Florida Highway Patrol

Emergency Lighting Research

&

Prototype Evaluation

March 2004

Authored by

Lieutenant James D. Wells, Jr.

Foreword

Beginning in 1998, the Florida Highway Patrol began to examine safety issues surrounding the roadside environment in which we do much of our work. This began with a holistic approach, looking into all aspects of the issue. This includes working with manufacturers to make the vehicles safer, the installation of aftermarket equipment, policies and procedures for making the stops and working outside the vehicle as a pedestrian. We also looked at collision avoidance through improved vehicle markings, lighting and roadside warnings, such as traffic cones. We also looked at the design of the roadway itself and motorist's behavior that resulted in actions such as the Florida Move Over law. This research continued with participation on the Arizona-Ford Blue Ribbon Panel and now the International Association of Chiefs of Police Law Enforcement Stops and Safety sub-committee of the Highway Safety Committee. The following report codifies the research specifically related to lighting and the evaluation of three prototype systems provided by Code 3, Federal Signal Corporation and Whelen Engineering. During the development of the lighting system, I also assisted with the development of a new low frequency siren. While not utilized during a traffic stop or while working a traffic crash or other roadside incident, it may increase the warning given during a response and hopefully the margin of safety.

Again, we dedicate this research to the brave men and women who daily risk their lives to protect ours.

Lieutenant James D. Wells, Jr.
Equipment, Compliance and Testing
Florida Highway Patrol

Background/Research

The manner in which we signal persons visually has changed little over the last several centuries. Some of the oldest references to signaling are found in chapter 13, verse 21 of the book of Exodus in the Bible as God was leading the nation of Israel in the desert: "And the Lord was going before them in a pillar of cloud by day to lead them on the way, and in a pillar of fire by night to give them light, that they might travel by day and by night (NASB)." References to elevated open fires that led pilgrimages across the desert and that served as early lighthouses for sailors are found well before the birth of Christ over 2000 years ago. Lighting systems evolved to gas and oil lamps and mirrors were devised to focus and pulse the light to better signal at a distance. These systems continued to evolve to electric arc lamps with Fresnel lenses such as the one shown here from the Ponce Inlet Lighthouse in Florida.

While current lighting on emergency vehicles has taken a technological leap from these lights, it is essentially miniaturized versions of the same. When the Arizona-Ford Blue Ribbon Panel met, we were fortunate to have on the Lighting and Conspicuity Committee, Doctor Luis Tijerina, who is a specialist in motorist behavior. We challenged ourselves to take a new look at emergency vehicle lighting along with human behavior and perceptions. Technology has advanced to the point that we can do more than just mimic previous work. We felt we had an opportunity to optimize the light design for our current environment. The lights that our current lighting evolved from (lighthouses and airport beacons) were intended for a different audience than what we encounter in our current work environment. These lights are focused to reach long distances; often many miles, to warn or to help sailors and pilots locate specific points. These sailors and pilots are usually well trained, alert and actively seeking this signal. The drivers in vehicles we are attempting to signal are often impaired by fatigue, drugs or alcohol, distracted by other factors in their environment and are not actively looking for stopped emergency vehicles. It is from this standpoint that we attempted to optimize the system. We also had one further challenge that designers of lighthouse and airport beacons did not have - we have vehicles passing very close to the emergency vehicles which becomes a factor at night. While we can continue to increase brightness as one means of increasing warning power, we are reaching the point that we must consider the impact on drivers that are close to our vehicles at night, when night or temporary blindness could occur. Too much light may keep the drivers from seeing officers ahead of the emergency vehicles who are directing traffic or assisting disabled vehicles or moving debris in the roadway itself.

What follows is a discussion of the lighting research that was located by the Blue Ribbon Panel and research located and reviewed by me after the Blue Ribbon Panel ended and the IACP LESSS began. I will then present the results of the recent evaluation of the prototype equipment that was designed and built using this research which is only now available due to advances in LED light sources and digital switching power supplies.

Study Review

In this section, I will review the studies that were used as the basis for the prototypes designed and evaluated for this study. Some of these studies are notable for the perceptual problems they identified with current lighting that we attempted to overcome, and some of the studies were used because they pointed out perceptual features of humans that did not appear to be accounted for in current lighting design that may provide improvement in crash avoidance.

Messages

Doctor S. Solomon[1] has reduced the goals for emergency lighting to the very basics. He has stated on several occasions that we have overly complicated our emergency lighting packages, that there is too much movement and not enough direction. In other words, with large multiple flash lightbars and strobes hanging on ever corner of the car, you have drawn attention to the vehicle, and relayed absolutely no information other than, “I am here,” to approaching motorists. He is also critical of single level amber arrow functions as not being well understood by the public. Dr Solomon currently advocates the old single dome rotating lamp as an effective warning signal. I think we have incorporated many of his philosophies and worked around several of his criticisms while improving our signal over the single dome lamp. Dr. Solomon also never specifies a particular signal color, rate, duration or intensity in his work.

The most important function of emergency lighting is the message you are trying to send. Are you attempting to draw attention or warn of a hazard? Are you trying to direct traffic in a certain pattern?

Dr Luis Tijerina and the rest of the Blue Ribbon Panel, Lighting and Conspicuity Committee tried to continue with the common sense approach of Dr. Solomon. We attempted to define what signal(s) we wanted approaching drivers to perceive. It is important to warn that a hazard exists. We also need motorists to know if the emergency is in a normal travel lane or off the roadway, how far they are from our vehicles and at what rate they are approaching, so they can take the appropriate action. These are the most desirable "true states" that our vehicle is in.

Additionally, we examined several states that due to human perception might not give the true state of the vehicle, but another acceptable state. Could we by optical illusion make the vehicle appear closer to the approaching motorist than it really is, or could we make the vehicle appear that the motorist was approaching or closing the distance between the two vehicles more quickly than reality? As long as the illusion is not so powerful as to create an undesirable overreaction, we believe these additional states could be helpful in collision avoidance.

Lighting and Human Response

One of the most basic of human responses we learned about was sensitivity to color. At night, sensitivity to blue is greater than sensitivity for red, while in daylight, sensitivity to red is greater than blue. With flashing lights[2], twice the amount of blue light energy is needed in daylight to be perceived as bright as red. At night, though, the situation is reversed. In night viewing conditions, only about one-third the intensity of a blue light is needed to match the perceived brightness of a red light. So, the sensitivity of the human eye to lighting of different colors depends, at least in part, on the ambient light levels in which those lights are being viewed.

Color Blindness

Also of interest in this discussion is the topic of color blindness. Almost 8 percent of males have one of the three most common types of color blindness, while only .5 percent of females exhibit these same characteristics. This may partially account for the over-representation of males in the Florida Highway Patrol *Rear End Collision Study 1999*. Normal vision is trichromatic or capable of seeing three (3) colors. The most important characteristic of color blindness for us is how they perceive the most common signaling colors[3]. Some color blind persons perceive the light with normal intensity regardless of the color they see, while others see certain colors with diminished intensity. It is the types that see diminished intensity that affect our choices the most. The three most common types of color blindness are as follows.

1. "Totally color blind" or monochromatic (one-color) vision. To these persons everything is just shades of grey.
2. There are two classes of dichromats (two-color) vision, each representing about 1 percent of males.
    a. The first is those that have trouble discriminating colors over the range that a normal person sees as red. These are called protanopes.
    b. The second are those that have trouble seeing green and are called the deuteranopes.

In these types of color blindness when looking at colored lights against a dark background, they see a red signal as yellow, the protanope sees a much dimmer light.

3. The third class of color blindness is anomalous thrichromats. The most common type of this, representing 5 percent of males, deuteranomaly. A deuteranomalous observer, unlike a deteranope, can see red and green as normal in the red-yellow-green range of hues and may show a very slight loss of luminous efficiency in the green-blue spectral range. Protanomaly affects about 1 percent of males and involves the same basic features listed above for deuteranolmaly, except that the luminous efficiency loss is in the red is quite definite, being similar to the loss in full protanopes.

All other types of color vision impairment are rare, even in males, but a third type of dichromatism, called tritanopia, is important despite its rarity. Tritanopes cannot perceive the qualities of blueness or yellowness, and to them all colors are red or green, the only variation being in lightness (or brightness) and saturation. Their luminous efficiency curve is nearly normal, but may show some loss of sensitivity in the blue. The significance of tritanopia, and its associated form of anomalous tritchromatism, is that as the size of the stimulated area of the retina becomes smaller and smaller such as warning lights at a distance, persons with normal vision may become tritanomalous. The cause of this is not known, but very brief flashes seem to aggravate it as well as lamps occupying a small area of the retina or that provide limited retinal illuminance[4]. If dim, small, brief flashes aggravate this condition, it would appear that a larger lamp of sufficient intensity, and that had sufficient on time, should overcome much of this affect.

Blue Advancing-Red Receding

Another interesting human perception is Blue Advancing-Red Receding. This effect could skew your ability to determine the true state of a parked vehicle. In other words, particularly in a dark environment, it could be difficult to determine whether the vehicle is actually parked or moving. At night or under darkened conditions, your eye will perceive that a lamp emitting a higher frequency, shorter wavelength of light (violet or blue) will appear to be moving closer to you, while a lamp with a lower frequency, longer wavelength of light (red) will appear to be moving away from you[5]. I have personally observed a different experiment where red and blue LED’s were simultaneously illuminated, closely together. I was very close (within 10 feet) but it was quite obvious that the red lamp appeared farther away than the blue. Had I not seen that the lamps were attached to each other and at the same distance I would not have believed it. This effect could either make it appear the vehicle was closer to the motorist than actual, creating an earlier response and cushion of safety, or could make the vehicle appear to be moving away and create a hazard.

