Fire Apparatus Emergency Lighting

Study Report

Emergency Responder Safety Institute

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Executive Summary

This report describes the history and development of changes proposed for the emergency lighting requirements in NFPA 1901 and NFPA 1906. The existing standards requirements were developed in the early 1990's and were a significant improvement over the standards of the day, but were largely designed based on pushing the limits of what could be achieved within the constraints of the technology of the day and the vehicle electrical system's ability to power the lighting systems.

For many years there have been concerns about the blinding effects of emergency vehicle lighting, particularly when parked at night. This issue has grown exponentially as lighting has transitioned from incandescent/strobe/halogen lights to brighter and brighter LED lights. In addition to being brighter, LED lights have a greater effect on the eye and brain because they are very narrowly monochromatic, they turn on and off with very sharp edges, and can produce a much greater number of flashes per second. These changes have created a situation that puts firefighters at risk on the highway because the approaching driver has increasing difficulty recognizing the situation, navigating successfully past the emergency scene, and seeing and avoiding emergency responders or civilians near the apparatus.

A study of existing research provided a wealth of information from researchers (academic and users) who have studied this issue. There is almost universal agreement that warning lights on vehicles should be less intense at night and when stopped along the road. Much of the work has been done by police agencies and for the amber (construction and towing) market, with limited research specifically for fire vehicles.

In response to many Public Inputs to the NFPA, draft language was developed for Public Comment and as a basis for further study. Information from this draft and research evaluation was used to develop an evaluation study to gather evaluations based on observations of 60 configurations by about 50 observers. The study was held at the Farm Show Complex in Harrisburg, PA the evening of May 16, 2019 in conjunction with the Fire Expo show.

The observers looked at various lighting intensities, flash patterns, and modulation depth. Each observer filled out a questionnaire about each configuration. The questionnaire was available both on paper and as a web-based questionnaire.

Based on the review of extensive research previously done on vehicle warning lights and analysis of these responses, the following conclusions emerged:

The current lighting optical levels were developed based on using the limited electrical power available, not on any evaluation on how bright the lights should be for optimal performance and safety. At that time lighting systems used strobes, sealed beam rotators, flashing halogen lights, and halogen bulbs with rotating mirrors. The current typical lighting systems using LED light sources produce lighting configurations that are much brighter than would ever be possible with the previous technologies. These can be much brighter than they should be at night. This makes it difficult and dangerous for drivers to safely navigate past an emergency scene.

Based on this study, and the many other referenced studies, the following changes are recommended to the emergency vehicle lighting requirements in NFPA 1901 and NFPA 1906:

- When blocking-the-right-of-way, the lighting display should change from the clearing-the-right-of-way display to a slower, calmer, less intense display.
- The blocking display should allow a lighting source flash rate as low as 60 flashes per minute, consistent with SAE standards.
- The lights should flash in single flashes with half of the lights alternating with the other half of the lights to show lights most of the time and generate a calm flash pattern.
- As much as practicable, lights should be synchronized to minimize the number of flashes.
- At night, the lighting intensity total in each upper zone should be in a range of 400,000 Cd-Sec/Min to 1,600,000 Cd-Sec/Min. At night the lighting intensity in each lower zone should be in a range of 150,000 to 600,000 Cd-Sec/Min. This makes a range that is broad enough to make it easily feasible to achieve with various manufacturers and technologies while controlling the overly bright nighttime displays capable with current LED technology.
- The main text should allow, and annex material should encourage, a flash pattern that remains on at a dim level during the “off” time in a flash.

Even before or without changes to NFPA standards, the industry can make changes immediately to improve safety for emergency responders.

Lighting manufacturers should:

- Develop and/or publicize their capability to produce slower, calmer, synchronized, and lower intensity lighting modes.
- Provide mechanisms to certify lighting equipment configurations that meet the NFPA standards in responding mode, daytime blocking mode, and a reduced intensity nighttime blocking mode.
- Advertise these improved systems to improve emergency responder safety when operating on highways and roads.

Apparatus manufacturers should:

- Work with lighting manufacturers to provide systems that automatically switch modes for blocking-the-right-of-way and nighttime blocking-the-right-of-way. This might include using apparatus multiplex systems to either inform the lighting system or to directly control flash rates and PWM dimming.
- Engineer and offer lighting systems to their customers incorporating these new safety features.

Fire Apparatus Emergency Lighting Requirements History

Emergency lighting on fire apparatus began to appear in the 1920's, and by the 1940's, generally all fire apparatus was equipped with some form of forward-facing red flashing lights. By the 1950's, rotating lights on the cab roof were typical, and eventually rotating or flashing lights were added to the rear.

By 1968, the NFPA standard 19, *Motor Fire Apparatus*, required that:

> "A flashing light or lights visible for at least 135º in each direction to the front and rear of the vehicle shall be provided. On trucks longer than 30 feet, an emergency warning light shall be provided at approximate midpoint on each side visible from the side. The lights shall comply with the following SAE Standards as minimum standards
>
> > …
> > Hazard warning signal unit J910 June 1996 and J945, February 1996.
> > Side emergency warning lights candle power requirements equal to J588d, Class A."[1]

In 1973, these requirements were revised and remained through the 1985 edition of NFPA 1901, "*Pumper Fire Apparatus*". That revision required a 360º light.

> "A red flashing light, or lights visible through 360 degrees in a horizontal plane, shall be installed. Lights shall comply with federal standards as a minimum."[2,3]

In 1991 these requirements were revised again and expanded to include upper and lower lights front and rear, intersection lights to the side, and a master warning light. An appendix item addressed the difference in effectiveness between red and blue lights under different lighting conditions.

> "**3-3.5.1*** Each apparatus shall have one or more rotating, oscillating or flashing lights, visible through 360 degrees in a horizontal plane, mounted on the cab roof or as high as practical. In addition, a pair of flashing, oscillating or rotating warning lights shall be affixed on the front of the vehicle facing forward and below the windshield level with another pair affixed at the rear of the vehicle facing to the rear. Also, an intersection light shall be affixed between the front wheel and the front of the vehicle on each side. The color of emergency lights shall be specified by the purchaser. All required warning lights must be SAE Class I as defined in J595, Flashing Warning Lamps for Authorized Emergency, Maintenance, and Service Vehicles; J845, 360 Degree Warning Lamp for Authorized Emergency, Maintenance, and Service Vehicles; or J1318, Gaseous Discharge Warning Lamp for Authorized Emergency, Maintenance, and Service Vehicles, for the applicable type of light. All warning lights shall be on the current AAMVA list.
> **A-3-3.5.1** The purchaser should strongly consider the use of a combination of red and blue warning lights where such combinations are permitted by state or local law. With lights of equal intensity, red is more effective in the day-light and blue is more effective at night.

3-3.5.2 A master warning light switch shall be provided."[4]

In 1988 a Safety Committee was formed by the NFPA Technical Committee on Fire Department Apparatus (the NFPA committee responsible for the fire apparatus standards). As an outgrowth of their work, research began into improving fire apparatus warning lighting. Automobiles of the time were increasingly sound insulated, making siren warning devices less effective. Improved lighting devices were available using halogen bulbs and strobe lights. At the same time, there were increasing problems with electrical loads on fire apparatus exceeding the capability of available alternators. This tended to cause problems with overloading of the electrical system and subsequent failure for the apparatus. A Conspicuity Task Team was formed to work on revising the standards. This team organized two sets of demonstrations to evaluate potential solutions. From these demonstrations and the evaluations of observers, the revisions for the 1996 edition of NFPA 1901 were developed. The report from this research is reproduced in Appendix 1.[5]

The Conspicuity Task Team was under the leadership of Ken Menke, Sr. They developed a proposed lighting configuration for initial testing using the best available technology. There were several constraints. The system was limited to 40 amps of power, and the lights available were 1990's technology using strobes, sealed beam rotators, flashing halogen lights, and halogen bulbs with rotating mirrors.

A series of demonstrations were held by the NFPA task team at FDIC on April 9 and 10, 1992, both day and night. These demonstrations used two pieces of apparatus equipped with lighting systems matching the existing standard and the proposed system. There was almost unanimous agreement that the proposed system was better than the existing standard. At the same time there were several observations accumulated for improvements that should be made.

Based on these observations, the proposed system was revised, and a second series of demonstrations were held at FDIC on April 6, 1993. This time three different configurations (eventually four) were prepared. The different trucks were all designed based on the same set of optical power requirements but used different lighting technologies. All were subject to the 40-amp power limit. The trucks were viewed in both day and night observations made by 42 observers. No configuration was perfect, and several comments were collected in addition to the statistical data. Using this data, the new configuration requirements were developed.

These new requirements were approved by the NFPA 1901 committee for the 1996 edition of *NFPA 1901 Standard for Automotive Fire Apparatus 1996 Edition*. The final text of these requirements is shown in Appendix 2.[6]

Minor changes, mostly clarification and editorial, were made to these requirements in the 1999[7], 2003[8], 2009[9], and 2016[10].

Between 1993 and 2018, the emergency lighting industry changed almost completely to LED light sources. They provide much better reliability, lower power consumption, smaller size, and other advantages that have made them the preferred light source. While the typical lighting system in the 1990's just met the minimums in the standards, by 2018 the typical lighting system exceeds those minimums by a factor of 5 to 15 times. This has created a situation where, especially when blocking-the-right-of-way at night, the lights are so bright and intense that drivers trying to navigate past an emergency scene are blinded and cannot easily determine where the apparatus (often multiple) and emergency responders in the area are located.

