U.S. may differ from those in Australia, and State and local jurisdictions may wish to define their environmental surroundings to be in closer accord with local conditions "on the ground." Second, given that luminance standards must establish maximum acceptable levels, it is important that the any measurement of DBBs in the field be done with the signs set to their maximum output, i.e. displaying a completely white screen. Because digital billboards can display an essentially infinite variety of colors and patterns, it is not appropriate to take field measurements of signs displaying actual messages, since, at any given time, such messages may not represent the maximum luminance values of which the sign is capable. (Figure 6 shows a DBB which, because of its color, may be representative of a low luminance level).

The OAAA, in its "Code of Principles on Digital Billboards" (OAAA, 2008) makes the following statement with regard to DBB luminance:

> We are committed to ensuring that the ambient light conditions associates with standard-size digital billboards are monitored by a light sensing device at all times and that display brightness will be appropriately adjusted as ambient light levels change.

Although not included within its code of principles, the OAAA (2008) states:

> The outdoor advertising industry has established guidelines after commissioning research by Dr. Ian Lewin, a former chairman of the Illuminating Engineering Society of North America (IESNA). Digital billboards, according to the standards, should have lighting levels no more than 0.3 foot candles (fc) above the level of surrounding ambient light conditions."

Unfortunately, this research study is not available on the OAAA website, and OAAA officials refused our request for access to Dr. Levin's research. The language reported by the organization on its website, however, suggests two problems with their approach. First, they used illuminance as their measurement technique, whereas other organizations used luminance. Second, the OAAA expert apparently recommended that DBBs be controlled such that their maximum display output is capped at a fixed amount (0.3 fc) greater than the surrounding environment. This specification may be inappropriate because illumination levels do not increase in linear fashion. Thus, a DBB with an output that is 0.3 fc higher than the ambient illumination in an urban environment (where the majority of DBBs are likely to be located) will appear to the driver to be much brighter than official TCDs and other traffic, whereas a DBB with an output that is 0.3 fc higher than that of a suburban or rural environment may not appear to be so extremely bright, and may be less likely to overwhelm important safety targets and signals of lower luminance.

There is one ambient lighting/weather condition that suggests a need for an exception to the recommendations that DBB luminance controls are unnecessary in daylight. This exception occurs during daytime fog. In daytime fog, the ambient lighting conditions may be described as high brightness and low contrast. The water vapor in the atmosphere scatters light sources and may cause glare. In dense fog, drivers may have difficulty seeing vehicles ahead of them, even when these vehicles have their lights on. Multi-vehicle crashes are not infrequent in dense fog, and this is often attributed to drivers being unable to see vehicles ahead of them in sufficient time and distance to stop. The very high luminance levels of which modern DBBs are capable, and to which they are typically set during daylight so as to be visible in full sunlight, may have a potentially deleterious effect in fog, especially if the DBB is placed so that it is close to the center of the driver's focal vision upon approach, such as might be the case on a horizontal curve

As recommended by the OAAA, DBBs should be equipped with sensors that measure ambient brightness, and dimmers that can control the sign output to predetermined levels. Although necessary, this is not sufficient. These predetermined levels should be established by the means suggested above. Further, if the onboard sensors cannot detect daylight fog and adjust the sign's output accordingly, jurisdictions should develop their own output limitations for these conditions.

The good news is that regulatory bodies and billboard companies seem to reach similar conclusions about the maximum luminance values that billboards should not exceed under defined conditions. If these two stakeholder groups can agree upon measurement methods, environmental descriptors, and means for ensuring that limits are not exceeded, one of the key concerns about the distraction potential of DBBs could be close to resolution.

DISPLAY LUMINANCE IN THE EVENT OF FAILURE.

There are a number of failure modes that can affect the luminance of a DBB, and there have been reported cases of failures in which the display luminance defaulted to a level far higher than intended or permitted.

Although, as discussed above, the OAAA provides guidance on its website and in periodic reports about suggested upper limits on display luminance (which it calls brightness, and suggests that DBBs include a device to automatically control the sign brightness relative to the ambient environment, the organization is silent on the issue of luminance control in the event of system or subsystem failure.

Recommendations.

Roadway authorities should incorporate into their guidelines verifiable requirements that, in the event of any failure or combination of failures that affect DBB luminance, the display will default to an output level no higher than that which has been independently determined to be the acceptable maximum under normal operation. If this cannot be achieved, then the display should be required to default to an "off" position until the problem can be resolved.