A study located by Dr. Tijerina found that not only did light color have an effect, but the sequencing, and number of warning lights mounted on the top of the vehicle also affected the results of the study[6].
The lighting systems evaluated were:

- Federal Signal Co. #184: single dome red, center roof mount, 4 sealed beams, 90^0 separation, 1.75 flashes per second
- Federal Signal Co. #184: single dome blue, center roof mount, 4 sealed beams, 90^0 separation, 1.75 flashes per second
- Federal Signal Co. #11: Twin beacon red, 2 sealed beams in each dome, 90^0 separation, 1.17 meters between lamp centers, 0.87 flashes per second (flashes alternate from side to side at 0.87 flashes per second each, 1.75 flashes per second overall)
- Federal Signal Co. #11: Twin beacon blue, 2 sealed beams in each dome, 90^0 separation, 1.17 meters between lamp centers, 0.87 flashes per second (flashes alternate from side to side at, 0.87 flashes per second each, 1.75 flashes per second overall)
- Federal Signal Co. #12: TwinSonic blue, 2 sealed beams in each housing, 180^0 separation, 1.12 meters separation between lamp centers, 0.87 flashes per second (front view), 3.50 flashes per second overall
- Federal Signal Co. #12: TwinSonic red, 2 sealed beams in each housing, 180^0 separation, 1.12 meters separation between lamp centers, 0.87 flashes per second (front view), 3.50 flashes per second overall
- Federal Signal Co. #12: TwinSonic red right/blue left, front view, 1.12 meters separation between lamp centers, 0.87 flashes per second (front view), 0.87 flashes per second overall
- Federal Signal Co. #12: TwinSonic red right/blue left, rear view, 1.12 meters separation between lamp centers, 0.87 flashes per second (rear view), 087 flashes per second overall

Table 2: "Desirable" responses in rank order (Wells 2003)

	Percent of Responses	
Light System	**Stationary/Moving Towards Combined**	**Moving Away**
TwinSonic (Blue)	73	27
Single Dome (Blue)	70	30
3 Blue Lights Together	66	34
Single Dome (Red)	64	36
Twin Sonic (B+R; rear)	64	36
TwinSonic(Red)	62	38
TwinSonic (B+R; front)	60	40
3 Red Lights Together	57	43
Twin Beacon (Blue)	56	44
Twin Beacon (Red)	45	55

For purposes of safety, a vehicle that appears stationary, or a vehicle that appears to be approaching the motorist would appear acceptable as long as the movement toward the motorist was mild and did not provoke an alarm response, creating panic and an inappropriate driving action. In fact, some degree of perceived movement toward the motorist may invoke a desirable early response. Revising the original study results by combining the response of "Stationary" and "Moving Towards", creates the above table in which the lights are ranked in order of those providing the highest score of "desirable" response to the least "desirable" response. This table shows that blue overall provides the preferred response. The only great exception is the Twin

Beacon. Here, the blue still significantly outscored the red, but both of these lights showed poor response compared to the other systems tested. This may indicate that side-to-side alternating lights provide an inferior pattern for motion detection regardless of the colors used. As this study only analyzed lamps at night, the results can only be used to predict lighting effects under dark lighting conditions.

Light Color

Again the ambient light affects perception. While we learned earlier that red light is more easily perceived during the day and blue at night, blue has another advantage at night. Because most vehicle lighting at night is red, the blue stands out against this background[7]. We must be aware of the deficiencies exhibited by color blind persons that perceive some colors as less intense than other persons. Traditional light sources also influence the perception of color. For example, halogen light sources tend to produce more light in the red frequencies while xenon discharge strobe tubes produce more light in the blue frequencies. Filtering either of these light sources reduces the light output. Because filters vary in the amount of light they let through we will not state numbers but in general for halogen lights, clear filters let the most light through followed by amber, red and blue. For strobe lamps, they let the most light through clear, followed by amber, then blue, then red. This explains in part why on vehicles using multi colored lights, the amber almost always overpowers either the red or blue lights. LED (light emitting diode) lamps only produce the color you see and no filters should be used. During the evaluation reported on in this document, we saw for the first time that the amber lamps could be overpowered by the red and the blue and this made the arrow function less clear to many observers.

Another consideration in light color has been suggested by several authors. They ascribe societal instinctive reactions to particular colors. For example, red is considered a color of danger. It turns out that green filters would allow a considerable amount of light to pass through from halogen and strobe lamps, but because we currently perceive green as "go" and associate it as an "okay" signal, its use is questioned as a warning lamp.

Red has another advantage over blue in hazy, smoky or certain types of fog. Red light tends to scatter less than blue and will retain greater intensity at a distance[8]. This is not a factor in larger particles such as rain. You can observe this by looking up at the sky. The blue that you see in the atmosphere is blue rays that have been scattered by small dust particles and other elements in the atmosphere. The larger particle water vapor scatters all light equally which is why clouds appear white, unless they are extremely thick and block a great deal of the light appearing grey or dark in color. Even when showing a dark color, the clouds are a neutral grey and no color shifting is noted.

Light Output

Generally, brighter lights produce greater conspicuity. The ambient light has great relevance in this, for example, a lamp that appears bright in the dark, may not be visible in bright daylight. Also, the duration of the on time affects perception if the on time is very short as in strobe lamps. The strobe lamp manufacturers have worked to increase on time through the use of double, triple and quad flashes. For example, Smith reports that the Society of Automotive Engineers found that halogen lights were perceived as bright as strobe lights because even though the halogen lights were 1/20th the peak intensity, they were on 100 times longer than the strobe light's 250 microseconds.

Flash Frequency

It appears that lamps with faster flash rates provide greater attention getting power than lamps with slower flash rates[9,10]. What rate is ideal then? The human eye has limits to what it can perceive. Lamps must be off for a certain amount of time before they can perceive that a lamp went off. Flash rates approaching 20 Hz or 1200 flashes per minute (fpm) begin to appear as steady lamps. You see this with television and movies that actually blank between frames, yet we perceive smooth movement between pictures and continuous action. Flash rates approaching 10 Hz (600 fpm) are thought by some to possibly produce increases in the alpha brain waves and this effect is known as photic driving. The subjective experience is usually unpleasant, and may include dizziness, nausea, nervousness, and strong urges to escape the situation. The essential nature of the disease known as epilepsy, is an instability of the brain's electrical activity. While some sources state that these quick flash rates can cause epileptic seizures, industry sponsored research disputes this with some authority. This author recognizes the conflicting data and has no independent research upon which to base a verdict. The Society of Automotive Engineers in its standards generally recommends flash rates between 1 and 2 Hz or 60 to 120 fpm.

After the design of the prototype lightbars was set, I was provided several studies by the Transportation Lighting Group, Lighting Research Center, Rensselaer Polytechnic Institute. These studies[11] indicate that flashing lights are more conspicuous than steady lights. Snow plows operating under impoverished visibility were actually less likely to be struck when a steady burning lamp was placed at the extreme ends of the plow itself (the plows are often much wider than the truck on which they are attached). The explanation was that the steady burning lamps, while actually detected well after the flashing lights, gave a better indication of the location of the plow, its speed and current path than did the flashing lights.

A study done by the Florida Highway Patrol in 2001 on electronic flare/fusee replacement came to a similar conclusion when attempting to inform motorists of a lane closure and the need to merge to another lane. The flashing lights did a poor job of indicating the lane was closed and a movement was desired/necessary.

A compromise never suggested by any study located to date was to combine flashing and steady lights. Some research was done with lamps that actually flickered, providing both steady and flashing elements in the same lamp[12]. It is reported that observers found these flickering lamps to be brighter than the same lamp shown steady. However, the optimum brightness was found at 10 Hz. It is unknown if a flickering lamp would trigger the epileptic episodes reported for lamps going completely on/off. It was noted in our flare replacement study that the current open flame flare we use was the most effective over both the steady burn and flashing lamps. The flame itself, while constantly bright, has a flicker effect to it that may have contributed to this observation.

Distance Perception/Rate of Closing

While not exactly the same, these two factors greatly influence our ability to properly react to not just stopped police cars, but all other vehicles on the road. The following paragraphs are excerpted from Committee Report: Conspicuity Enhancement for Police Interceptor Rear-end Crash Mitigation[13]:

"There are a lot of visual indicators to distance that might be used by a driver. The following list is compiled from several sources[14]:

- Visual angle: Change in size or shape of an object with changing distance (more about this later);
- Linear perspective: This refers to the apparent convergence of parallel lines, e.g., railroad tracks or lane lines that appear to converge to a vanishing point on the horizon;
- Texture gradients: Many objects have a surface structure or "grain". The farther away an object, the smaller its details and the more densely packed those details become and this gradient of texture provides information on distance. Also, equal spaces appear increasingly smaller with increasing depth or distance. Very uniform or homogenous road surfaces take away such cues;
- Interposition: Near objects partially conceal objects farther away such that the fully exposed object appears nearer;
- Elevation: The horizon is higher in the vertical dimension of the optical flow field than is the foreground. Near objects appear below the eye level while distant objects appear at or above eye level.
- Motion parallax: Nearer objects are displaced more rapidly than objects farther away as the vehicle changes direction (or the driver's head is moved).
- Aerial perspective or Clearness: Closer objects appear sharp and distinct while objects much farther away appear blurry or less distinct due to dust, water vapor, or other particles in the air.
- Familiarity: Familiar objects have an expected size and shape based on prior experience.
- Relative size: When two similar objects are viewed at the same time, the larger one will appear closer.
- Equidistant tendency: In the absence of effective distance information, objects that appear close to each other will tend to be perceived as equally distant from the viewer.

Other cues might also be mentioned but they are thought to play a less important role in driving. These cues include accommodation (i.e., change in the shape of the lens within the eye), convergence (i.e., tendency of the eyes to turn toward each other while observing very close objects), stereopsis (i.e., the slightly different images in each eye that results from their different vantage points), and brightness constancy (i.e., dimmer objects appear to be further away than the same object at a closer distance). These cues will not be discussed further because they a) either operate only for distances so close or so far as to be unimportant for driving, or b) because they are relatively weak cues as compared to visual angle or motion-based cues.

The information for distance to another object on the ground appears to be related to the amount of texture in a visual angle of the optical flow field. Researchers had observers on a level field of grass move a mobile marker on wheels to a halfway point between themselves and another marker up to 350 yards away (Purdy and Gibson[15]). People were able to do this fairly well. As Gibson[16] explains, the number of grass clumps in the farther half of a stretch of distance is the same as the number of the nearer half even though the optical texture of the farther half is denser and more vertically compressed. What remain invariant are equal amounts of texture for equal amounts of terrain."