In 2018, many Public Inputs were submitted for NFPA 1901 and NFPA 1906 suggesting changes to the emergency lighting sections to implement improvements, particularly addressing the blinding characteristics of new LED based lighting systems. The electrical task group, working with lighting manufacturers and other interested parties, worked to develop some draft language to present to the NFPA Technical Committee on Fire Department Apparatus. In October 2018 in Orlando, with the help of Whelen Engineering, there were a series of informal demonstrations showing what could be done. These demonstrations showed various intensities and flash patterns. Some minor revisions were made to the proposal to be presented to the full committee. There was a good discussion with the full committee, including agreement that before the next meeting of the committee to review Public Comments, there should be some more testing and evaluation done to determine whether the details in the First Draft proposed language should be adjusted. The proposal for First Draft language was approved by the committee. That language is shown in Appendix 3. It was further edited by NFPA editors and that language was approved in the letter ballot of the committee in April 2019. That language was published on the NFPA web site as the first draft.

The documents opened for Public Comments on the First Draft, with comments due to the NFPA by June 25, 2019 (delayed from the original May 8, 2019). Those comments were to be used by the Technical Committee on Fire Department Apparatus to determine the final language to go into the Second Draft, which would eventually become the 2021 edition of NFPA 1901 and NFPA 1906.

In mid-April 2019, the NFPA did a major reorganization of many standards and the revision process. NFPA 1901 and NFPA 1906 will become part of a single document which will come out in 2022, with a new first draft process with Public Inputs due sometime in Fall 2020 and Public Comments for a second draft due sometime in Summer 2021 for a new document effective in 2023. The previous Public Inputs, committee work, and Public Comments on the first draft will be re-evaluated by the committee in this process.

Recent Research on Emergency Vehicle Lighting

Over the intervening 20+ years, some major changes have taken place in the emergency vehicle lighting industry. One of the most significant has been the changeover from predominantly halogen and strobe lighting to predominately LED lighting. This has resulted in the availability of much brighter lights with much lower electrical demands, more complex flash patterns, and the other characteristics of LED lights. In 1996, the industry had to make major changes and enhancements to provide systems that met the new standard. Now many systems, particularly front light bars, exceed the standard by an order of magnitude or more. In addition, most LED lighting systems provide much more "activity" and variety of flash patterns. There are also characteristics of LEDS that make them more attention getting than flashing or rotating halogens such as sharp on/off times and monochromatic color sources. These characteristics cause the LED lights to have a more intense and jarring effect on the observer and can create greater distraction.

There has been increasing concern that while these new lighting systems are very effective in the daytime and in responding (calling-for-the-right-of-way) mode, at night while parked alongside a roadway (blocking-the-right-of-way mode) they could be blinding and actually distract drivers from their task of negotiating safely past an obstruction, possibly requiring lane changes or merging.

There was an extensive study and report done in 1999 at Loughborough University in the United Kingdom.[11] While some aspects of the study are unique to the UK, much of the material is very valuable. As part of a study on flash intensity, they found that the minimum acceptable daytime intensity for conspicuity was above the maximum allowable level to avoid discomfort glare at night. This study also brought out an additional issue not often studied in the other referenced studies. In looking at the risk of triggering epileptic seizures, they found that this risk was low but that the flickering light in the emergency responder environment caused discomfort, distraction, and additional mental workload. In other words, working in this environment slows the mental processes. The concern from one police officer was ""It can be distracting when working under flashing lights for a length of time. This seems to be a mental workload issue, not a vision problem in that it feels that it takes longer to process what is going on and what needs to be done; more concentration is needed." Their recommendation was that "consideration of the psychological/neural response to flashing lights have to be considered in the specification for the design and use of beacons because the effects may not be restricted to those who suffer from epileptic seizures." Reports from multiple studies report that this effect starts at about 5 Hz (which could be 4 randomly flashing lights at 75 flashes from minute) and peak at about 20 HZ (4 trucks parked together).

Much of the formal research into lighting intensity issues has been done in the police field and the "amber" market for maintenance/construction/towing industries. Several state police organizations have done significant research into how to reduce collisions with police cars parked alongside roadways at night. One such study was conducted by Lieutenant James D. Wells, Jr. of the Florida Highway Patrol,[12] This work was originally published in March 2004. He developed a configuration that used random flashing while moving and an all on/all off flash pattern when stopped to send a different signal that the vehicle was moving vs stopped. The design also used brighter, all red, light in the daytime and a dimmer, all blue, light at night. Florida police are allowed to use both red and blue lights.

In the summer of 2010, the Massachusetts State Police (MSP) had a total of eight serious rear-end collisions involving police vehicles. One was fatal. The MSP started a project to research ways to reduce the number of collisions with police cars parked alongside roadways. They realized that the warning light intensity and flash rate that was appropriate for responding in the daytime was not appropriate when stopped along a highway at night. They experimented with intensity, flash patterns, flash rates, and steady/background light. This study resulted in a new lighting package design that was deployed on more than 1,000 vehicles. According to Sergeant Karl Brenner, MSP fleet administrator, after the changes were made the instances of rear-end collisions to parked police vehicles were reduced dramatically.[13]

The lighting configuration that the Massachusetts State Police are now using for new police cars (after several iterations) consists of Whelen Liberty II series LED Lightbar, rear facing taillight and reverse light LED Inserts. The control unit is a Whelen® CanTrol® System that is receiving inputs from the vehicle for the shift lever position, brake pedal position, driver's door, reverse lights and an ambient light sensor. Programmed within the system are 3 modes of operation for warning light activation. One is a fast unsynchronized and alternating mix of mostly blue and white flashes at full intensity. The CanTrol® system displays this mode whenever the warning light switch is active, and the vehicle is not in park. A second mode slows the flash rate to 60 flashes per minute and creates a fully synchronized 'in and out' flash pattern at full intensity. The CanTrol® system displays this pattern whenever the vehicle is in park, during daylight or high ambient light conditions. The third mode ceases all flashing within the lightbar. The blue warning lights switch to a low intensity glow with a flicker every 2 and a half seconds. The white reverse light inserts turn off and the red brake lights inserts switch to a simultaneous flash rate of 60 single flashes per minute. The CanTrol® system displays this pattern whenever the vehicle is in park, during nighttime or low ambient light conditions. In the event that the vehicle is taken out of park, during either of the two park modes, the system will change the warning lights to the first mode and ready for an emergency response.[14] The lighting configuration that the Connecticut State Police are using is very similar, but not identical. It has more flashing at night, although slow, dim, and fully synchronized. These systems in the clearing-the-right-of-way mode display 4,000,000 to 7,500,000 Cd-Sec/Min total to the rear with a minimum of 48,000 to 139,000 Cd-Sec/Min minimum at any H point (measured per NFPA definitions). In the nighttime blocking-the-right-of-way mode the flashing energy totals about 1,000,000 Cd-Sec/Min total and 11,000 to 14,000 Cd-Sec/Min at any H point minimum and an additional 5,700 to 12,000 Cd-Sec/Min minimum at any H point in steady lighting.[15]

Another study was sponsored by the United States Fire Administration and led by Michael Flannagan of The University of Michigan Transportation Research Institute.[16] This studied the visibility of a firefighter working near an emergency vehicle. One of the conclusions from this study was that "Warning lights, at least at the very high levels used in this study, can measurably reduce the visibility of pedestrians in an emergency scene by causing glare for passing drivers." The "very high" light levels in the 2007 study were lower than typical 2019 fire truck lighting levels.

One study, done by the Illinois State Police in 2003, used rotating and flashing halogen lights at two different levels of intensity. While the higher level of lighting provided slightly higher detection distances, the comments from the observers were significantly different. The reaction to the brighter lights were "strikingly different." The observers described their reaction to the brighter lighting as "frightening, overpowering, very disturbing, distracting, confused me, too much, can only see spots, worse as you get closer, left me seeing spots, and had to concentrate." Their conclusions are: "Our judgment is that the negative side of a higher level of emergency lighting outweighs the positive side. The negative side is that drivers appear to be much more likely to be distracted by higher levels of emergency lighting. The positive side is being visible at a greater distance affords drivers more time to react appropriately. The greater visibility appears to be less important in our opinion than reducing the increased chance of being hit by distracted drivers."[17]

Many ambulances are purchased based on the Federal Specification for the Star-of-Life Ambulance, KKK-A-1822F.[18] This specification is very specific on light colors, location, flash rates, flash energy, and flash pattern. It defines two modes, primary (clear the right-of-way) and secondary (hazard vehicle stopped on right-of-way). In addition, it calls for all lights to dim to 10-30% at night. At a flash rate of 100 flashes per minute (requirement is for 75-125 flashes per minute), the secondary mode minimum total intensity for what NFPA 1901 calls zones A, B, and D would be 24,000 cd-sec/min at any H point day and 2,400 cd-sec/min night. For zone C the minimum would be 54,000 cd-sec/min at any H point day and 5,400 cd-sec/min night.

The Cumberland Valley Volunteer Firemen's Association's Emergency Responder Safety Institute produced a white paper in 2018 summarizing many of the police and fire innovations in improving lighting and conspicuity for emergency responders. This white paper also makes recommendations for standards improvements.[19] Some of their conclusions on emergency lighting include:

- *More lights are not necessarily better, as too many lights can be confusing or "blinding" to motorists.*
- *Faster flash rates draw more attention than slower flash rates; however they may engender distraction and eye discomfort for drivers, especially when on stationary vehicles.*
- *Bright white lights facing drivers can cause visibility problems.*
- *Using emergency lighting to differentiate moving ("calling for right-of-way") from stationary ("blocking right-of-way") vehicles is helpful for drivers to discern how to react. Differentiation can be achieved through different means, including strobe pattern, light pattern, and light color.*
- *Some Industry standards for emergency vehicles lack an upper limit on light intensity, which can allow the use of lights that are "too bright" lights and can cause visibility problems for drivers.*

- *Some industry standards lack a flash sequencing requirement, which can create a hazard because non-synchronized flashes create a distorted sense of vehicle size and position.*
- *Lower light intensity at night and higher light intensity during the day produce the best visibility for drivers.*
- *Technologies now exist to adjust lighting intensity automatically to respond to ambient lighting conditions (i.e., night vs. day).*

They also made some specific recommendations that apply to changes to NFPA 1901 and 1906 including:

- *Standards-making bodies should consider reviewing standards related to emergency lighting to:*
    - *incorporate research findings*
    - *take into account changes in technology like the higher intensity of LED lamps*
    - *consider new/revised requirements to incorporate technologies that have been shown to improve visibility (such as flash sequencing and automatic light intensity adjustment), adding maximum optical power limits to address the possible "blinding" effects of high intensity lights, and revisiting minimum optical power limits to allow for low intensity lights during night and dark operations.*
- *Light intensity should be adjustable for daytime (higher power) and nighttime (lower power) conditions, preferably based on to ambient light conditions and automatically adjusted.*
- *Flash rates should be used to thoughtfully and with regard to what research says about what they communicate to drivers. At this time, best guidance is that faster flash rates be used on vehicles in motion, as that draws more attention, and slower flash rates be used on stationary vehicles, as that helps drivers determine vehicle shape and size with less lighting distraction.*
- *Use emergency lighting to visually differentiate vehicles in motion (calling for right-of-way) from stationary vehicles (blocking for right-of-way). Options include flash pattern, light pattern, and light color.*
- *Departments should consider employing flashing light patterns of slow for stationary and fast for moving that can be automatically adjusted via a device like ambient light sensor or parking brake engagement for calling for right-of-way (faster) vs. blocking right of way (slower).*
- *Consider multi-level and high-level lighting, especially in visually dense environments like cities, to give drivers the best chance to see the vehicle and recognize it as an emergency vehicle.*
- *Take advantage of automatic adjustment technologies like ambient light and parking brake sensors. This enables lighting changes to happen without the need for personnel to remember to initiate them.*

There have also been several formal studies of optimal emergency lighting for the "Amber" market, including highway maintenance, construction, towing, utilities, and others who work alongside active highways. One such study, *Toward Performance Specifications for Warning Beacons*, conducted at the Lighting Research Center, Rensselaer Polytechnic Institute had some very relevant tests and conclusions.[20] This study involved a scientifically controlled set of conditions with 26 subjects each seeing and responding to 96 views seeing 32 combinations of conditions involving light intensity, day/night ambient light, urban/rural background clutter, and light location. There were particularly three relevant conclusions to the current issue. First, daytime response times to see and identify the warning light improved up to about 750 cd peak intensity (equivalent to 22,500 cd-sec/min at 50% flash pattern). At nighttime the improvement was significantly less with little improvement above 250 cd peak intensity (equivalent to 7,500 cd sec/min at 50% flash rate). Second, at night the glare effect did not significantly decrease the ability to see surrounding objects (people) as long as the peak intensity was below 2000 cd peak intensity (60,000 cd-sec/min at 50% flash pattern). Third, in a test of the ability of a driver to detect vehicle closure the detection was significantly better if the light went "off" to 10%, or higher, of the peak intensity rather than going completely off. This might look like the visual effect of a rotating bulb or reflector inside a colored lens which remains visible even when the beam moves on. The study also found that 2 lights allowed significantly better detection of closure than a single light. Fire trucks always have multiple lights and would have a pair visible if the lights flash in synchronism.

Another study was conducted at Penn State University's Thomas D. Larson Pennsylvania Transportation Institute.[21] This study looked at the ability of drivers to see a worker alongside warning lights under various conditions. One key result from this study was that flash rates faster than 1 Hz did not result in improved detection. Another was that at night, 200 cd peak intensity (equivalent to 6,000 cd-sec/min at 50% flash pattern) was sufficient to minimize detection times. Brighter lights resulted in worse performance by the observers. This study also worked with a 100%/10% flash based on previous studies that showed the effectiveness of this type of flash.

The *Manual of Uniform Traffic Control Devices*, the standard for all traffic controls, addresses the use of emergency-vehicle lighting at traffic incidents. One of their conclusions is that the "The use of too many lights at an incident scene can be distracting and can create confusion for approaching road users, especially at night."[22]

The New York State DOT has developed procedures for operating at highway incidents.[23] They recommend that "In some instances, emergency vehicle lighting can be a hazard and blinding to traffic and/or the responders at the emergency scene. Emergency-vehicle lighting should be reduced if good traffic control is established at the incident scene."

It is important to note that there are several levels of glare or temporary blindness caused by bright lights, particularly at night. The lowest level is discomfort glare that is uncomfortable for the viewer to look at. As a result, the viewer (driver) may look away. Actual vision is not actually affected, but the viewer may not see details of the scene they are approaching because they are not looking directly at the vicinity of the bright lights. Another level of glare is disability glare. As the bright light level increases, the eye undergoes physical (pupil constricts) and chemical (sensitivity of the retina decreases) that make it more difficult or impossible to see objects in the vicinity of the bright light. Light scattering within the lens and vitreous humor in the eye reduce contrast necessary to see and identify other objects in the field of vision. Although these effects are temporary, recovery is not instantaneous, so the temporary blindness lasts from one flash to the next. Many factors affect this blindness including light intensity, flash rate, color, geometry, flash rise time, and other factors.[24] A related effect is phototaxis, commonly known as the "moth-to-flame" effect, or just distraction. Although there has not been scientific study on this effect, the idea is that a driver impaired by alcohol, drugs, or tiredness is drawn to bright lights and tends to drive towards them, resulting in collisions with emergency vehicles parked on or alongside the roadway.[25]

A study funded by the United States Fire Administration and performed by the University of Michigan Transportation Research Institute looked at the "Effects of Warning Light Color and Intensity on Driver Vision." This study looked at how quickly a driver noticed a flashing light on an emergency vehicle, how quickly the driver saw a pedestrian responder near the emergency vehicle, and how the driver subjectively rated the conspicuity of the warning lights. The study looked at various light intensities, color, and both day and night conditions. The number one recommendation from the study was to "use different intensity levels for day and night." They concluded that brighter lights provided faster recognition during the day but did not improve recognition speed at night.[26]

The common conclusion from these and many other studies was that to improve safety of emergency vehicles blocking or alongside the roadway they needed a different lighting configuration in the blocking mode and at night. While responding, day or night, the emergency vehicle needs to project the urgent message that "***I AM AN EMERGENCY VEHICLE!! I NEED THE ROAD!! PULL OVER!! GET OUT OF MY WAY!!***" To achieve this, lots of activity (flash rate, variation, randomness) and high light intensity do the best job. In the daytime, it is almost impossible to be too bright when competing with the light from the sun. In this scenario the civilian driver is expected to slow down and pull over, allowing the emergency vehicle to drive past.

When blocking, the message that needs to be projected is very different. It is a calm message that "*There is something unusual here. Do not run into me or the people nearby. Slow down and maneuver as necessary around me.*" When blocking at night it is very important for the lights not to distract the driver or draw their attention away from concentrating on driving. They also must not be so bright that they blind the driver as they maneuver close by the emergency vehicle and personnel. To achieve this, synchronized flashing, slower flash rates, and lower lighting intensities are more effective. In this scenario, the emergency vehicle is stopped, and the civilian driver is expected to identify the situation correctly and maneuver their vehicle safely past the emergency scene.

Research for Specific Changes to NFPA 1901/1906

The process of making these changes was triggered by about 25 Public Inputs submitted for NFPA 1901 and NFPA 1906 suggesting changes to the emergency lighting requirements in the blocking mode, particularly at night. In evaluating these proposals, it turned out that the issue of too bright emergency lights goes back a long way, and there has already been a lot of research on the subject, as described above. The issue was even noted and discussed in the research that developed the 1996 standards, although nothing was included in the standards requirements except to turn off the white lights when in the blocking-the-right-of-way mode.

In the process of dealing with the submitted Public Inputs, revised language was proposed to address the suggestions, incorporating information from the available research and discussions with lighting manufacturers, firefighters, and other constituents. The language was revised by the Electrical Task Group and then by the full Fire Department Apparatus Committee. The language was approved with the understanding that research would continue through the Public Comment stage to further adjust and validate the new requirements.

Whelen Engineering, which has been very active in developing new technology for improving night-time emergency lighting, showed interested members of the committee and others some options that are achievable. There was universal agreement that the new concept lighting was much more appropriate for a vehicle blocking-the-right-of-way at night.

Since that meeting, further searching has found more documented research related to the issues of night-time emergency lighting. Additional discussions have been held with lighting manufacturers about what is possible with today's technology. A study was defined to get observational evaluation of several issues related to the ideal lighting configuration for fire apparatus when parked along the roadway at night.

A definition of the evaluation study was developed defining:

Who will be invited to be observers for the study?
Information required from participating lighting manufacturer(s).
Invited lighting manufacturers.
Lighting configurations to be shown.
The data collection process.
The data analysis process.

The full definition document is in Appendix 4.

The study was conducted in Harrisburg, PA in the parking lot of the Farm Show Complex which provided adequate space to set up the lights and position the viewers at various distances. The parking lot lights were left off, so the conditions were dark but lighted. The vertical ambient light (looking up at the sky) at the start of the test was about 10 lux and the background light intensity behind the lights being observed was about 5 lux. These numbers dropped as the testing progressed. The first display was shown at 8:40 pm (about 20 minutes after sundown) and the last display was shown at 9:30 pm.

Each observer saw 60 different lighting configurations. For each lighting configuration, each observer was asked to answer a few questions about what they saw. The questionnaire is in Appendix 5. The observers either filled out the questionnaire electronically on their smart phone or on a paper questionnaire provided.

There were about 50 people present for the study. A few only observed and did not fill out questionnaires. There were three people who started an electronic questionnaire but did not answer questions about any of the displays or only the first few and they were dropped from the analysis. There were a few people who left early or stopped answering questions. Their answers were included for the ones they answered. The result was 38 full sets of data.

Analysis of the data

There were two key questions to be evaluated using the data. The first is “What should be the limits (minimum and maximum) on the intensity of the lighting in the nighttime blocking-the-right-of-way mode?” The second is “What is the best flash pattern in the blocking-the-right-of-way mode to properly alert passing motorists and allow them to safely navigate past the emergency scene?”