LONGITUDINAL SPACING BETWEEN DIGITAL BILLBOARDS.

As noted by the OAAA, different States have widely varying longitudinal spacing requirements for billboards in general and DBBs in particular. These requirements are typically described by the distance in feet that the nearest billboards must be spaced from one another. Often there is a different spacing requirement for billboards on opposite sides of the road. From the perspective of potential driver distraction, however, longitudinal billboard spacing should not be based on absolute distance, but upon whether two or more such billboards are within the driver's field of view at the same time, and, consequently, whether the unsynchronized changing messages on such billboards can distract by conveying the appearance of flashing. Accordingly, longitudinal spacing minima may vary depending upon prevailing travel speeds, sight distance, and topography, and thus may vary considerably from one location to another, even within the same jurisdiction.

Recommendations.

Governments or roadway operating authorities should establish minimum longitudinal spacing requirements for DBBs such that an approaching driver is not faced with two or more DBB displays within his field of view at the same time. This minimizes the risk of distraction and ensures that a flashing effect (that may be caused by two [or more] different signs cycling through messages on different programs) will not occur. Any such longitudinal spacing requirements should address signs on both sides of the roadway. If a consistent spacing requirement is appropriate or necessary within any particular jurisdiction, then the most conservative spacing consistent with the above requirements should be established.

DBB PLACEMENT WITH RELATION TO TRAFFIC CONTROL DEVICES AND DRIVER DECISION AND ACTION POINTS.

Beyond the design and operational characteristics of DBBs themselves (brightness, display duration, etc.) perhaps the most important DBB characteristic with impact on traffic safety is the placement of such signs in relation to driver decision and action points, and to the traffic control devices (signs, signals and markings) that aid drivers in these decisions and guide them in these actions. Specifically, it is understood that the cognitive demands on drivers is greatest (other factors held constant) when they must position themselves to take an exit, enter a freeway, reduce or drop lanes, merge with other traffic, change route, etc..

The independent research reviewed for this report recognizes the importance of such constraints almost without exception, and the many jurisdictions, in the U.S. and abroad, that have published guidance and/or regulations nearly all address these concerns. And although these guidelines and restrictions are not fully consistent across regulatory agencies, they are remarkably similar. Although some published guidance and regulation is too vague to be useful in terms of enforcement potential or proven safety benefits. Others may well serve as a model that State and local governments, and other roadway authorities might adopt.

We believe that the adoption of objective constraints for DBB placement in relation to official TCDs, to intersections and interchanges, and to decision and action points is firmly justified because, to a great extent, the design and placement of TCDs themselves is the result of empirical research that has led to nationwide standards. Similarly, the design of intersections and interchanges, and of roadway design for safe and efficient traffic movements, is based on long-standing, well-researched, thoroughly documented principles. Accordingly, we believe that prohibitions against the placement of distracting irrelevant stimuli in roadway settings where drivers must make decisions and take actions should be imposed.

Recommendations.

The guidance provided by the government of Queensland, Australia is particularly well researched and documented, and might serve as a basis for US highway agencies. Similarly, the recommendations promulgated in New South Wales, Australia, are relevant, as is the guidance developed in South Africa, with specific regard to the placement of DBBs relative to official traffic signs.

ANNUAL OPERATING PERMITS.

There are several reasons why a Government agency or toll road or other roadway operating agency might want to rescind the operating permit for a DBB after initial approval. For example, traffic delays, crashes, or other operational difficulties may increase and the authority may attribute such difficulties to the presence or operation of the sign. New technologies may become available and used on the sign that the authorities find inappropriate. The sign may experience frequent failures or misoperation. The road abutting the sign may need to handle increasing traffic, or may need to be upgraded with additional lanes, interchanges, or signage, placing the DBB, after the fact, in a location that the authorities believe to be unsafe.

The City of Oakdale, Minnesota, as discussed in Section 5, grants annual permits to operate DBBs; the permits must be renewed each year. This allows the City to maintain oversight of sign operation, and facilitates updates to controlling legislation should new technologies emerge or should new operational data or research findings suggest needed changes to sign location or operation. Without such a process, a permitted sign may continue to operate unchecked, regardless of whether new information would suggest modifications to placement or operation.

Recommendation.

Government agencies and roadway operating authorities might consider the practice adopted in Oakdale, Minnesota, whereby owners of DBBs are granted a permit to operate a sign for a year, and must renew the permit annually.