Dr. Tijerina also examined the method by which we know relative speed to another object and then control braking. The following two sections, "How do I Control My Braking" and "How Do I Know Closing or Relative Speed?" are taken verbatim from the Blue Ribbon Panel report.

How Do I Control My Braking?

The imminence of collision with an object is specified in the optical flow field by an explosive rate of magnification called looming[17]. If a driver approaches a stopped vehicle ahead at a constant speed, this is accompanied by an accelerated rate of magnification. This explosive rate of magnification called looming has been studied to determine how it might provide time-to-contact information. Optical time-to-contact is called tau and tau at any given point in time of approach is equal to the instantaneous visual angle of an object to the driver's vantage point (in units of radians or degrees of visual angle), divided by angular rate (given in units of radians per second or degrees per second). This ratio yields seconds of time-to-contact. In physical (rather than optical) terms, this equates to range (in meters or feet) divided by range rate (in meters/second or feet/second), the ratio of which also yields seconds to contact. This is currently an area of research and evidence exists that people may use tau, optical expansion rate alone, or some combination of visual angle and expansion rate other than tau[18]. What is clear is that a) looming is a critical cue to collision, b) to avoid hard contact, looming must be cancelled through braking action or else the driver must steer away from the object.

How Do I Know Closing or Relative Speed?

Drivers sometimes drive into the back of slow-moving vehicles, vehicles stopped in the travel lane, or parked vehicles on the side of the road. These crashes occur when visibility is not a problem and intoxication or health factors are not at play. These types of crashes are often attributed to driver inattention but perceptual deficiencies may be intermingled as well.

Olson[19] and others have analyzed the difficulties people have in judging closing speed. It was mentioned above that a main cue to distance is the image size an object subtends at the driver's point of view. If the image grows larger, we know the object is coming toward us (if we judge we are at a standstill as indicated by other information in the visual flow field) or we are moving toward it (if so indicated by the information in the visual flow field). The rate of change of object size, looming, has been discussed as a primary cue to control braking. Perceptual deficiencies in detecting change in object size will contribute to crash risk under certain conditions, e.g., at night.

The rate of change in image size depends on both speed of approach and viewing distance[20]. Consider Figure 1, which shows how the visual angle an object subtends at the driver's vantage point changes with viewing distance. This figure assumes a 6-ft wide vehicle viewed from an initial separation distance of about 1000 ft. The first point to note is that the relationship between object size and distance is highly non-linear. The second point to note is that the image size of the object does not change much for most of the approach, even though it doubles with every halving of the viewing distance. At 1000 ft, the object subtends about 0.006 radians or one-third of one degree of visual angle. At 500 ft, the image size doubles to about 0.012 radians or two-thirds of one degree of visual angle. At 250 ft it doubles again. Because of this nonlinear relationship, drivers may not realize they are closing in at high speed until quite close to collision.

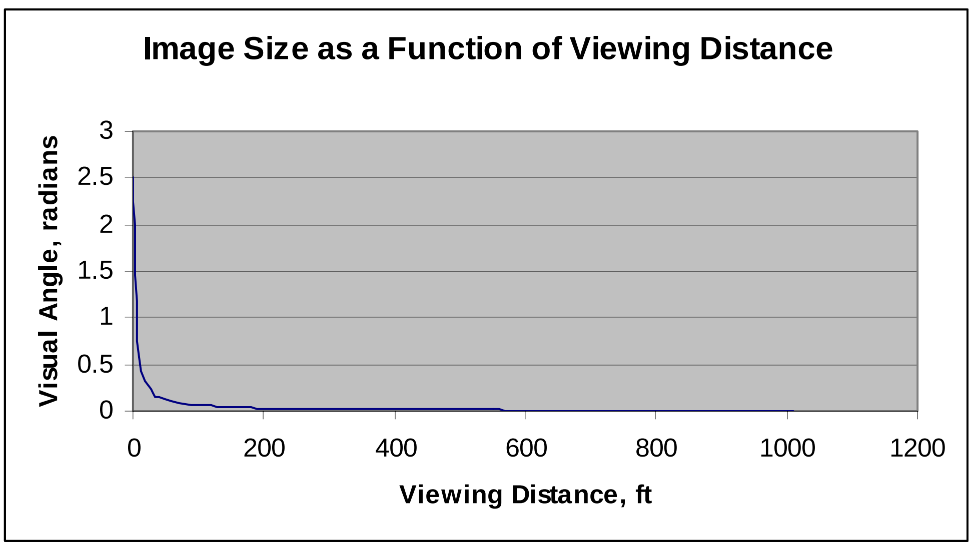

Figure 1. The relationship between image size and viewing distance.

Another aspect of this problem is human sensitivity to various visual information. Visual expansion rate (one aspect of looming) is a key stimulus to detect motion toward an object. Mortimer[21] has reported that a nominal threshold for visual expansion rate is 0.003 radians/sec. A fully alert driver, then, would only be able to detect that he or she is closing in on a 6-ft-wide stopped vehicle within a certain range, as determined by the following equation (see Appendix for derivation):

$$R(t)\_threshold \leq \sqrt{2000 * Rdot(t) - W^2}$$

where R(t)_threshold is the threshold range for detecting visual looming , Rdot (t) is the closing rate (i.e., approaching vehicle travel speed if the other vehicle is stopped), and W is the width of the vehicle ahead (assumed to be 6 feet in the following figure). This relationship is plotted in Figure 2.

At a closing rate of 60 mph approaching a parked vehicle (i.e., Rdot = range rate = 88 ft/sec), an alert and attentive driver could perceive (in the absence of other cues) that a 6 ft-wide lead vehicle (W= 6 ft) was stopped at a range of approximately 420 ft, or less than 5 seconds of travel time away. This leaves little time for delayed response and maneuvering. Normally, this is a moot point because vehicles ahead are indeed moving or else other factors (e.g., traffic lights, intersections, the movement of vehicles ahead of the vehicle ahead) indicate a standstill. This analysis does, nevertheless, show perceptual limitations that might contribute to such crashes in impoverished viewing conditions.

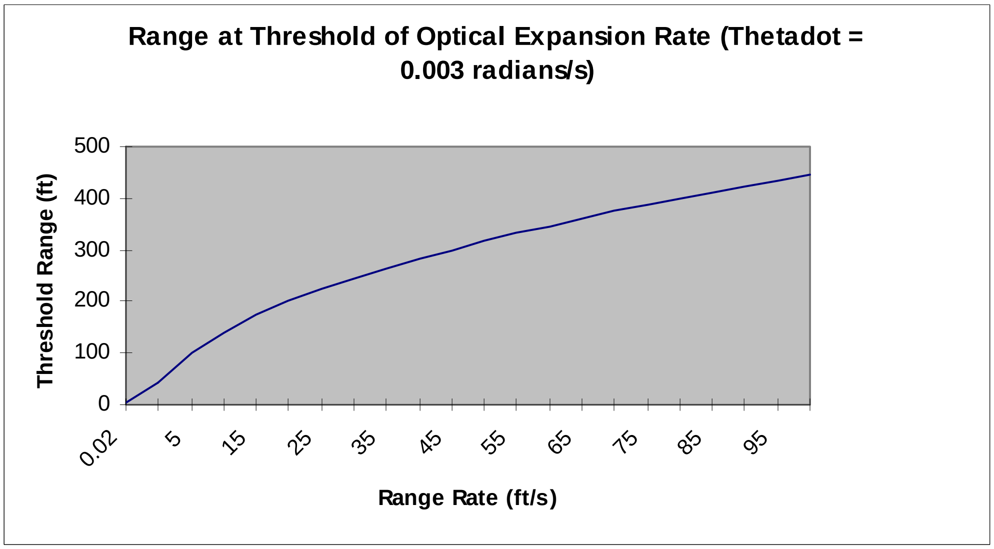

Figure 2. Range at which an optical expansion rate threshold of 0.003 radians/s may be detected at various closing rates.

An interesting hypothesis is that ground 'extent' (i.e., the length of pavement between the observer and the object ahead) may also be an effective stimulus for distance and closing rate. Mathematically, image size and ground extent are represented in the same way or are equivalent. However, they offer different means to influence an approaching driver. Image size may suggest treatments to the vehicle, lighting, or markings to induce an approaching driver to slow down or steer away. Ground extent may suggest manipulations of the pavement markings or task lighting to accomplish the same goals.

Training the Public

One of Dr. Tijerina's favorite sayings during our meetings was about driver behavior and expectancies. This concerns how drivers react to a given signal. They tend to follow previous behavior that had a favorable outcome. He used the example that it's good to tell people to be careful (and for parents it relieves guilt when children leave home), but it is better to tell them how to be careful. This is a prime reason for the Move Over laws. It teaches drivers the expected and desired behavior upon approaching a stopped police vehicle. Therefore, it is our responsibility to inform with the correct signal that the vehicle is stopped. Generally, we have in the past only had lights that could generate one repeating pattern whether the vehicle was moving or not so this distinction was not possible.

Light Sources

Currently the most common light sources are halogen bulbs and xenon strobe tubes. Light emitting diodes are quickly being accepted and gaining on the two traditional types. Each source has its own unique positive and negative points.

<u>Halogen bulbs</u> produce a light that is biased to red/yellow. If you filter the light, you loose effectiveness in the following order. Yellow produces less light than a clear filter, but the most light of any other of the three public safety colors of red, yellow and blue. Next is red followed by blue. Blue filters can reduce light output up to 90% of a clear lens. Halogen bulbs draw the greatest amount of current of the three lighting types for the light output given. Halogen bulbs are also difficult to focus, again losing light output and creating inefficiencies. Halogen bulbs also have limitations in the type and rate of signaling they can provide. Because the filament takes time to warm-up to produce light at the beginning of a "flash" and takes time to cool when turned off, a flashing bulb does not have a sharp on-off characteristic that aids conspicuity. Also, because of this time lag, the rate at which a halogen bulb can be flashed is limited. It is also difficult to experiment with other flash cycles/patterns other than half-on, half-off. These type bulbs are often rotated to overcome some of the flash difficulties and this does permit greater flash rates and crisper on/off characteristics. The rotating mechanisms, while inexpensive, tend to add complexity and durability issues and require additional power to operate. The main advantage to halogen bulbs has been expense and they are currently the least expensive systems to purchase. The bulbs are inexpensive for replacement and most parts are easily serviced.

