1) How much training is needed to use the luminance measurement equipment?

For all intents and purposes, anyone can be trained to use this equipment in 5 minutes or less. The meter that I use is one of the more "complex" ones (i.e. it has more controls than most). But the reality is that, even when using my meter, I keep most of these controls on the same setting at all times. The only controls that are needed for other than scientific (laboratory) use are: (1) An ON-OFF switch; (2) A switch to select between cd/m^2 and % brightness; (3) A switch to select between whether you want a "fast" or a "slow" reading; (4) a rotating knob on the viewfinder eyepiece that allows the user to adjust the view to be in proper focus; (5) a focus ring on the lens (just like a camera); and (6) a pull trigger to take the reading. I tend to leave switches #2 and #3 set the same every time. Once the viewfinder is set for my eyes (just like you might focus a pair of binoculars) I never change it. And I tend to leave the ON-OFF switch ON when I am in the field, because the meter does not impose a big drain on the battery, and can be used for many hours. My meter uses a standard 9-volt battery; newer meters may be different. In practice, you turn the meter on, make sure the viewfinder image is sharp, aim the meter at the target, focus the lens, and pull the trigger. Depending on the meter, once you release the trigger, the reading that you just took will be "held" in the display until you either turn the meter off or pull the trigger to take the next reading.

2) Which jurisdictions have adopted the luminance measurements as a standard? And do they identify what their pros and cons to this standard are?

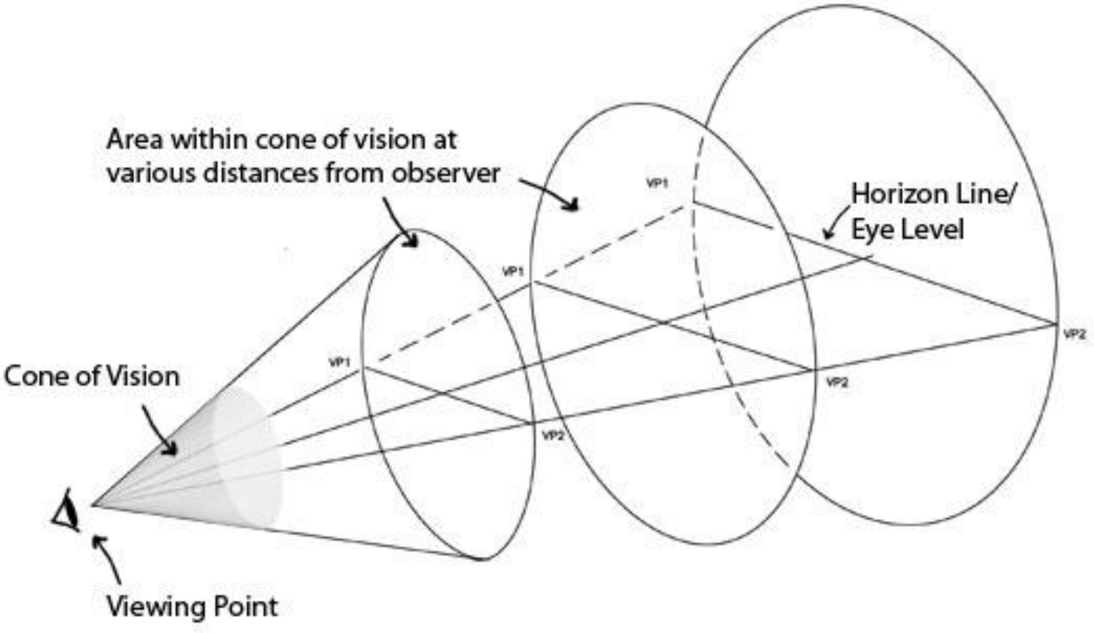
Because I don't follow this issue closely, I am only aware of the standards used by jurisdictions with which I have worked, or whose work I have come across. Therefore, this is neither a complete nor a representative list. Jurisdictions that use luminance include: (1) Outside the US: Australia, The Netherlands, Great Britain; Province of British Columbia, Canada; (2) Within the US: New York State, Chicago, Pittsburgh, PA. I'm not aware of any that have described the pros and cons of the standard that they use. (Such discussions may have taken place in earlier efforts by the jurisdictions, prior to arriving at a specific standard, but I have not seen these descriptions). The Federal Highway Administration (FHWA) does not set a brightness standard for billboards, but does uses luminance standards when measuring the required brightness for pavement markings and official traffic signs. And the consultants to the on-premise sign industry (from Penn State University) recommended the use of luminance standards for all on-premise advertising signs.