In all the charts below, the three columns represent the answers to three questions:
Visibility: What is the visibility of truck lights at this distance?
1=Insufficient, 5=Ideal to identify, 9=Way too intense

Navigation: What would be the ease of navigating past/around vehicle with lights on?
1=No problem, 5=Could pass safely but distracting, 9=Difficult to pass

Glare: What is the level of discomfort glare?
1=Just noticeable, 3=Satisfactory, 5=Just acceptable, 7=Disturbing, 9=Unbearable

Intensity

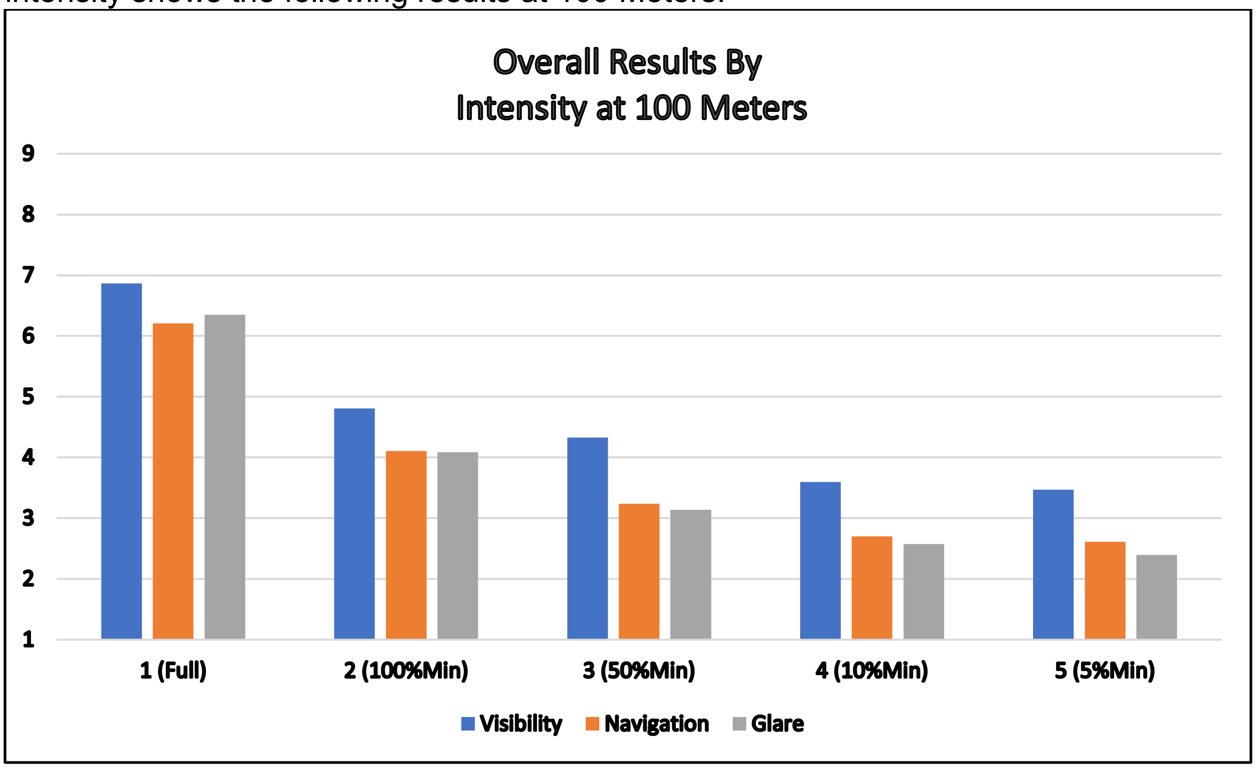
Ideally the lights would be bright enough to be easily seen and identify the truck and the emergency scene, but not so bright as to make it difficult to navigate safely past the scene and not so bright as to cause high levels of glare. There is probably no lighting level that is perfect for all situations.

For this study, the test lights measured per the NFPA procedures had H total intensities as follows:

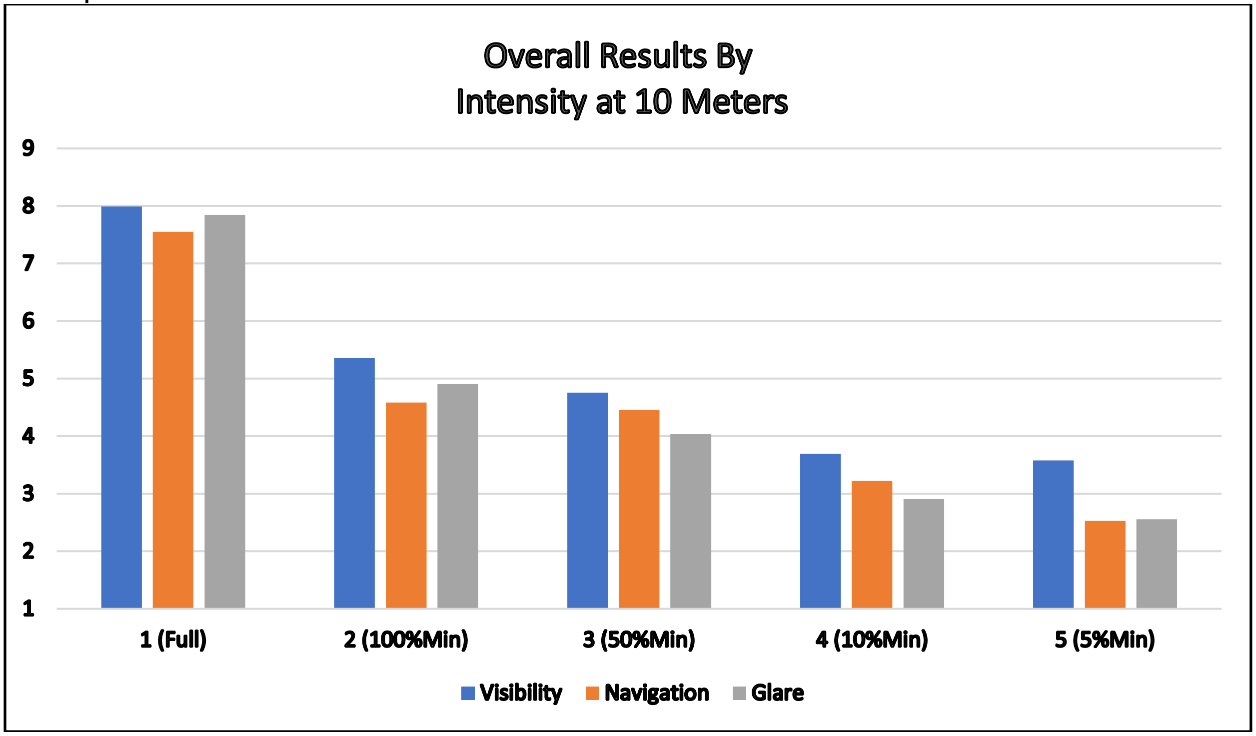
	Upper total	Lower total
Level 1 (Typical full intensity)	4,994,870	2,026,062
Level 2 (Minimum per current standard)	920,750	166,040
Level 3 (50% Minimum)	472,476	83,020
Level 4 (10% Minimum)	95,363	16,604
Level 5 (5% Minimum)	55,801	8,302
Minimum per current standard for rear of vehicle when blocking right-of-way	800,000	150,000

The reason for the tests at level 4 and 5 was to simulate the situation of viewing the lights off angle such as when an apparatus is used in an angled blocking position on the highway. Except for oscillating lights or simulated rotating beacons, most LED light sources have a large difference in light intensity between straight out and 45º off center. This difference is often a factor of 5 to 15 or more. As the viewer approaches 45º the lights from the adjoining zone, but before that point there can be a significant drop in lighting intensity.

Combining all the observations and looking at the responses as a function only of the intensity shows the following results at 100 Meters:



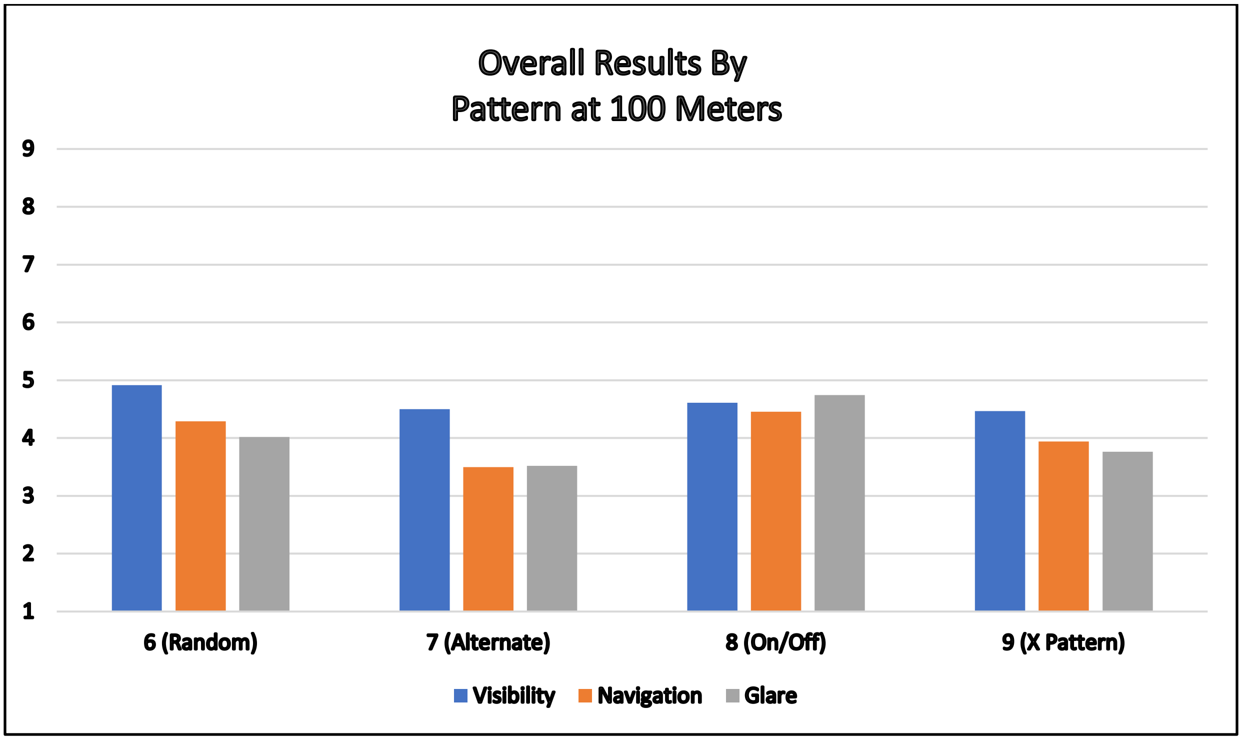
At 10 Meters the results were similar, with the full intensity even more extreme as might be expected:



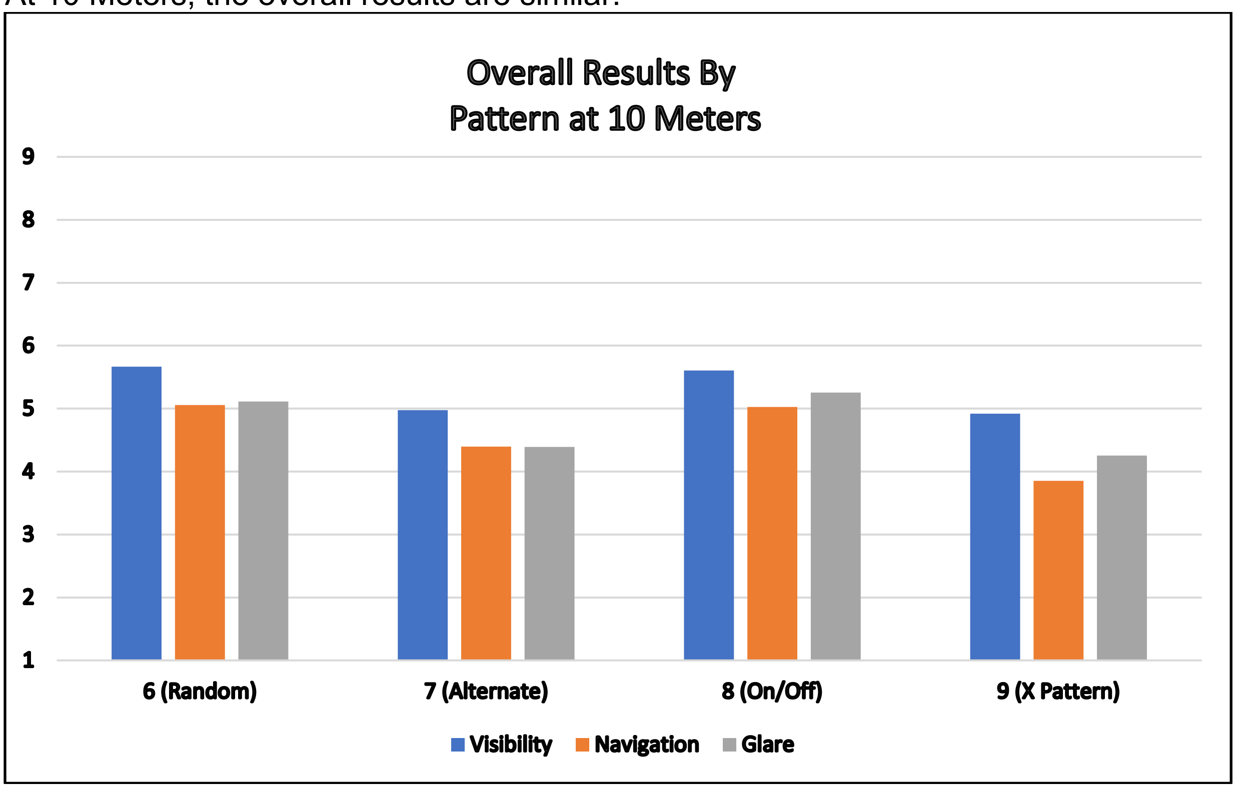
At both 100 Meters and 10 Meters, the full intensity lights were rated as too bright. Anecdotally, each time level 1 lights were displayed, there were groans from the observers and many people turned away. This goes along with the statistical data showing the level 1 lights were definitely too bright at night. Even at a lower level, the study observers still reported that the lights would be distracting when they would drive past the emergency scene. The results for the two dimmest levels are not statistically different (T-test P<.40).

Flash Pattern

The data on flash pattern is less clear. Combining all the observations at 100 Meters, the results are:



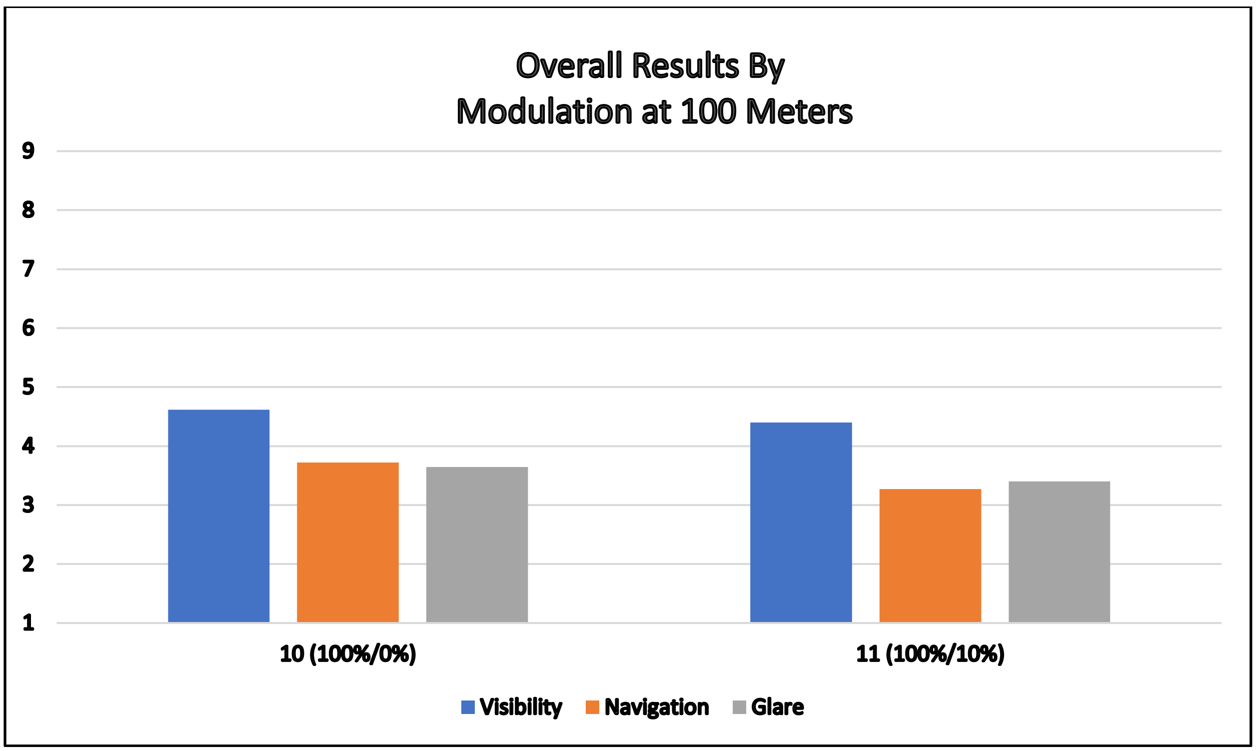
At 10 Meters, the overall results are similar:



The results show that the Random (typical current pattern) and the On/Off patterns are less desirable than the Alternate and X Patterns. Comments about the random (typical current pattern) were often that it was “too fast”, “distracting”, “way too distracting”, and similar comments. Comments about the On/Off pattern talked about the fact that the truck disappears when the lights all go off. There were comments about the up/down Alternate pattern that it looked like a car with 4-way flashers. The Alternate pattern, where opposite pairs of lights are not lit at the same time, does not give as good an impression of the size of the vehicle.