<u>Xenon strobe lamps</u> tend to produce a light biased to blue. If you filter the light, you loose effectiveness in the following order. Yellow produces less light than a clear filter, but the most light of any other of the three public safety colors. Next is blue, followed by red which traditionally looses over 50% of the available light output. Strobes disadvantages include short on times that tend to make location and motion of the vehicle difficult to determine unless multiple lamps/flashes are used. Strobes are more efficient than halogen bulbs, but still have a significant power requirement. The use of multiple closely spaced flashes, timed as a single flash, have overcome some of the difficulties. Often strobes, particularly in areas with little ambient light, create a "disco" or stop motion effect that can be distracting and make watching the movement of persons at a scene difficult. These flashes also make certain sobriety testing,

particularly Horizontal Gaze Nystagmus, difficult. As with halogen bulbs, focusing a strobe is difficult and considerable losses of light are found here. Pattern type and on/off time have been greatly enhanced by the multi-flash option. On the plus side, the rapid almost instantaneous on/off characteristic of strobes make them very conspicuous.

Light Emitting Diodes. Truly, I expect these to become the predominant light source of the future. Light Emitting Diode (LED) lamps are the newest lighting technology for police cars. One of the most efficient methods to produce light, they run cooler and draw less electricity from the car than other sources for the same amount of light output. They also have a very long life. LED's are monochromatic which means they only produce light of one color. This assists with output because they do not have to be filtered to produce a particular light color. Designers and manufacturers are just exploring the potential of LED's and the field is advancing rapidly. Many things are possible with LED's that are not possible with any other light source. For example, LED's ramp on/off very quickly, similar to strobes, but the on time can be completely controlled, so you can have longer on times for greater conspicuity without any stop motion action similar to a halogen lamp. One unknown with LED's is the duration of the intensity. LED's do lose some brightness over time. Because they are so new in this application, research has not been completed to accurately predict the amount of dimming or the time it will take. LED's have one unique characteristic that may open an opportunity unavailable to other lamps. It has been considered LED's greatest weakness that they are very directional with little off axis brightness. However, it may be possible to turn this into a great strength. Lenses are already being developed to spread the beam to a wider angle. One possibility listed by Howett, Kelly and Pierce[22] is that it might be possible to design in more on time than off time and create conspicuity with the "off-flash" rather than the "on-flash". They state this has never been tested in this environment, but is used extensively in marine applications and could produce undesirable effects, but may have benefits. They do not list the possibilities but one is that it would give observers a perception that the vehicle was moving and not stopped. However, the possible upside is that because there was more on time, it might assist motorists in properly locating the vehicle and determining the proper avoidance.

Moth Effect:

This is one of the most curious and enduring topics of discussion regarding emergency vehicle lighting. First, I must say that there are well known human behaviors that give rise to this theory. First is that flashing or moving objects tend to attract attention. This attention then causes us to focus on the object. And finally, we tend to drive where we are looking. This is the basis of the moth effect.

The research in this area is limited. There are no known studies that have not been disproven that substantiate the actual existence of this effect in real world driving. For this effect to be real, you would expect that other objects that attract attention and focus would be driven into on a regular basis, as is the theory with emergency vehicles. Drivers regularly look at, focus on and read; road signs, billboards, movie marques and actively look for building addresses and business names. This all occurs regularly and if an accident occurs during this activity, it is usually a rear-end collision into a vehicle ahead that slowed or stopped while the drivers attention was diverted. My point here is this - as we learn to drive, we learn to counteract this effect. Just as you were taught to look to the edge line as a vehicle approached on a two lane roadway to avoid being blinded by the oncoming lights - you don't cross the centerline and have a head on collision even though the natural tendency is to be attracted to a bright light and stare at it. It took some time to learn to avoid looking at these lights but you learned to do it. This is also the same as learning to reach into the backseat when driving. The first few times you tend to turn the wheel as you turn, but then you learn to compensate and keep driving forward.

The Conspicuity subcommittee of the Blue Ribbon Panel did an examination of over 100 serious rear end collision police vehicle crashes. There were unexpected results, but we did not find any collisions where the people just ran into the car because they were transfixed by the lights. We found a large number of people that made inappropriate reactions to the lights and ran into the police vehicle as a result of a loss of control, but this is a different issue. The issue is made of impaired drivers possibly being unable to use their learned behavior and react to counteract the moth effect. My personal observation of impaired drivers (with probably close to or exceeding 200 DUI arrests) tells me that impaired drivers have often very delayed reactions to stimuli. This varies from striking vehicles stopped ahead, driving through stop signs and red traffic signals and even delayed or no reaction to police lights and sirens when you are attempting to stop them. It is then hard to believe that impaired drivers are seeing and reacting so well that they veer from one course of action and drive into a police vehicle. Impaired drivers are well known to have a high rate of roadway departure accidents. Evidence seems to indicate that police vehicles struck on the side of the road by impaired drivers are mostly victims of the impaired driver's departure from the roadway due to their impairment and not a conscious or unconscious reaction to lights they may never have seen.

Only a couple of studies were located dealing with this issue. The first two studies were reported in the 1999 Florida Highway Patrol Rear End Collision Study[23]. The first of these studies was performed at the request of the then President of the Police Benevolent Association, our bargaining unit at the time. This study found no evidence to support the existence of the moth effect in police vehicle rear end collisions. The second study conducted analyzed data obtained from the Illinois State Police. In this study, fully marked cars with lightbars were compared to vehicles that did not have roof lighting and were fully marked, semi-marked and covert vehicles. You would expect if the moth effect were valid that the greater the amount of lighting used, the greater likelihood that the vehicles would be struck. This did not happen. The vehicles were struck at exactly the same percentage that they represented in the overall fleet. Since some of the covert vehicles were administrative cars, they may have not been conducting as many traffic stops as the fully marked vehicles and this comparison may indicate more lights are better. However, we did not request miles driven by the two groups to compare this more closely.

Dr. Tijerina was able to locate two studies on the moth effect[24]. The first by Helander[25] indicated that drivers sometimes tend to steer toward an object of perception. In this study, 17 experienced drivers drove toward a car parked on the side of the road. The steering wheel input was measured for 10 seconds before and after the test vehicle passed the parked vehicle. Helander did not record lane position during this test. On average, Helander found the steering wheel turned toward the parked vehicle about 2 seconds from passing the parked vehicle. He concluded that this meant persons steer toward objects of interest.

In the second study Summala, Leino and Viermaa[26] (1981) used the same methodology and came to an entirely different conclusion. Analyzing their subjects driving further, they concluded that the steering toward the parked vehicle observed by Helander was necessary, because the drivers had already steered away from the vehicle and moved over in their lane and had to straighten the vehicle's wheels to change this path away from the vehicle, straighten the vehicle in the lane and pass the vehicle.

All this said, we have followed the suggestion of Dr. Solomon and used a much simpler flash pattern that should be less dazzling and if the moth effect is real and affects drivers, should be easier for a trained driver to overcome.

Serviceability:

Our communications engineer supervisor Mr. Fred Malfa gave all the systems a cursory examination. Because it was raining he was not able to do complete disassembly to examine changing circuit boards, etc. Of note on the negative side was the design of the end caps on the Code 3 bar as difficult to realign and reinstall. Also negative, the large low frequency siren speaker on the Code 3 system was placed in the trunk, and the size and location of the amplifiers for this system were large and used precious trunk space. The Whelen engineering speaker system was criticized based on the number of speakers used (4or 5) and the possibility that their placement could disrupt airflow through the radiator. Mr. Malfa was told the system could be reduced from 4 or 5 speakers to 2.

He was pleased that the bars did not have any moving parts and were of solid state construction. The only negative note to the Federal System is that the Smart Siren controller was user programmable through the keypad. We have found this to be problematic in the past when individual officers with the time and knowledge reprogrammed their light and siren systems. In our fleet, each vehicle is to be exactly the same so that if an officer changes cars or picks up a spare vehicle while theirs is in the shop, they know what to expect.

Audible Warning Devices

While we were examining the visual warning signals for improvement we also decided to examine the audible signals to determine if there was any way to improve these signals. We had determined from observation on-duty as a siren listener and off-duty as a signal receiver that sirens did not seem to be as effective today as they used to be. It was determined that modern vehicles are much tighter in construction and have improved seals and insulation that effectively blocks more sound transmission than vehicles of even just 10 years ago. We looked into technologies that could make the siren more effective. The first thing we did was examine the frequency (or pitch) of the current siren. We found that the Society of Automotive Engineers requires wail and yelp sirens to be between 650 Hz at the low end to 2000 Hz at the top end. These tones encompass the upper mid-range of human hearing. I was told casually by one expert in the field that this range was chosen due to it being the range of frequency that is best heard by humans and remains the best heard as hearing diminishes with age. However, this does not make it the best frequency to penetrate a well sealed and insulated motor vehicle. Lower frequency sound penetrates solid objects better than higher frequency sound. You have probably seen this demonstrated with "boom box" cars. You hear the low frequency bass and drums long before the vehicle pulls up next to you, but even when the vehicle is next to you, you can not hear the melody or other parts of the music. It is this phenomenon that we desired to exploit with a new siren.

Another important phenomenon of lower frequency sound is that it is not as directional as higher frequencies. The current siren can be pointed in a specific direction and the siren will be significantly louder in that direction than to the sides or rear. The lower the frequency the sound, the less it will tend to adhere to this directional principle. At some point the sound will be almost as loud in all directions. This has significance when looking at intersections. It is difficult for persons to see the patrol car when you are approaching an intersection because you may be blocked by buildings or other vehicles. The siren may be the only warning they can perceive. However, if the main focus of the siren is straight ahead, we are not providing the optimum warning. Theoretically, the low frequency siren should be even more efficient to the side of the patrol vehicle than it is directly to the front.