It should also be pointed out that the IESNA (Illumination Engineering Society of North America), which is the standards body from which Ian Lewin, working for the billboard industry, incorrectly chose the wrong standard to use in his work for OAAA, uses luminance, not illuminance as a standard for roadside advertising signs.

3) Is the size of a sign a consideration like it is with the foot-candle measurement? If not, why?

Sign size is irrelevant for luminance measurement, with one minor exception, discussed below.

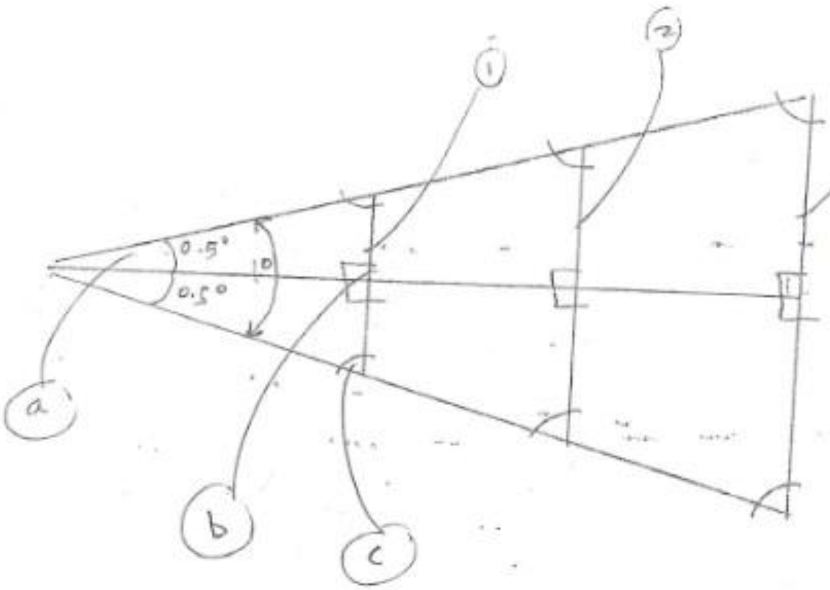
First, it's useful to know that the luminance meter (officially called a photometer; and called a Nit gun by the advertising industry) is designed to capture light (geometrically) much the way the human eye does. That is, we refer to the human eye as having a "cone of vision," through which we see the world. The cone of vision is often depicted in a drawing similar to the one shown here:



The cone expands as the distance from the eye increases, and thus covers an ever-larger area. The photometer works the same way. But whereas the cone of vision of the human eye is about 60°, the cone of vision for the photometer (depending on make and model) is only about 1° (some are as small as 0.3°).

When using the photometer, the user holds the meter up to his/her eye and looks through the viewfinder (much like a camera viewfinder). In the center of the viewfinder is a small circle, visually superimposed on the field of view. It is this small inner circle that represents the "angle of acceptance" of the meter; i.e. the size of the scene that will actually be measured by the meter's photocell. This angle of acceptance is the equivalent to the cone of vision, and therefore this circle represents, typically, either one degree (1°) or one-third of a degree (0.3°).

Let's use a 1° meter as an example, and apply basic trigonometry. I've made a crude drawing to show a flat plane (a slice) taken from the cone. The 3 vertical lines (#1,2,3) represent signs or billboards at different distances from the meter. The horizontal line across the center of the drawing represents the measured distance (along the "line of sight") to each sign. There are also 3 angles involved, (a,b,c). To make our calculations simple, we'll take our measurements from either the upper or lower triangle (as divided by the horizontal line). The measurements are identical for each of the two triangles.



We know that the "acceptance angle" of the meter is 1 degree. Therefore, the acceptance angle for each of the two triangles is 0.5 degree. Angle (b) is always 90° because it is the meeting of the horizontal line with the vertical line representing a sign. Since every triangle contains 180° total, that means that angle (c) = 89.5 degrees. (In our drawing, EVERY angle (b) = 90° and EVERY angle (c) = 89.5°. The only thing that will change is the length of the horizontal and vertical lines.

Let's say, arbitrarily, that line (1) is 100 ft. from the photometer; that line (2) is 200 ft. and that line (3) is 300 ft from the meter. We can now perform our trigonometry calculations to determine the "height" of Lines (1), (2), and (3).

We will use the tangent function. In the case of Line (1), we have the following info:

- The angle (a) is 0.5°
- The length of the horizontal line is 100 ft.
- The length of the vertical line (think of it as the height of the billboard) is unknown – this is what we want to solve for.