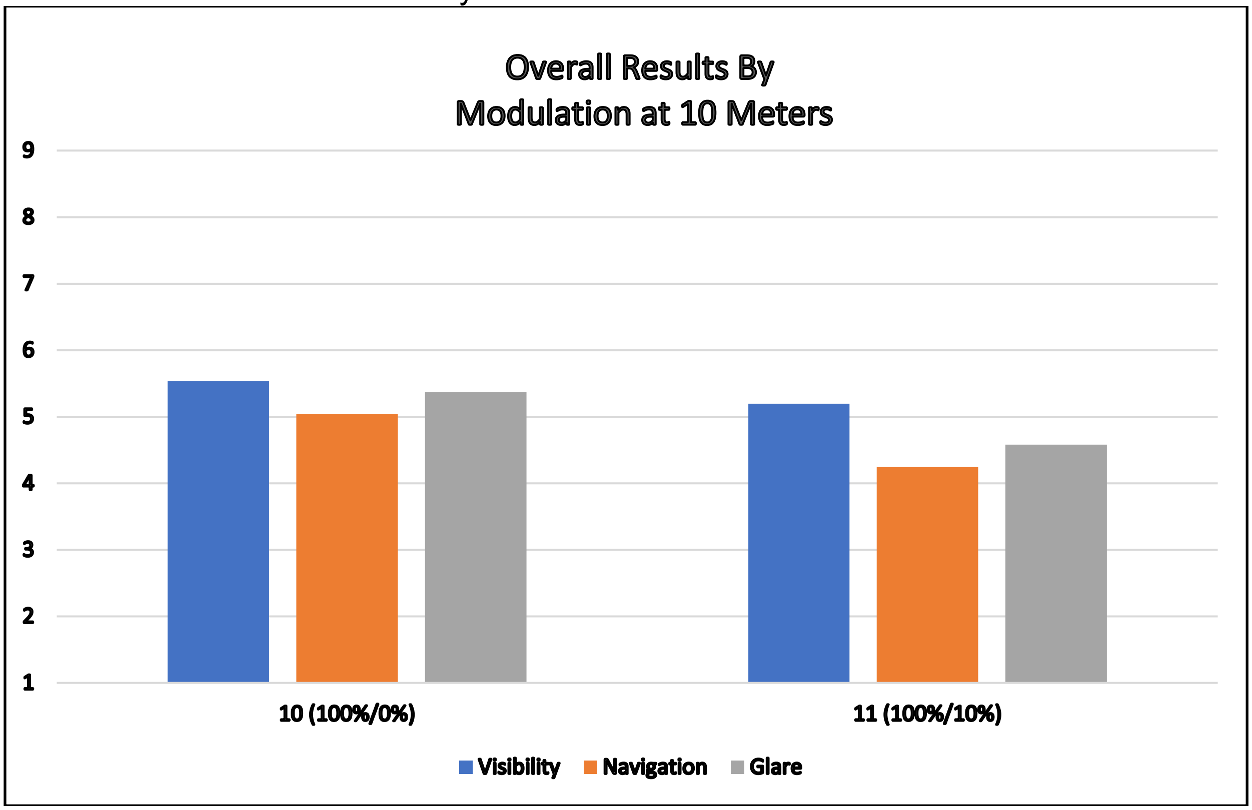
Modulation

The third factor looked at was modulation, the difference in lighting where the flash either goes completely off of retains a “glow” during the off time. Previous studies[20] have shown that drivers are better able to track the vehicle they are approaching if the lights retain about 10% of their peak intensity. This study showed one flash pattern (7, Alternate) at all five intensity levels both with a 100%/0% modulation and with a 100%.10% modulation. The overall results, averaged across all five intensity levels at 100 Meters are:



Note that both the ease of navigating past the emergency scene and the level of discomfort glare improved when the lights remained partially on during the off cycle. This is because the light always remains visible for a position reference and the contrast change between on and off is reduced. Although the study data only shows a small improvement, comments from the participants in discussions after the data collection frequently were comments about how they liked the glow effect. The visual effect is like a light source with a halogen bulb and a rotating mirror. When the mirror is not pointing at the observer, there is still visible light directly from the bulb or from internal reflections from the lens.

The results at 10 Meters are very similar:



The improved ability to track where the vehicle is becomes even more important as the driver maneuvers past the emergency vehicle and scene.

Conclusions and Recommendations

Based on the study of available research, and this study, we would recommend the following changes to NFPA 1901 and NFPA 1906 emergency lighting requirements. Any change to these requirements must not only be based on photometric research data, but also what is acceptable to the NFPA committee that must approve the changes, what is practicable for lighting and vehicle manufacturers to produce (possibly with research and development between the time of publication and the effective date of the standards), and what will be acceptable to the fire service user community (since the standards are voluntary).

This study, and the many other referenced studies, clearly show that there is a problem with emergency lighting at night. Since the NFPA standards place several requirements on fire apparatus lighting, those standards should be adjusted to reflect the new technology and the research on how to improve emergency vehicle lighting. The following recommendations apply to NFPA 1901 and NFPA 1906 requirements for emergency lighting:

- When blocking-the-right-of-way, the lighting display should change from the clearing-the-right-of-way to a slower, calmer, less intense display.
- The blocking display should allow a lighting source flash rate as low as 60 flashes per minute, consistent with SAE standards.
- The lights should flash in single flashes with half of the lights alternating with the other half of the lights to show lights most of the time and generate a calm flash pattern.
- As much as practicable, lights should be synchronized to minimize the number of flashes.
- At night, the lighting intensity total in each upper zone should be in a range of 400,000 Cd-Sec/Min to 1,600,000 Cd-Sec/Min. At night the lighting intensity in each lower zone should be in a range of 150,000 to 600,000 Cd-Sec/Min. This makes a range that is broad enough to make it easily feasible to achieve with various manufacturers and technologies while controlling the overly bright nighttime displays capable with current LED technology.
- The main text should allow, and annex material should encourage, a flash pattern that remains on at a dim level during the "off" time in a flash.

Many of these recommended changes can at least be partially implemented without, or before, changes are made to the NFPA standards. This will allow improvements to emergency responder safety as quickly as possible.

Lighting manufacturers should:

- Develop and/or publicize their capability to produce slower, calmer, synchronized, and lower intensity lighting modes for blocking-the-right-of-way.
- Provide mechanisms to certify lighting equipment configurations that meet the NFPA standards in responding mode, daytime blocking mode, and a reduced intensity nighttime blocking mode.
- Advertise these improved systems to improve emergency responder safety when operating on highways and roads.

Apparatus manufacturers should:

- Work with lighting manufacturers to provide systems that automatically switch modes for blocking-the-right-of-way and nighttime blocking-the-right-of-way. This might include using apparatus multiplex systems to either inform the lighting system or to directly control flash rates and PWM dimming.
- Engineer and offer lighting systems to their customers incorporating these new safety features.

Ideas for Further Research

This study was specifically directed at developing specific information for finalizing changes to NFPA 1901 and NFPA 1906 section 13.8 on emergency lighting. Due to limited time and funding, some questions could not be further investigated. FEMA/USFA has indicated an interest in funding further studies. Other organizations might be interested in researching related issues.

Should the lighting levels and configurations recommended based on this study be adjusted, either up or down.

Additional research on the optimal flash pattern could give better clarity to this issue. To get better data, it would probably be best to present pairs of flash patterns, probably each twice, and then ask the observers to pick the better one. For 4 flash patterns this would result in 6 pairs to be compared. The selection might be binary (pick A or B) or trinary (A is better, B is better, or they are equally good/bad).

Should states improve consistency on colors allowed or required in various applications such as fire, police, EMS, volunteer firefighters, towing/recovery, construction, and school busses? There are many different state laws on this so as drivers cross from one state to another, they may be confused by the messages presented by warning lights.

How should traffic direction devices (arrows or traffic direction sticks) be designed, mounted, and used on fire apparatus.

How significant a risk or effect is the Bucha Effect (psychological physiological effects from rapid flashing/strobing lights) on emergency responders working in an environment with bright flashing lights and nearby drivers or motorists.

Fire Service Research Institute

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Background and History of the Current Requirements for the Warning Lights Used on Emergency Vehicles

January 27, 2003

In 1988, the NFPA 1901 Committee on Fire Appaatus created a Safety Committee to look at the causes of fire fighter deaths and injuries related to the operation of fire apparatus. Among the major concerns was the dramatic reduction in the effectiveness of audible warning devices caused by the. installation of airconditioning and improved sound proofing of automobiles. A closely related problem was that of the shut down of the new computer controlled engines and transmissions on new fire apparatus caused by low voltage.

During interior firefighting, the loss of water to the hose line places the the fire crew in immediate peril. The electrical systems then installed were simply too small and poorly designed to provide electrical energy of quality and in the quantity to operate many computer controlled fire engines. At the same time, the change in vehicle design substantially reduced the effectiveness of audible warning devices.

On April 9 and 10, 1992 a series of demonstrations was held by the NFPA to evaluate the performance of the then required systems of warning lights as compared to an identical vehicle equipped with a state of the art system incorporating devices using the best available technology. Both day and night demonstrations were held. The tabulation of these results is attached. While the observers indicated a strong preference for the higher proposed system, a substantial minority expressed concern over the use of the white light at night. It was universally agreed that any system that was effective during the day would be fine at night.

On April 6, 1993, a second series of daylight demonstrations were arranged by the NFPA in Cincinnati to generate data to be used for the development of the specification of the minimum acceptable performance for the system of warning lights used on fire apparatus. The information developed from these demonstrations was incorporated in the 1996 edition of NFPA 1901, Standard for Automotive Fire Apparatus, and in other related fire apparatus standards. These requirements have been reaffirmed with minor revisions in the 1999 and 2003 editions of this standard.

Following the adoption by NFPA, the SAE Emergency Warning Lights and Devices committee expanded the work of the NFPA to apply to all emergency vehicles including ambulances and police cars.
SAE 2498, the National Standard for the Minimum Performance of the System of Warning Lights Used on Emergency Vehicles, was adopted in 1999.

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In the Cincinnati demonstrations, four fire engines, each having a lighting system drawing 48 amps or less, but projecting different format warning signals, were viewed by a group of about 40 observers during the day demonstrations. Among the formats viewed were signals consisting of a small number of very high energy flashes and signals having the same energy content but a larger number of flashes having lower energy per flash (higher activity).

The warning light systems demonstrated on test engines 1, 2, and 3 were created collectively by senior engineers from all of the major warning light manufacturers, except Whelen, who declined the invitation to participate. Each system was designed to provide information on the relative importance of one or more specific concepts relating to the effectiveness (conspicuity) of optical warning.

The systems shown were not production products and the demonstrations were not intended to be a trade show or a comparison of commercially available products. A key requirement was that the photometric performance of each system be fully documented by the team creating the system and the data available to all participating in the demonstrations.

The Cincinnati Fire Department provided identical reserve pumpers to be used as platforms for the demonstrations. All photometric tests were made at 12.8 volts using power supplies that controlled the voltage to +/-.1 volts. Photos of these engines and of the panel of observers are attached.

On the day of the first test, Whelen arrived with a brand new fire engine (Test Engine 4) and requested, and was granted permission to participate. Unfortunately, after the demonstration, Whelen refused to provide photometric data on their system claiming it was proprietary. Without this information, it was impossible to include the performance of Engine 4 in the development of the minimum photometric requirements. The comments of the observers pertaining to Engine 4 are included in the list of comments.

The evaluations, including comments are attached as well as the numerical values of the optical energy projected around the perimeter of test engines 1, 2, and 3 for both the upper and lower level devices. With respect to the current UMTRI project, it is interesting to note that in section 1 (performance of individual engines), there were 93 comments to the effect that the lights were insufficient or not bright enough and only one comment that the light was blinding (in daylight)

All of the personnel involved in the preparation and operation of the Cincinnati demonstrations were invited to a meeting in St. Louis on December 7 and 8, 1993 at which time the data was evaluated and a first draft of the minimum system performance requirements developed. After extensive discussion, the following scheme for standard development was devised.