We next considered the tone or pattern the siren had. Could we develop a pattern that was more conspicuous and noticeable? We contacted four manufacturers of electronic sirens for their input. It was felt that the current siren is so recognizable that it would be difficult to develop anything that was this easily recognized as an emergency vehicle. Eventually we decided that we should leave a primary siren in the vehicle and utilize the low frequency secondary siren as a supplement.

The manufacturers were required to provide sound level measurements on their low frequency sirens in the interior of the patrol vehicle. Federal Signals siren was just over the allowable 8 hour exposure level in the 4 hour OSHA exposure level. Code 3 and Whelen Engineering's sirens were within the 8 hour level, but very close to the line. At least within our agency, we cannot envision a scenario where officers are exposed to any siren 4 hours or more per day, let alone several days. This did not seem much of a concern. However, since as a group, the manufacturers were concerned about possible long term hearing loss, even given these ratings, the decision was made that these sirens would be utilized only on a temporary basis. They require a separate button to activate and only remain on for 60-90 seconds. This should be sufficient to approach and cross an intersection. The instruction for the sirens should explain their purpose and proper use.

Prototype Design

This section discusses the design of the prototype lighting and sirens as configured for our test. The prototypes incorporate as many elements to bring into these items as were analyzed in our study review. When improvements over current designs were technologically possible, we put them into the new system. Only the information from Rennsselaer Polytechnic Institute concerning steady burning lamps arrived too late for this particular evaluation.

Technology

The first thing we had to do was to choose a technology to use. Due to the flexibility, efficiency and packaging advantages of LED's, we chose to use LED's as our primary light source. The use of LED's as effective devices for warning is also backed up by one study[27] that showed point source lamps (in the particular case of the study) were better at eliciting rapid visual responses (conspicuity) than diffuse sources (in the study a neon tube) which one would assume should transfer to halogen bulbs (being a larger surface areas would qualify as diffuse) as well.

Patterns

We agreed with Dr. Solomon's assertion that some lights are unnecessarily busy and because we often place an "arrow" function in with the signal light we are sending too many messages for persons to comprehend easily and quickly. He also stated that the current arrow functions were poorly understood and perceived. I did not believe this, but began to speak with persons not directly connected to law enforcement and discovered several that did not even know we had this built into our current lighting systems that have been in use for over 10 years. So we set out to correct these issues.

First, we decided we would try separating the arrow function from the light bar and creating two separate signals. We also wanted to make the arrow larger and give it more of an arrow shape similar to the arrows used by DOT at construction sites. So we moved the arrow out of the lightbar and into the rear window. We then created a rectangle within the window rather than a stick or bar of single height. This gave the arrow function height and if not a formal arrow shape at least a rectangle pointing in the proper direction. Notably the prototype from Code 3 only used one segment of LED's on the vertical ends of the rectangle centered between top and bottom. At a distance this rectangle appears to give the ends a pointed shape and their system most resembled an arrow.

Because we found that there are perceptual difficulties in determining the movement of the vehicle, we thought we might be able to overcome some of this by using two different patterns. Also, we found one study that seemed to indicate that when multiple halogen lamps across a bar were all lighted and turned away simultaneously, viewers were best able to determine the relative motion of the vehicle. We decided that having a bar with two different patterns, one to denote movement and one to denote a stopped vehicle would be beneficial, especially if the patterns were intuitive enough to communicate the message to the viewer without special training. What we chose was to have a pattern that flashes all the red and blue elements in a somewhat random pattern when the vehicle is moving and a pattern that flashes the entire lightbar as a single unit using only the particular (and optimum) color for the conditions existing. The multiple flashes seem to imply movement where the solid pattern seems to imply a stopped vehicle so these patterns were selected. The switch in patterns is automatic, provided by a switch on the park function of the vehicle transmission. When the lights are activated, they operate in the moving mode when the vehicle is in any gear position other than park. They operate in the stationary mode when the transmission selector is in the park position.

We also tried a "looming" pattern early in the prototype process. This light failed to impress. When the looming rate was slow enough to really provide the sense of looming or making the illusion believable, the cycle rate was so slow as to cause concern over conspicuity. This observation was confirmed when studies of similar lamps tested for use as a replacement for the Center High Mounted Stop Lamp were submitted to us by Rensselaer Polytechnic Institute[28].

Color

The first thing we addressed was the issue of red and blue. It became obvious that red signals were desired for daylight and blue for the night. We could have followed the practice of current vehicles with half the bar red and half the bar blue, but better alternatives have become available. With LED's we could package them to alternate segments or individual lamps to provide the ability to switch to just one color or the other and have the entire bar illuminate as one color. So we put a photocell in the lightbar to sense the intensity of the ambient light and tell the bar whether red or blue was most appropriate. Because we felt and then found research to verify that the longer wavelengths of light (red) would penetrate smoke and fog better, we asked for an override switch so that if the diminished atmospheric conditions tricked the photocell into providing a blue signal, the operator could trigger the bar to go all red.

In the literature submitted by Rensselaer Polytechnic Institute[29] was some information on the effect of color on the time of perception by wavelength of the light that showed the longer wavelength LED (630 nm) versus the shorter wavelength (615 nm) elicited a small but consistent advantage in both response time and missed responses. The study did not particularly address a difference as great as red versus blue, but does indicate we may want to request the manufacturers provide the LED's with the longest wavelength allowable under SAE standards for a particular color, at least with the red LED's and possibly yellow/amber. Even if blue were to have a slightly longer response time, it would still be advantageous at night due to the reasons explained previously under study review. It may be difficult to use longer wavelength blue LED's as they may tend toward green and not give the appropriate signal or all the advantageous characteristics of true blue.

Light Output

From observation, our current all blue lighting with an amber traffic direction bar is difficult to observe under very bright daylight conditions. This is a significant weakness that we wanted to overcome. However, increased brightness could become a liability at night and we must be conscious of this in our design. Currently, red LED's have a significant output advantage over blue. This assists in a brighter light for daylight use, since we will only use it then or in impoverished viewing. Since blue outputs less light and we need less blue at night, we can reduce the intensity of the blue and still have equivalent response and hopefully since we have less intensity, reduce the chance of night blindness. Whelen Engineering states that depending on the particular LED's used, the red LED's can range from 2.5 to 6 times brighter than the blue. The significant difference in intensity and perception between the colors would appear to be sufficient to accomplish our goals.

Takedown lights

The concept for the prototype takedown lights was, as many good things are, quite an accident. While meeting with representatives from Whelen Engineering and viewing an early prototype of theirs, an idea came to mind. We had noted previously that when the red and blue segments were illuminated simultaneously a flash of white light appeared where they joined. Whelen wanted Captain Kenneth L. Spears and myself to evaluate a new white LED that they had been experimenting with for takedown lights. It then occurred to me that lighting in theaters is made by combining independent red, green and blue filtered lamps so that the mood of the illumination can be changed by mixing different amounts of this light. I asked the representatives from Whelen Engineering to rewire the prototype so we could evaluate the use of the red and blue lights on simultaneously as a single take down light encompassing the entire front of the bar. The amount of light produced was amazing and while the color produced being entirely deficient in green light was somewhat unnatural, is was completely useful and much brighter than the traditional halogen spot lamps. We decided to include this feature as a part of the evaluation.

Siren

We advised the manufacturers what we desired. At first we requested a very low frequency below 100 Hz and attempted to go down to 40 Hz. What we found was that power requirements were very high and that the speaker(s) would have very large space requirements. We still believed in the concept and Federal Signal Corporation performed a demonstration for us that used several different frequency ranges so we could balance performance against practicality. During the demonstration, we found that we felt the tones below 100 Hz more than heard them. This indicated that the optimal frequency was probably somewhat higher. We found the range of 130 Hz at the low end with a maximum of 250-300 Hz at the top end to give the best results. It is also possible to mount speakers and amplifiers for a system like this within most standard police vehicles. The manufacturers asked us to specify a tone for this system. We declined to do that and asked them to explore possibilities of new tones that may be more conspicuous than the current, or that may provide a greater sense of urgency.

Prototype Testing

The testing has consisted of two phases. The first phase prior to the side-by-side evaluation was a 60 day field trial. During this time we allowed the Troopers who were chosen to assist in this exercise time to work with the units during the course of their regular duty. They gave the systems a full work-out using the various modes of lighting, new take-down and alley lights along with the new sirens.

Field Test

During this test each manufacturer was allowed to tweak the design if elements did not meet the written specification provided or if a component failure occurred. Because each of these systems were hand assembled prototypes, some maintenance and tweaking was expected. The Troopers were overwhelmingly in favor of all the elements of the new system except one. The Florida Highway Patrol has never in its history utilized red lights as part of the warning system on its vehicles. Even though they acknowledged red's superiority in daytime, several were resistant to changing tradition.

Service Issues

The systems were evaluated from an installation and maintenance standpoint by Mr. Fred Malfa.

Side-by-side evaluation

On February 24, 2004 we assembled the prototypes submitted by Code 3, Federal Signal Corporation and Whelen Engineering. We also assembled a diverse group of 15 individuals to act as evaluators. These persons ranged in age from 18 to 77 years of age. Education ranged from non-high school graduates, to college graduates. We were unfortunately only able to recruit 1 female evaluator. The life experience ranged from police officers to auxiliary police officers to fleet managers and non-police personnel. Not all entries were completed by all persons. This reflected presence at the scene or additional duties of the evaluator, such as video taping the evaluation. Below is the demographic information of the evaluators.