To determine the height of the vertical line (1), at the distance of 100 ft from the meter, we calculate:

- Tangent of 0.5° = Opposite (unknown) divided by Adjacent (100 ft).
    - The answer is that Line (1) is 0.87 feet tall.

Performing the same calculation for Line (2) at 200 ft, and for Line (3) at 300 ft., we have the following:

- Line (2) is 1.745 ft tall
- Line (3) is 2.618 ft tall

Now, since we did our calculations with only one of the two triangles (representing a 0.5° photometer field of view), we have to double the answer given for the height of each sign to accommodate the full 1° that the meter reads. Thus, we have the following in this example.

- Using a photometer with a 1° field of view
- Positioning ourselves 100 ft in front of a sign, the meter will read an area of the sign that measures 1.74 ft x 1.74 ft. (Of course, it's actually circular, so technically we are measuring a circular area that is 1.74 ft. in diameter).
- With our meter 200 ft away from the sign, our meter measures a circular area on the sign that is 3.49 ft in diameter.
- With our meter 300 ft away from the sign, our meter measures a circular area on the sign that is 5.24 ft in diameter.

The point of all this is simply to show that the photometer can hone in on a very small section of the sign to capture the light being emitted from that small area. Even from 300 ft away, we are measuring an area only about 5 ft in diameter, on a sign that may be as large as 20x60 ft. You would have to get thousands of feet away from the sign before the meter would capture an area that was larger than the sign.

So, to finally answer the question, the size of the sign is irrelevant unless we are so far away from it (many thousands of feet) that our meter's "angle of acceptance" is larger than the sign itself. In reality, of course, we don't want to measure the entire sign since it will be made up of many smaller areas with different colors and brightnesses. We want to measure only a small area of white – which is where the meter's small angle of acceptance comes in handy.

4) Does it matter what angle the measurement is taken from?

Essentially, no. Experts have reported that the angle of measurement makes a very minor difference (i.e. the greater the angle, the lower the luminance that will be read). But they report that the amount of difference, even for very wide angles away from straight ahead, is trivially small.

5) Are there any distance criteria? If so, what are they?

There are effectively no distance criteria. The viewer can be as close to, or as far from, the sign being measured as is desired. The only caveat to this is more fully explained in response to Q3 above.

6) For digital signs, how is it decided which message display to use when making the readings?

It makes no difference what message is being displayed as long as some part of that message (or its background) is displaying white or another bright color (such as yellow).

7) Did the readings in your study use the same message display on each digital sign, or did it use multiple message displays?

As described in more detail in response to Question 10, the readings that I took for the digital signs were of different, sequential message displays.

8) Does the use of the foot-candle measurement standard of turning on the all white message display make sense in terms of consistency? Otherwise, wouldn't there be a big discrepancy in the measurements taken from one message to another, based on the brightness of the message?

If I understand your question correctly, the all white message display (together with the fully off display) is necessary/required when using the foot-candle measurement. That's because, with this measurement, you are not measuring the brightness of the sign itself, but the brightness of the overall scene as it hits the viewer's eye – and the full-on vs. full-off measurement is the only way to know how much a particular sign is contributing to this overall scene brightness. But when measuring luminance, we are measuring the exact brightness of the sign itself – and as long as a portion of that sign is displaying white, the photometer can read that, and no more is required. So, while it is true that there will be large discrepancies between the brightness of one overall message to another, there will be little or no variation between white segments of any signs. So, as long as there is some white being displayed, that's all that's needed.

If, in the unlikely event that a given digital sign is not displaying any section that is white in any of its cycling messages, we can always do what we must always do for foot-candle measurement; that is, tell the manufacturer to turn the sign on to display white.

9) Why is there such a wide variation/discrepancy in digital sign measurement readings? Specifically, why is the average brightness of the I-395/2nd Street sign five times brighter than the GSR sign? When viewed from a distance, the GSR sign appears to be the brightest sign (or light) in the entire valley; Is it possible that there was a typo in the study with regards to the GSR sign?