APPENDIX 1
Report on Development of 1996 Changes

1. An estimate was collectively determined as to the total optical power that could reasonably be produced using 48 amps at 12.8 volts which was felt to be about as much power as was available on the commercial chassis used for about half of all fire engines.

2. As can be seen from the Tables of Summary Data by Zone for both the upper and lower levels, there was a substantial variation of the Optical Power produced by the different systems.

The system on Engine 1 employed oscillating halogen devices and was designed to be the most efficient. Indeed it had the highest optical power levels. It was judged to be acceptable, but it was not judged to be the most conspicuous.

The system on Engine 2 utilized strobe technology that generated less optical energy but had more activity. It, too, was judged to be acceptable, but not judged to be the most conspicuous.

The system on Engine 3 was designed to generate the most activity and while generating less optical power than either the systems on Engines 1 or 2, it was judged to be the most conspicuous.

3. Using the data and comments from the Cincinnati observations, agreement was reached `as to how the available optical power should be distributed to achieve the minimum performance of the system of warning lights used on fire apparatus. The requirements for total system performance were then established:

When Clearing the Right-of-Way: 2,800,000 CandellaSeconds/Minute

When Blocking the Right-of-Way: 2,600,000 CandellaSeconds/Minute

Following the adoption of these minimum standards on fire apparatus by the NFPA, the SAE Emergency Lights and Devices Committee expanded the NFPA work to cover all emergency vehicles including ambulances and police cars.

I think your selection of the Missouri data is excellent. Fire Service Research Institute is pursuing a related study using this data base. Using the MODOT data as a starting point, we intend to determine the year of manufacture for each fire apparatus involved in an accident. The department operating an engine involved in an accident is on the accident report, and hopefully, so is the date of manufacture of the engine. I have spoken with MODOT but am not sure exactly what data is in the data base. It may be necessary to contact the department to get the date of manufacture.

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The current requirements for warning lights were adopted on July 26, 1996 and virtually every new fire apparatus in America ordered after January 1, 1997 was equipped with the higher performance lighting system mandated in the 1996 edition of NFPA 1901. This means that virtually every 1998 or later fire engine would have a high performance system conforming with NFPA 1901-1996 edition. With a little effort, we should be able to determine whether fire apparatus in Missouri with newer, higher performance (possibly blinding at night?) warning lights are involved in more or less accidents than those using warning lights conforming to the older, lower performance requirements.

I also hope to determine how many police vehicles involved in accidents were operating lightbars and how many were using only dashlights or other lower performance systems. Virtually any lightbar, of reasonable quality, will provide enough optical power to comply with the SAE 2498 requirements for small vehicles while very few dash lights, Kojak lights, or other stealth packages provide enough energy to comply with this standard (particularly in Zones B and D). I am virtually certain that contact with the department operating the vehicle involved in the accident will be necessary to get this information.

If UMTRI is interested in participating in this study, their participation would be welcome. If not, FSRI has the resources to get the job done and will share the data with all who are interested.

With nearly every car on the road now heavily soundproofed, emergency sirens are marginal at best and provide effective warning to no one except pedestrians and bicyclists. Today, with the dramatic reduction the effectiveness of siren performance, I suspect that higher performance, possibly "blinding light" systems may be the only way practical way to alert motorists of the approach of an emergency vehicle during direct viewing in daylight and indirect viewing at night.

At night, the performance needed for daylight operation may well be less than that needed at night. The logical solution would obviously he to mandate a dual intensity warning light system. While slightly more expensive, such systems have been available for at least 25 years.

The problem has been that the drivers of emergency vehicles having dual intensity systems have, in general, refused to use the lower output lights at night. When automatic change over has been incorporated, emergency vehicle operators have invented ingenious means to defeat them.

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While logically an intelligent solution, the use of dual intensity warning light systems will create training and management problems that are real and very difficult to solve. I am also concerned that any emergency agency forcing the use of warning lights lower in performance than that are (or once were) required by national standards, will face legal action brought by any first responder who is injured of killed while being forced to use lower performance warning lights.

Enclosed are my thoughts on the Conspicuity Requirements for Emergency Warning Lights When Operating Under Various Viewing Conditions for anyone on the distribution list who has not received them. I will of course keep you up to date as our research. Best regards to all.

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APPENDIX 1
Report on Development of 1996 Changes

THE FIRST CINCINNATI NFPA DEMONSTRATIONS
APRIL 9-10, 1992

DAY AND NIGHT OBSERVATIONS OF TWO IDENTICAL TRUCKS
TRUCK 1 HAVING A SYSTEM THAT WAS EQUIPPED WITH WARNING LIGHTS
THAT MET BUT DID NOT EXCEED THE MINIMUM REQUIREMENTS THEN IN EFFECT

TRUCK 2 HAVING A SYSTEM THAT WAS EQUIPPED WITH WARNING LIGHTS
THAT INCORPORATED, HIGHER PERFORMANCE, STATE OF THE ART TECHNOLOGY

Fire Service Research Institute

ADVANCING THE STATE OF THE ART WHILE REMEMBERING THE TRADITION OF THE PAST

A NON-PROFIT AGENCY

To: All members of the Apparatus Committee
and Safety Subcommittee

From: Ken Menke, Chairman, Conspicuity Task Team

Date: November 10, 1992

Subject: Demonstration of Proposed Requirements for Improved Apparatus Warning Lights at the Next Committee Meeting

The Conspicuity Task Team appreciates the input provided by the large number of observers who took the time to participate in the apparatus warning light demonstrations held in Cincinnati last Spring. Based on the analysis of the data obtained, the Task Team hope to present a demonstration of a proposed, new, standard for a system of Warning Lights at the Spring Committee meeting. This presentation, is of course, subject to getting enough support from various manufacturers to assemble the necessary hardware.

As can be seen from the attached recap of the Cincinnati data, the observers were very supportive of the general direction taken by the Task Team. However, they did detect several areas that need improvement. These were:

1. More separation is required between the head lights and the lower level warning lights to avoid Washing out the warning lights.

2. The white light at night was blinding to a substantial minority of the observers.

3. Additional low level rear warning is needed.

In addition to these problems, the Task Team has developed the following additional concerns since the demonstration.

1. There was a very large dark area between the front and rear lighting array and it may well be desirable to have some sort of "mid ship" lighting on vehicles longer than the relatively short vans used in the demonstration.

2. The system proposed for full sized apparatus may well be excessive for smaller vehicles such as initial attack vehicles, brush buggies, staff cars and the like. Of particular concern, the available electrical systems on these smaller vehicles may simply not be able to handle the larger loads.

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For these reasons, the Task Team is proposing a series of systems that provide equivalent protection for vehicles of various sizes but are responsive to the differences in physical size. We would appreciate your immediate consideration of the following definitions so that the Task Team can begin working with manufacturers to prepare the hardware needed for the next meeting. Ideally, we would like to present a small, standard, and large apparatus equipped with an appropriate system, for committee evaluation.

Please review the attached proposed definitions and return them to me before you leave Fort Worth, or if this is impossible, as quickly as you can provide meaningful comment.

The three classes of vehicles being suggested are:

1. Automobiles and vehicles up to including full size pickup trucks.

2. Vehicles larger than full size pickup trucks up to and including standard size pumpers.

3. Longer vehicle such as heavy rescues, goose-neck trailers, and aerials. Basically, these larger vehicles would have one or more "mid ship" devices added to the system required for class 2 apparatus.

After reviewing these definitions, please make any additions or corrections. Use the back of the sheet if room is needed for longer comments or sketches.

Print your name on the top of the sheet so that I can contact you, if necessary, to discuss your comments.

Recap of Cincinnati Observations - April 9-10, 1992

EMERGENCY WARNING LIGHT OBSERVATIONS 3-31-92

Name: NFPA 1900 Committee (15), Safety Subcommittee (10), Others (12)

Date: April 9-10, 1992 Day xxxxx

I. General Observations

Having observed the separate operation of the warning systems on the two test vehicles, please answer the following questions.

1. Did you see any difference between the present system and the proposed system. Yes_ 28_ No_0__

2. If Yes, what difference(s) did you see?________________________________

__See List of Consolidated General Comments________________________________

3. Under these viewing conditions, does the CURRENT system provide an adequate level of warning? Yes_2__ No_27_

4. Under these viewing conditions, does the PROPOSED system provide an adequate level of warning? Yes_17_ No_13_

5. Was the CURRENT system blinding? Yes_0__ No_29_

6. Was the PROPOSED system blinding? Yes_0__ No_29_

II. Side by side comparisons. When viewed from the following Points, indicate which system was more effective.

	CURRENT	PROPOSED
1. From the side, calling for the right of way?	_0___	_27__
From the side, blocking the right of way?	_0___	_28__
2. From 45 degrees front, calling for right of way?	_0___	_29__
From 45 degrees front, blocking the right of way?	_0___	_30__
3. From the front, calling for the right of way?	_0___	_28__
From the front, blocking the right of way?	_0___	_28__
4. From 45 degrees rear?	_0___	_28__
5. From the rear?	_0___	_27__
6. Which system best outlined the size and shape of the vehicle?	_0___	_28__

6. Comments: ____

______See List of Consolidated General Comments__________________________

Recap of Cincinnati Observations - April 9-10, 1992

EMERGENCY WARNING LIGHT OBSERVATIONS 3-31-92

Name: NFPA 1900 Committee (15), Safety Subcommittee (10), Others (12)

Date: April 9-10, 1992 Night xxxxx

I. General Observations

Having observed the separate operation of the warning systems on the two test vehicles, please answer the following questions.