AGE	SIGHT	POLICE OFFICER	EDUCATION
77	CL	Auxiliary	NHS
72	NV	Auxiliary	SC
67	CL	Auxiliary	HSG
18	NV	No	SC
34	CL	No	SC
27	CL	Yes	CG
74	CL	Auxiliary	HSG
35	NV	Yes	SC
54	CL	Yes	SC
53	CL	No	CG
46	NV	Yes	SC

49	NV	Auxiliary	SC
53	CL	No	SC
67	CL	Auxiliary	SC
59	FS	No	CG

Below are the abbreviations used in the above chart:

Sight:
NS - Near Sighted
FS - Far Sighted
CL - Corrective Lenses
NV - Normal Vision

Education Level:
NHS - Not a High School Graduate
HS - High School Graduate
SC - Some College
CG - College Graduate

We selected a location locally nicknamed the "road to nowhere". This two lane paved road is just west of the small community of Sopchoppy, Florida, dead ends at a river and only has one family living on the portion used for testing. This allows a safe environment for the test to be conducted. The road also has absolutely no artificial lighting to interfere with the night time testing. There is a dirt road that forms a cross road to provide a crossing for simulating intersection effectiveness. The road to nowhere is bordered by woods on both sides at this intersection, allowing a simulation of a vehicle crossing with limited sight distances as in a built up urban environment.

Since the primary reason for beginning this entire research and prototype process was to better protect our Troopers while they are stopped on or near the road, we focused much of our research, lighting development and testing on how the package presented itself when viewed from the rear of the vehicle. We were still concerned about maintaining at least the present level of effectiveness from the side, another vulnerable position when responding to calls and crossing intersections. You will see this in the design of the testing. The only significant departures are in the design and testing of the siren and the takedown lights. Finally, because the new traffic direction function used the back window, we ran a test to determine if, and by how much, rear vision was affected.

The following scoring criteria was used during the test:
"Scoring criteria: Every test will be scored against the control unit, the Federal Signal Vector Bar with 100 watt Smart Siren. This control will always be the first unit shown or heard and will be scored as "A". You will rate each unit on a scale of 1-10 with 10 being best. Unit "A" will always be a 5 and that score has already been entered for you. If you think a new unit is worse than the old unit, enter a score lower than 5. If the same enter 5. If better, enter a score higher with the better units receiving a better score."

Daylight testing

As the test began, it was dry and very overcast, noticeably affecting the ambient daylight. We began at approximately 1:30 PM. Much of the test description that follows is taken directly from the instructions to the evaluators.

The first test was conducted with the evaluators stationed ¼ mile from the vehicles. The vehicles were not placed onto the roadway and shoulders side-by-side until the testers were in position so they could not be biased by any possible manufacturers preference or dislike. The score sheet also was marked A, B, C, D to prevent any identification of the units.

The scoring instructions are below along with the test scores.

"Rear View – Top Light Only Stationary (Red): You will be rating conspicuity. Conspicuity is defined as the ability to be conspicuous or attract attention. In lighting, this is how you perceive the equipment and factors such as flash rate/pattern and brightness affect perception. For this test, we want to find the most conspicuous signal light. Please note if you find anything unusual such as if the color is not correct, the light is harsh or annoying or anything particularly positive about one light over the others. If you rate the new system less than 5, we particularly need to know why."

NAME	Federal Smart Vector	Whelen	Federal	Code 3
Tpr deMontmollin	5	5	3	4
Franklin Roberts	5	7	6	8
Lt. Barrie Glover	5	8	4	7
Kenneth Spears Jr.	5	9	6	8
Angel Dollard	5	8	6	7
Timothy Roufa	5	10	7	8
Charles Deal Sr.	5	7	6	10
Brent Woodward	5	8	6	9
Edward Creel	5	8	6	7
Bill R.	5	7	6	6
Ronald Middel	5	10	7	9
Donald Severance	5	10	7	8
Joe Ferguson	5	6	5	6
Charles Landrum	0	0	0	0
Fred Malfa	5	8	6	7
AVERAGE	**4.6**	**7.4**	**5.4**	**6.9**

The second test still had the participants at a ¼ mile distance. The weather was similar. For this test we were reviewing the effectiveness of the manufacturers installed moving mode. Since the lightbars were similar front to rear with the exception of the takedown lights, these results should be reasonably similar if applied to the front. The vehicles were still stationary, but the transmissions were placed in neutral and the parking brake applied.

NAME	Federal Smart Vector	Whelen	Federal	Code 3
Tpr deMontmollin	5	7	3	5
Franklin Roberts	5	8	6	7
Lt. Barrie Glover	5	9	6	8
Kenneth Spears Jr.	5	9	7	9
Angel Dollard	5	10	6	8
Timothy Roufa	5	10	7	7
Charles Deal Sr.	5	6	7	8
Brent Woodward	5	8	6	9
Edward Creel	5	9	7	8
Bill R.	5	7	5	6
Ronald Middel	5	10	7	8
Donald Severance	5	10	7	8
Joe Ferguson	5	6	5	7
Charles Landrum	0	0	0	0
Fred Malfa	5	9	7	8
AVERAGE	**4.6**	**7.8**	**5.7**	**7**

The third test was conducted with the evaluators still at ¼ mile. The vehicle lights were in the stationary mode and we added the arrow/traffic direction function.

"Rear View – Rear Window display/traffic direction signal. For this test we are attempting to determine if the rear window display sends a more recognizable traffic direction signal than the current arrow strip. We also need to know if it is easier to see separated from the lightbar itself. The light bar will be operating in the stopped mode."

NAME	Federal Smart Vector	Whelen	Federal	Code 3
Tpr deMontmollin	5	4	3	5
Franklin Roberts	5	9	8	6
Lt. Barrie Glover	5	3	6	2
Kenneth Spears Jr.	5	8	9	6
Angel Dollard	5	5	7	7
Timothy Roufa	5	10	9	7
Charles Deal Sr.	5	4	4	4
Brent Woodward	5	5	7	9
Edward Creel	5	8	10	7
Bill R.	5	7	5	6
Ronald Middel	5	7	8	7
Donald Severance	5	7	8	4
Joe Ferguson	5	6	7	6
Charles Landrum	0	0	0	0
Fred Malfa	5	6	8	7
AVERAGE	**4.6**	**5.9**	**6.6**	**5.5**

The fourth test was our **intersection test.** The evaluators were closer to the intersection to better simulate actually being affected by the vehicle entering the intersection. The exact distance was not recorded but it was not less than 100 feet nor more than 300 feet. The vehicles were driven across the intersection once from the viewer's right and then again in the same order from the viewers left. The approach and crossing speed was 10 mph.

NAME	Federal Smart Vector	Whelen	Federal	Code 3
Tpr deMontmollin	5	4	2	5
Franklin Roberts	5	7	10	6
Lt. Barrie Glover	5	7	6	6
Kenneth Spears Jr.	5	9	5	5
Angel Dollard	5	8	5	6
Timothy Roufa	5	9	9	9
Charles Deal Sr.	5	7	6	6
Brent Woodward	5	8	7	9
Edward Creel	5	8	8	8
Bill R.	5	7	3	5
Ronald Middel	5	10	6	7
Donald Severance	5	8	7	6
Joe Ferguson	5	7	5	5
Charles Landrum	5	6	10	7
Fred Malfa	5	8	6	7
AVERAGE	**5**	**7.5**	**6.3**	**6.4**

<u>The fifth test was **the siren test.**</u> We placed two similar Ford Crown Victorias side-by-side in the roadway. They were in park with the engine running and climate system fan on high. I had pre-measured with a 100 foot steel tape points 100 feet apart behind the vehicles for ¼ mile. The last cone was of course only 20 feet from the 13th cone. Orange traffic cones were placed at these 100 foot intervals. We placed two evaluators in each car in the front seat. When the evaluators heard the siren they were to raise their hands. There were two proctors, one for each car. When the proctor saw the hand raised, they looked to determine the distance of the approaching vehicle that had its siren activated. The drivers of the vehicle that was being evaluated activated the siren at the start point ¼ mile from the evaluators and approached at 10 mph. We had wanted to have music playing on the radio during the test, but found it impractical to find a piece of music that maintained a consistent volume level long enough to conduct the test. If the music had a wide dynamic range it could get quiet and loud and either increase or decrease the hearing of the siren in a random and non-repeatable fashion.

NAME	Federal Smart Vector	Whelen	Federal	Code 3
Tpr deMontmollin	500	600	650	650
Franklin Roberts	300	450	600	600
Lt. Barrie Glover	400	600	400	500
Kenneth Spears Jr.	900	900	800	800
Angel Dollard	400	900	800	700
Timothy Roufa	600	400	700	650
Charles Deal Sr.	250	500	350	450
Brent Woodward	250	600	500	600
Edward Creel	250	550	450	600
Bill R.	0	0	0	0
Ronald Middel	500	550	800	500
Donald Severance	600	600	500	500
Joe Ferguson	600	800	550	750
Charles Landrum	450	600	750	450
Fred Malfa	250	500	400	350
AVERAGE	**416.6**	**570**	**550**	**540**

Visibility test. This test consisted of two components. Since we installed a light that circled the entire rear window, we wanted to determine if visibility would be impaired. The results of this test were not conclusive. Part of the problem was that Ford raised the rear end height in 2003 with the 2004 model cars. The vehicles with the prototypes had the raised rear end. The vehicle with control lightbar did not. However, the front of the control was placed in a pothole that somewhat compensated and brought parity. The control vehicle had two small rectangular strobes on the rear deck as per our current fleet. Most of the prototype vehicles had prisoner partitions installed where the control did not. Following are the instructions for this test and the results.

> "You will sit in each of the 4 cars. Placed behind each vehicle are our standard issue traffic cones. These cones are spaced at 10 foot intervals. After adjusting the driver's seat and inside rear view mirror, note how many cones you can see completely.
>
> Now look in the rear view mirror and determine if rear visibility is acceptable for general driving, such as changing lanes, etc. Rate on a scale of 1-10. Scored below as part 2."