You are correct. Although I tried to explain this in my report, it was buried in footnotes and thus easily overlooked. As I think you know, I took measurements on two different dates, and I measured the GSR pylon sign on both dates. I returned for the second site visit because it was pointed out to me that I had concentrated on the City of Reno on the first visit, at the expense of the City of Sparks and the County. Although I can't be certain, I believe that the surprisingly low readings of the GSR sign during the first visit were simply a result of the fact that the sign was presenting images on that date that were of lower luminance than was typical, or that, whoever was controlling the sign had it set to a lower luminance level. During the second visit, the luminance levels of the GSR sign were much higher, and close to the brightest signs that I measured. For clarification, see Note 5, on page 36, Appendix 1, Part 2. Also see Appendix 2, Part 1, where the sign measurements are shown for the first visit (it is shown as Sign #17), and Appendix 2, Part 2, where the measurements are shown for the second visit (here it is shown as Sign #40). Hope this clarifies things.

10) Why are there a different number of readings for each of the signs in your study? (I.e. one has two; one has eight, etc.).

When I measured static (i.e. non-digital) signs, I took several readings of each sign in order to capture a range of the brightest to the dimmest parts of the message and background. Although I didn't follow any specific self-imposed rules, I generally took fewer readings for signs that displayed fewer colors or tones, and more readings for those signs that displayed more colors. In addition, although all of the static signs were lit by floodlights (mostly below and aimed up at the sign) some had 4 floodlights, some had fewer. In some cases, there were only 1 or 2 floodlights for a given sign. This led to darker and lighter sections of the sign – even when the message or background was consistent across the sign. When I observed such a case, I took additional readings to account for the different levels of brightness caused by less or more light falling on the sign from its floodlights.

This method also permitted me to document that, even with some signs (or parts of signs) that were quite dim, and far below the digital signs in brightness, the signs could easily be read by an approaching driver with no difficulty. (This was true even for the dimmest billboards, and the one that was lit by only a single floodlight).

When I measured digital billboards, I could only capture one meter reading per message cycle (given the time to aim the meter, take the reading, and record that reading in my notes). So, for each different display, my goal was to try to capture the brightest part of the display – since our objective was to find out “how bright” these signs were. If several different displays in the rotation had similar luminance values, I found no need to take additional readings. The higher number of readings took place at signs that had very diverse levels of brightness form one display to another.

11) When Sparks staff measured a bright digital sign with a foot-candle meter, they discovered that the sign was over 4 times brighter than the allowable .3 foot-candle measurement; when the sign was dimmed to the .3 foot-candle measurement, the result (difference) was significant? Based on your research, is there an acceptable foot-candle measurement that compares with an acceptable luminance measurement?

I think we could approximate this, but it would not be very precise. That’s because, since luminance and illuminance are measuring two very different qualities (i.e. light coming off a surface vs. light falling onto a surface), there is not a simple formula that allows us to compare one to the other.

Keep in mind that the illuminance measurement is .3 footcandles *above* ambient light levels. Ambient light can change dramatically based on what’s surrounding the sign from buildings, streetlights, and other signs, to the presence of moonlight. When ambient light is higher for any reason, the sign brightness can be raised accordingly, and could reach levels that cause glare to drivers and other road users. And, from my perspective in traffic safety, I believe that sign ordinances are meant to protect the driving public as well as the community.

At the risk of repetition, I should stress that a foot-candle meter, when using 0.3 fc as the criterion, is not a measure of how bright a sign is; rather it is a measure of how much brighter that sign is than surroundings in which it is seen. So, 0.3 fc is not equivalent to 300-350 nits. There are no signs that measure 0.3 fc; rather there are signs that measure 0.3 fc above the ambient light levels. And since we know that signs measuring 0.3 fc above ambient tend to also measure about 300-350 nits, we can say that this measure is approximately 3 to 3.5 times brighter than necessary, because numerous studies (including those by the on-premise sign industry) have shown that no sign need be brighter than about 100 nits.

These same studies have shown that signs that reach 350 nits are unnecessarily bright; that they are not easier but more difficult to read; and that, under certain circumstances, they can cause glare that can compromise driver performance.

12) The foot-candle system measures brightness above ambient light and the nit measurement doesn’t. Measuring above ambient seems to be the preferred method when measuring sound, why not when measuring brightness?