NAME	Federal Smart Vector	Whelen	Federal	Code 3	PART 2 A	PART 2 B	PART 2 C	PART 2 D
Tpr deMontmollin	1	1	2	2	5	10	10	10
Franklin Roberts	0	0	1	1	5	4	4	2
Lt. Barrie Glover	0	0	0	0	5	2	2	3
Kenneth Spears Jr.	1	1	0	2	5	5	3	7
Angel Dollard	0	1	0	1	5	4	4	5
Timothy Roufa	2	1	0	2	5	5	5	5
Charles Deal Sr.	0	1	0	2	5	4	3	2
Brent Woodward	2	1	1	2	2	2	0	2
Edward Creel	2	0	0	1	5	10	10	10
Bill R.	0	0	0	0	0	0	0	0
Ronald Middel	1	1	0	2	5	4	3	3
Donald Severance	1	1	0	2	5	10	2	10
Joe Ferguson	1	0	1	1	5	5	3	3
Charles Landrum	1	1	0	2	5	6	4	2
Fred Malfa	1	0	2	0	5	4	5	5
AVERAGE	**0.8**	**0.6**	**0.4**	**1.3**	**4.4**	**5**	**3.8**	**4.6**

Nighttime testing

The first 4 tests below are exactly the same as the daylight version in terms of observer distances and scoring criteria. We repeated the test because steady blue lights were being used instead of the red during the daytime.

Rear View – Top Light Only Stationary (blue)

NAME	Federal Smart Vector	Code 3	Whelen	Federal
Tpr deMontmollin	5	10	10	9
Franklin Roberts	5	6	9	5
Lt. Barrie Glover	5	8	9	8
Kenneth Spears Jr.	5	9	9	8
Angel Dollard	5	8	8	6
Timothy Roufa	5	9	10	7
Charles Deal Sr.	5	8	8	7
Brent Woodward	5	10	8	7
Edward Creel	5	9	10	8
Bill R.	0	0	0	0
Ronald Middel	5	9	10	7
Donald Severance	5	9	9	7
Joe Ferguson	5	7	7	7
Charles Landrum	5	10	8	6
Fred Malfa	5	8	7	6
AVERAGE	**4.6**	**8**	**8.1**	**6.5**

Rear View – Top light only, Moving signal (Red and Blue together).

NAME	Federal Smart Vector	Code 3	Whelen	Federal
Tpr deMontmollin	5	10	9	9
Franklin Roberts	5	7	6	4
Lt. Barrie Glover	5	10	8	7
Kenneth Spears Jr.	5	10	7	6
Angel Dollard	5	8	9	7
Timothy Roufa	5	9	10	9
Charles Deal Sr.	5	8	6	7
Brent Woodward	5	10	6	7
Edward Creel	5	10	9	8
Bill R.	0	0	0	0
Ronald Middel	5	9	10	8
Donald Severance	5	10	9	7
Joe Ferguson	5	7	8	9
Charles Landrum	5	10	8	7
Fred Malfa	5	9	8	7
AVERAGE	**4.6**	**8.4**	**7.5**	**6.8**

Rear View – Rear Window display/traffic direction signal.

NAME	Federal Smart Vector	Code 3	Whelen	Federal
Tpr deMontmollin	5	9	10	9
Franklin Roberts	5	8	6	5
Lt. Barrie Glover	5	9	8	7
Kenneth Spears Jr.	5	8	9	8
Angel Dollard	5	6	6	7
Timothy Roufa	5	8	8	8
Charles Deal Sr.	5	7	8	6
Brent Woodward	5	10	6	8
Edward Creel	5	7	7	10
Bill R.	0	0	0	0
Ronald Middel	5	5	4	7
Donald Severance	5	9	8	10
Joe Ferguson	5	3	3	5
Charles Landrum	5	7	6	9
Fred Malfa	5	6	7	8
AVERAGE	**4.6**	**6.8**	**6.4**	**7.1**

Side View –

NAME	Federal Smart Vector	Code 3	Whelen	Federal
Tpr deMontmollin	5	9	10	9
Franklin Roberts	5	5	7	6
Lt. Barrie Glover	5	9	8	6
Kenneth Spears Jr.	5	8	7	6
Angel Dollard	5	8	8	7
Timothy Roufa	5	9	10	8
Charles Deal Sr.	5	7	6	8
Brent Woodward	5	10	6	7
Edward Creel	5	8	9	10
Bill R.	0	0	0	0
Ronald Middel	5	5	7	5
Donald Severance	5	6	7	4
Joe Ferguson	5	6	6	7
Charles Landrum	5	10	8	9
Fred Malfa	5	8	7	7
AVERAGE	**4.6**	**7.2**	**7**	**6.6**

"Take down lights – This involves a new light using the red and blue LED's turned on simultaneously. Let us know if the red/blue causes any color perception problems or has any benefits. Please compare to the current."

NAME	Federal Smart Vector	Code 3	Whelen	Federal
Tpr deMontmollin	5	10	9	9
Franklin Roberts	5	7	8	5
Lt. Barrie Glover	5	10	8	6
Kenneth Spears Jr.	5	10	9	7
Angel Dollard	5	9	5	5
Timothy Roufa	5	10	10	10
Charles Deal Sr.	5	9	6	5
Brent Woodward	5	10	3	5
Edward Creel	5	10	5	9
Bill R.	0	0	0	0
Ronald Middel	5	5	7	7
Donald Severance	5	7	4	4
Joe Ferguson	5	8	4	7
Charles Landrum	5	9	7	4
Fred Malfa	5	6	5	5
AVERAGE	**4.6**	**8**	**6**	**5.8**

"Take down lights – Some manufacturers included white lamps in the light bar. Evaluate the lightbars with these activated in addition to the red/blue only and please comment on these versus the red/blue takedown alone."

NAME	Federal Smart Vector	Code 3	Whelen	Federal
Tpr deMontmollin	5	10	9	9
Franklin Roberts	5	7	7	6
Lt. Barrie Glover	5	10	8	6
Kenneth Spears Jr.	5	8	9	8
Angel Dollard	5	7	8	7
Timothy Roufa	5	6	10	8
Charles Deal Sr.	5	9	7	6
Brent Woodward	5	10	4	6
Edward Creel	5	6	8	10
Bill R.	0	0	0	0
Ronald Middel	5	5	7	6
Donald Severance	5	10	7	9
Joe Ferguson	5	7	8	6
Charles Landrum	5	10	8	8
Fred Malfa	5	6	5	6
AVERAGE	**4.6**	**7.4**	**7**	**6.7**

<u>Night blindness evaluation</u> – You will be conducting this test twice with two different lighting configurations. The rear lighting on these cars was designed to be focused in several different phases to allow very intense long range lighting that is intended to drop off in intensity as you near the police vehicle. This is hoped to keep you from being blinded by the more intense light and be able to see what is going on at the scene. The vehicles will be spaced apart. Please drive by the vehicles at approximately 30 mph and note how you are affected. A standard issue traffic cone will be placed 5 feet in front of the vehicles in line with the left side of the vehicle. Note if you can see the cone. This is to determine if you could see an officer directing traffic in front of the vehicle while using reflective gloves and vest. The vehicles will have their standard low beam lamps on with the overhead signal only on for the first run and the rear window signal in the left arrow pattern will be added for the second run.

NAME	Federal Smart Vector	Code 3	Federal	Code 3	PART 2 A	PART 2 B	PART 2 C	PART 2 D
Tpr deMontmollin	5	10	9	9	5	10	9	9
Franklin Roberts	5	8	6	7	5	6	8	6
Lt. Barrie Glover	5	8	8	9	5	8	10	6
Kenneth Spears Jr.	5	5	5	5	5	4	5	5
Angel Dollard	5	6	6	7	5	5	5	4
Timothy Roufa	5	10	10	10	5	10	10	10
Charles Deal Sr.	5	6	6	5	5	8	8	7
Brent Woodward	5	10	10	10	5	10	10	10
Edward Creel	5	10	10	10	5	10	10	10
Bill R.	5	6	7	6	5	4	6	4
Ronald Middel	5	5	8	7	5	5	7	7
Donald Severance	5	5	5	5	5	0	0	0
Joe Ferguson	5	5	6	5	5	5	5	5
Charles Landrum	5	9	6	7	5	10	7	5
Fred Malfa	5	4	5	5	5	5	8	7
AVERAGE	**5**	**7.1**	**7.1**	**7.1**	**5**	**6.6**	**7.2**	**6.3**

Two of these lights and sirens were presented to a group of about 40 chiefs and staff members of departments from around the country and Canada at the Highway Safety Committee Agenda screening committee meeting on March 14, 2004. The daytime viewing took place at the Institute for Police Technology and Management in Jacksonville, Florida. The evening viewing took place at the Spring Hill Suites Marriott Hotel, 4385 Southside Blvd, Jacksonville, Florida. The third vehicle on which the Whelen lightbar and siren was installed was unable to be present as the transmission failed and the vehicle was undriveable.

Unlike the day of the side by side testing, the day was bright, sunny and the sky was cloudless. The vehicles were set up side by side approximately 450 feet from the viewers. When the current all blue halogen Federal Signal Vector was turned on it was very dim in the bright light. When the next light, the Code 3 was turned on, it was so much brighter that there was an audible reaction from the assembled onlookers. While not as bright as the Code 3, the Federal LED bar was considerably brighter than the control. The onlookers were all very positively impressed by the difference in the control and the prototypes and felt a significant improvement in safety could be attained.

The siren demonstration was less impressive. The Federal Low Frequency siren was activated after all the observers were moved into a variety of vehicles. The vehicles ranged from standard passenger cars to 15 passenger vans and full size SUV's to a 40 passenger diesel rear engined bus. All observers commented on the impressive gains in sound level with the low frequency siren except the passengers in the 40 passenger bus. They stated they could not tell any difference between the sirens. This is the first vehicle located so far in this evaluation process that the passengers could not hear the siren significantly better. We have even found significant penetration of the siren into concrete block buildings. Theories for this lack of response into the bus were varied and included the size of the bus may have been just correct to absorb or filter the frequencies, the lower pitch of the diesel engine or the particular air conditioning unit may have put out enough low frequency sound to overpower the siren.

Later that evening we had another demonstration of the lights and take down light systems. The observers felt that the lights overall may be too bright, but yet had no trouble seeing past the vehicles. The comments were stronger when the arrow function was on as opposed to when the blue signal was on by itself. The observers were impressed with the output from the Code 3 takedown lights and did not seem to have any difficulty with the color rendering. There was some lighting present from the parking lot overhead lamps, but the takedowns were focused onto adjacent property that was under construction and not illuminated.

The other notable comments included that the arrow function should not be on during moving mode as this could cause confusion later when it was used during the stop mode. The observers felt that while the arrow function was an improvement, they wanted more of an arrow shape and wished it was even more separated from the lightbar.

Recommendations

The following recommendations are based on the applicable theory and our observations, both at the side by side evaluation, the evaluation from the Troopers with the equipment and those at the presentation in Jacksonville.

Messages:

The idea of a different set of patterns for moving and stopped has drawn nothing but favorable comments from all sectors. The pattern for stopped must be distinctly different from the moving pattern. The stopped pattern should flash the entire lightbar as one unit in the appropriate color for the ambient lighting and atmospheric conditions (an override to go red during fog, smoke or haze). The moving pattern should flash the red and blue in a pattern with a lot of movement that occasionally activates contiguous red and blue segments to produce white flashes.

The arrow function should not operate automatically during moving mode. The operator should have the option to turn it on, if necessary, perhaps when escorting a slow moving vehicle. This function should operate whenever the signal light is activated when the vehicle is stopped. This function can be operated independently as well. An in-out or side to side pattern should be the default.

It is desired that the rear window display have more of an arrow shape, if possible. A good start to this end is the placement by Code 3 of only one segment on the vertical end. This helps create an optical illusion of an arrow or pointed end at long distance. A stripe across the middle of the window with actual arrow points was proposed, but not practical for vision purposes. Maybe two segments on a diagonal at the ends (one diagonal from the top and one from the bottom) would meet this recommendation.

Color Blindness:

Because the vehicle will display multiple colors when moving and when stopped (red and blue moving, red or blue and amber when stopped), most color deficiencies should be accommodated.

Light Color:

Research and practical field evaluation seems to indicate that there are significant differences in the output and observation of these colors. Each color also provides advantages that our system seems to take advantage of. We have also reduced the disadvantages using the design in the prototypes. Red is definitely more easily seen in the brightest of sunlight and we can reduce the output of blue to reduce the chances of night blindness at night over red and still have a signal that is equally effective. It's recommend that we stay with the Red-Blue scheme with a photocell that determines the best color. It is also recommended that we provide a red override for foggy, smoky or hazy atmospheric conditions.

Light Output:

The new lightbars from Code 3 and Whelen Engineering appear to provide sufficient brightness during the daytime in red. They also offer a significant decrease in light output when blue for night operation. Interestingly, many complained about night blindness with the new systems. The complaints increased when the arrow function was on. While complaints were lodged about the intensity at night, no one complained they could not see an object at the front of the vehicle. True night blindness would prevent the seeing of these objects. People were actually reporting discomfort not night blindness. I recommend that the rear window display reduce in intensity somewhere in the range of 3-5 times when the top light changes from red to blue. This reduction in the rear window display should lessen many of the complaints.

It also appeared that the focused light presented by the Whelen Engineering bar did not seem to notably affect the night blindness rating. Also, while we found an interesting optical illusion that made the vehicle appear to get wider as the intense center section dropped out. It appears that this is such a minor illusion that no one observed it until it was pointed out. That should not indicate that we should not explore this illusion further, just that it is not ready to be a requirement at this time.

Flash Frequency:

During the stopped mode, 90 flashes per minute with 50 % off and 50% on appears a good compromise. Having a breakup pattern that provides a triple or quad flash every 3-7 on-off cycles also appears to make the light more visible and still retain the qualities we wanted in terms of relative motion and depth perception.

Training the Public:

The move over law and having a two mode lighting system seem the best approaches to eliciting the desired response.

Light Sources:

LED's appear to be the source of choice. They are energy efficient, reliable and provide the flexibility to provide the functionality that we desire in this system. The electronic controls are also more reliable and create less radio interference than the current solenoids.

Take-down lights:

By far one of the most impressive displays on these vehicles is the Code 3 take down lights. Using only the red and blue LED's on the front of the lightbar, they provided the greatest illumination of any system present. All LED's facing forward should be activated. The segments facing diagonal at the ends should not be activated, as particularly the left segments may blind approaching motorists on undivided highways. The right segment may be desired to be turned on to widen the field of view of the front takedowns for activities on the shoulder or for ticket writing. The color is slightly off from true white but useable. We have not been able to test the effect of this color shift on video recording equipment. One vendor of such equipment stated that if they knew the exact components of the lighting, they may be able to provide a white balance program for the camera that could account for the color shift.

One comment was made that the Code 3 had a very effective intersection presence because they retained a standard halogen alley light at the end of the bar. It is recommended that we pursue that configuration for any light purchased because the amount of LED's provided in the ends of any of these bars is greatly reduced. The ends are composed of LED's placed on a 45 degree diagonal from the front row and the rear row. There are generally very few oriented directly to the side. Certainly there are not enough to equal the output of a small halogen projector bulb either for side visibility during the response mode or for alley lighting.

Sirens:

With the exception of one vehicle (a 40 passenger bus), this siren has proven effective and during measured testing increased the distance at which a siren could be heard a minimum of 30%. This is significant by any measure. Following the recommendation of the manufacturers, I agree that this siren should continue to be installed with a momentary 90 second function. The lower frequency sound being developed by these supplemental systems is less directional in the Federal and Code 3 systems. Whelen Engineering did not go as low in frequency as did Federal and Code 3. However, their siren is significantly louder than and an improvement over the current siren. The sound produced by the Whelen siren is definitely directional. The advantage over the current siren to the sides is unknown and untested. The Whelen siren by not going as low in frequency is not as loud in the passenger compartment of the patrol vehicle and manages to stay in the 8 hour safe exposure range along with the Code 3, while the Federal Siren does not and is rated for 4 hours of continuous exposure *per day*. As installed, the Code 3 system is not practical because it uses a large subwoofer in the trunk that could interfere with rear end collision protection and useable storage space. The Whelen siren as installed is overly complicated and we fear that the multiple drivers required (4 or 5 in this installation) would block sufficient air flow to the air conditioning condenser or radiator. Whelen may have different plans for production. Federal Signal had the most fully developed siren for this evaluation that is only somewhat limited by its slightly higher operator sound exposure. In any case, it is recommended that this low frequency supplemental siren be pursued for purchase.

Future research needs

We should follow-up the installation of these new lights with a study to determine if they do indeed offer our officers increased safety. There are several areas of lighting research that came to our attention too late to be included in this evaluation or that did not have enough research available on the predicted human response for us to be comfortable in using them for this next generation of lighting.

The first concept, a flickering light, was described by Howett, Kelly and Pierce[30] and by another source in this research. This light has the unique properties of having a steady on component and enough contrast in intensity to be conspicuous and attract attention. This is much the effect seen in our Flare Replacement evaluation several years ago. Due to the nature of the flame of the flare it flickers, and remains steady. This light source was the best for conspicuity and being able to understand the message. The same source that discusses flicker as a possibility denotes several negatives to this effect also. Therefore, within the scope of this study we were not able to consider designing this effect into a next generation light without more knowledge of the ultimate effect. In concert with the following effect, we may be able to introduce an element of flicker with minimal risk.

Information came to us too late to incorporate an element of research provided by Rensselaer Polytechnic Institute. This phenomenon is called steady lights. The interesting component of their research is that while steady lights were not as conspicuous as flashing lights and were not observed as soon as flashing lights, vehicles equipped with them were less likely to be struck. Much of this is due to the improved ability to judge distance and relative motion with a steady light than with flashing signals. This research was primarily done with snow plows operating in impoverished lighting conditions, but much of the basic research does apply to other areas. This steady lighting should be compensated for partly by the arrow function that almost never has any off time and the retro reflective markings proposed in other studies. Also, while significantly dimmer, the taillights will be illuminated at night. Because we are not working primarily in impoverished viewing conditions, these lamps should help. We have considered in the past a steady light with a flashing component after conducting our Flare Replacement evaluation. We were not able to locate any research on this type of combination of lighting. We have also considered in our search for proper messaging that we activate the brake lights on our cars when stopped on the side of the road. Using only the tail lamps, while required under most state uniform motor vehicle codes sends a conflicting message that perhaps this vehicle is moving. Also, Federal Motor Vehicle Safety Standards require that the Center High Mounted Stop Lamps is only activated by the application of the brake system itself. Activating the service brake pedal deactivates most transmission interlocks and antitheft devices. So while a promising way to send a proper message and a brighter steady light, this method appears to have its hurdles. A possible secondary benefit to engaging the entire brake system on a stop is that if the vehicle was struck, the front brakes would also act to brake the vehicle and stop its motion sooner. Of course if the brakes were set too tight and the front wheels were locked, any pre set steering input would be lost. There are negative consequences as well such as the new fire suppression system from Ford that relies on the wheels rotating after a crash to indicate when the system should be triggered.

One additional type lighting that may improve the judgment of relative motion and distance is called negative flash. In this scenario, lamps are on more than 50% of the cycle and only flash off shortly for conspicuity. This extended on time may improve judgment without any of the drawbacks of a flickering system. Because the only documented use of this type lamp was in marine use (a relatively slow moving environment), we are not able from the available evidence to sufficiently predict motorist response (a relatively high speed environment) to incorporate this type system into the current project.

Code 3, takedown lights.

Code 3, Solid red (stationary) and rear window display.

Code 3, Solid Blue (Stationary)

Code 3, lightbar unlighted appearance photo.

Federal Signal, takedown lights.

Federal Signal Corporation, Solid Red (stationary)

Federal Signal Corporation, solid blue (stationary).

Federal Signal Corporation, Rear Window Display.

Federal Signal Corporation, red and blue moving mode.

Whelen Engineering, takedown lights

Whelen Engineering, all red stationary pattern.

Whelen Engineering, all blue stationary pattern.

Whelen Engineering, rear window display.

Whelen Engineering, Moving mode, note red, blue and white simultaneously.

Work by

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