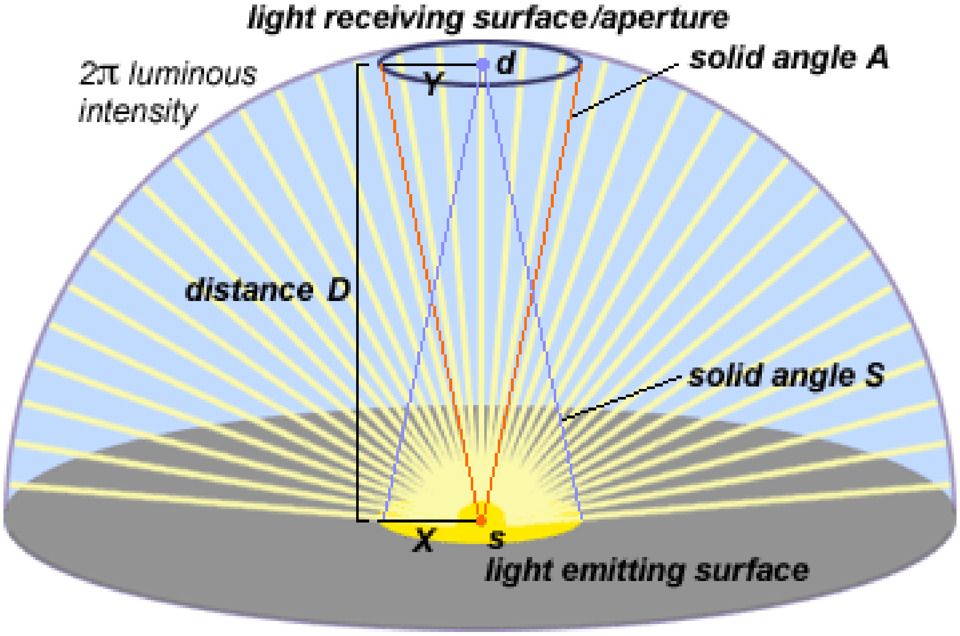
I respectfully disagree. When we set standards for a wide variety of auditory signals (e.g. home smoke alarms; train horns; emergency response sirens; warning alarms in factories and process control plants, etc.), my experience tells me that these are always set for specific, absolute values of loudness, measured on the db/A scale (i.e. the "A-weighted decibel scale"). This is in part for simplicity – i.e. a single standard for, say, a household smoke alarm or for a police vehicle siren means that the manufacturer has to meet only a single, well defined requirement. But the principal reason is that scientists have found that a single decibel standard for each type of auditory device is sufficient to accommodate the vast majority of circumstances in which it may be used. (Again, this is analogous to the sign brightness standard).

This is not to say that "one size fits all." For example, a household smoke alarm is required to have a lower db/A value than a safety alarm required in a noisy factory building. But the research has shown that two levels (let's call them home and factory) suffice for essentially all cases.

Note that traffic signals, pavement markings, and official traffic signs are all designed to a single standard – even though they are used in environments varying from illuminated city streets and highways to rural, unlit roadways. In addition, the NHTSA (National Highway Traffic Safety Administration) sets rigorous standards for vehicle headlights – and prescribes only two brightness requirements – regular and high beam, because these two different settings have been shown to accommodate the vast majority of applications. But all vehicles used on public roads in the US (whether they are cars, trucks, buses, motorcycles, etc.) are required to meet the same, single standard for headlight brightness (as well as many other details).

Final Note. Although not mentioned in my report, and not addressed in the responses to your questions, we have recently learned, through another issue in another city, another disadvantage to using illuminance (footcandles) as the measure. This is of particular relevance in cases where digital signs may be in close proximity to each other, as might be the case with on-premise signs.

When using the illuminance measure, the meter being used (intentionally) is devoid of a viewfinder. This is because the meter measures light from the entire scene (a half-sphere in front of the meter face (see illustration below – but ignore the text). The meter measures ALL of the light that is falling onto its receptor. Thus, a measurement is taken once with the sign turned off, then again with the sign turned on to full brightness. The difference between the two meter readings is the amount of additional light contributed to the scene by the presence of the sign. Lewin, working for the OAAA, has determined that a sign is acceptable if it adds no more than 0.3 footcandles (o.3 fc) of illumination to the scene.



But here is the problem. Instead of resulting in a single, repeatable standard that is applicable to all digital signs that may be proposed, this method instead inevitably results in a steady increase in the lighting levels permitted. This is because, as each new sign is permitted and constructed, the background (ambient) illumination of the overall scene as recorded by the illuminance meter will be increased by the presence of that sign. Thus, when (let's say) Sign #1 is proposed, it is allowed to be 0.3 fc brighter than the environment without any signs. But, once Sign #1 is built ad operational, Sign #2 may be proposed. This sign may now be permitted if it is no more than 0.3 fc brighter than the environement that now includes Sign #1. Similarly, when Sign #3 is proposed, it may be permitted to become 0.3 fc brighter than the environment that now includes both Sign #1 and Sign #2. The closer these signs are to each other, the worse this problem becomes. But the bottom line is that there is not a single standard; rather a standard that permits ever increasing sign brightness.