1. Did you see any difference between the present system and the proposed system. Yes_ 37_ No_0__

2. If Yes, what difference(s) did you see?________________________________

__See List of Consolidated General Comments______________________________

3. Under these viewing conditions, does the CURRENT system provide an adequate level of warning? Yes_6__ No_28_

4. Under these viewing conditions, does the PROPOSED system provide an adequate level of warning? Yes_26_ No_9__

5. Was the CURRENT system blinding? Yes_0__ No_36_

6. Was the PROPOSED system blinding? Yes_15_ No_21_

II. Side by side comparisons. When viewed from the following points, indicate Which system was more effective.

	CURRENT	PROPOSED
1. From the side, calling for the right of way?	_0___	_37__
From the side, blocking the right of way?	_0___	_37__
2. From 45 degrees front, calling for right of way?	_1___	_36__
From 45 degrees front, blocking the right of way?	_1___	_36__
3. From the front, calling for the right of way?	_0___	_37__
From the front, blocking the right of way?	_2___	_35__
4. From 45 degrees rear?	_0___	_37__
5. From the rear?	_1___	_36__
6. Which system best outlined the size and shape of the vehicle?	_1___	_36__

6. Comments: ____

_______See List of Consolidated General Comments__________________________

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Report on Development of 1996 Changes

Recap of Cincinnati Observations - April 9-10, 1992

EMERGENCY WARNING LIGHT OBSERVATIONS

Consolidated General Comments

Name: NFPA 1900 Committee (15), Safety Subcommittee (10), Others (12)

Night	Day	
13	0	The white light was "blinding" (proposed system).
1	0	Low mounted rotating lights are not practical (proposed system).
11	0	Head lights wash out lower level signal (proposed system)
6	8	Rear needs lower level signal like front (proposed).
4	2	Headlights brighter on Truck 2 (proposed system) than on Truck 1 (present system).
4	2	Need more side lighting (proposed system).
24	18	Proposed system is more visible in more directions than the present system.
2	0	Current system looks like a service vehicle not an emergency vehicle.
3	1	White light is attention getting.
1	0	Proposed system needs more off angle coverage.
1	0	Rotating signals are better than flashing signals.
1	0	Add headlight flashers to proposed system.
2	0	Add blue lights to proposed system.
1	2	Upper lights on proposed system are no good.
0	4	Need day/night mode for proposed system.
0	4	Proposed system is not good enough.
0	2	Need more current at idle.
0	1	Need evaluation of operating electrical loads including battery recharge.

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Report on Development of 1996 Changes

THE SECOND CINCINNATI NFPA DEMONSTRATIONS

APRIL 6, 1993

DAY OBSERVATIONS

THREE FIRE ENGINES WITH ENGINEERED SYSTEMS OF WARNING LIGHTS TO TEST VARIOUS CONSPICUITY CONCEPTS
AND

A NEW FIRE ENGINE (UNPLANNED) WITH A PRODUCTION WARNING LIGHT SYSTEM

APPENDIX 1
Report on Development of 1996 Changes

EMERGENCY WARNING LIGHT OBSERVATIONS - PART I 4-6-93

VEHICLE NUMBER _________

Name:____ 1901 Committee_____ Safety SubCommittee_____

I. General Instructions

The information obtained from todays observations will be used to prepare the revised requirements for warning Lights on all fire apparatus. In the first portion of these observations you will see several different approaches to generating effective signals using 40 amps or Less. Each of these systems is for a "Standard Vehicle" of between 20 and 30 feet in length.

Each engine will be shown alone and you are asked to make a judgement of the adequacy of the signal under various viewing conditions. Please mark your evaluation sheet after the number of the question is announced. The evaluation sheet will be collected after viewing each engine.

In the second part of the observation, all of the engines will be shown at the same time and you will have the opportunity to comment on the relative strengths and weaknesses of the different systems.

THE COMMITTEE DEFINED THE SYSTEMS TO BE SHOWN AND WISHES TO THANK THE MANUFACTURERS WHO VOLUNTEERED TO CREATE THESE SYSTEMS FOR YOU TO VIEW. THE SYSTEMS SHOWN DO NOT NECESSARILY REPRESENT PRODUCTS IN PRODUCTION OR PLANNED FOR PRODUCTION.

A. Moving Observations. Having observed the operation of the warning systems on this vehicle while in motion and calling for the right of way,

1.Was the overall performance of the system adequate? Yes____ No____

2.Comments?____

____

B. Stationary Observations. When viewed from the following points, does this system provide adequate warning?

1a. Front, calling for the right of way? Yes____ No____ 1b. Blocking the right of way? Yes____ No____

2a. Front, 35 degrees, calling for right of way? Yes____ No____ 2b. Blocking the right of way? Yes____ No____

3a. Front, 75 degrees, calling for right of way? Yes____ No____ 3b. Blocking the right of way? Yes____ No____

4. Side, blocking the right of way? Yes____ No____

5. Rear, 45 degrees, blocking the right of way? Yes____ No____

6. Rear, blocking the right of way? Yes____ No____

7. Comments: ____

____

____

EMERGENCY WARNING LIGHT OBSERVATIONS - PART II 4-6-93

VEHICLE NUMBER __________

Name:____ 1901 Committee_____ Safety SubCommittee_____

I. General Instructions

"In the second part of the observations, you will see all of the engines in close proximity. During the moving observations, the engines will appear in the same order as they were seen in part 1 of the observations. The first engine you see will be engine 1, etc. When lined up side by side in the stationary viewing, engine 1 will be to your right. Under each viewing condition, please indicate any engine(s) that appeared to be SUBSTANTIALLY BETTER or SUBSTARTIALLY POORER in their performance than the others.

THE COMMITTEE DEFINED THE SYSTEMS TO BE SHOWN AND WISHES TO THANK THE MANUFACTURERS WHO VOLUNTEERED TO CREATE THESE SYSTEMS FOR YOU TO VIEW. THE SYSTEMS SHOWN DO NOT NECESSARILY REPRESENT PR7UCTS IN PR7UCTION OR PLANNED FOR PR7UCTION.

A. Moving Observations. Having observed the operation of all of the warning systems white in motion and calling for the right of way, was the overall performance of any engine(s) SUBSTANTIALLY DIFFERENT than the others?

1a. Better, engine(s)__________ 1b. Poorer, engine(s)__________

2. Comments? ____

____

B. Stationary Observations. When viewed from the following points, was the overall performance of any engine(s) SUBSTANTIALLY DIFFERENT than the others?

	Better Engine(s)	Poorer Engine(s)		Better Engine(s)	Poorer Engine(s)
1a. Front, calling for the right of way?	_______	_______	1b. Blocking the right of way?	_______	_______
2a. Front, 35 degrees, calling for right of way?	_______	_______	2b. Blocking the right of way?	_______	_______
3a. Front, 75 degrees, calling for right of way?	_______	_______	3b. Blocking the right of way?	_______	________
4. Side, blocking the right of way?	_______	_______			
5. Rear, 45 degrees, blocking the right of way?	_______	_______			
6. Rear, blocking the right of way?	_______	_______			

7. Comments: ____

____

____

Fire Service Research Institute

ADVANCING THE STATE OF THE ART WHILE REMEMBERING THE TRADITION OF THE PAST

A NON-PROFIT AGENCY

To: Terry Dawson
Andy Olson `
Scott Sikora
Greg Sink/Ed Stanuch
Drew Smith/Bob Kreutzer

From: Ken Menke

Date: April 18, 1993

**Subject: Tabulated Data from the Cincinnati NFPA demos
Held at Riverfront Stadium April 6, 1993**

As I mentioned in my previous memo, I have loaded all of the Part I information into a data base. Enclosed are the following:
1. The data sorted by observer.
2. The data sorted and tabulated by engine for all viewers.
3. A recap sheet comparing the performance of the various systems.
4. A copy of the Part I data sheet to permit review of the questions.
5.

I. Methodology

Working with copies of the data sheets, I grouped the Part I sheets by observer. After matching the handwriting and style on the dozen or so sheets without names, I was able to assemble 42 complete data sets which came from the following:

Members of the 1901 Committee - 21
Members of the Safety Subcommittee NOT on 1901 - 7
Other Observers - 14 (including 2 who gave no names)

Drew Smith has the originals and his secretary is extracting and correlating the large number of written comments.

I first looked to see if there was any significant difference between the subsets of observers. While the members of the 1901 Committee closely match the total of all viewers, a significant number of the 7 Safety Subcommittee members not on the 1901 committee apparently felt none of the systems were adequate. I am afraid that this small group may have totally unrealistic expectations of what can be done by warning lights. Given the small size of the data base, I think it is best to work with it as whole. All the enclosed tabulations are based on ALL viewers.

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II. Initial Conclusions

The difference in the performance evaluation obtained by compositing the individual observations (Part I, B Questions) and the overall evaluation (Part I, Question A1) is really interesting.

Rank Order and Adequacy Rating of Engines

	Based on the Single Question A1	Based on the average of the 9 questions in B
1.	Engine 4 - 92%	Engine 3 - 83%
2.	Engine 3 - 89%	Engine 1 - 77%
3.	Engine 2 - 82%	Engine 4 - 76%
4.	Engine 1 - 73%	Engine 2 - 69%

It is important to note that in addition to the dramatic shift in rank order, the use of all 9 data points also reduces the overall adequacy rating of the best system by nearly 10 percentage points.

It would appear that most of the observers tended to base their overall rating of the engine on the appearance of the system from the front of the vehicle. One could reasonably argue that this failure to give adequate consideration to the rear and off angle performance is the cause of accidents and is the reason that we have been asked to do this study.

As you remember, the demonstration was planned around Part I in the hope of obtaining independent measures of adequacy of various systems. Part II was an encore event to handle the anticipated demand to see the systems side by side and perhaps glean a little 'additional information.

As it turned out, we were able to run only the first portion of Part II before time constraints and equipment problems forced an end to the demonstration. The limited data from Part II simply appears to confirm the information generated from question A1 in Part I.

III.Work to be Done

I see the primary objective of the Scottsdale meeting to be the correlation of the photometry with the observations. We should have enough information from diverse systems to address the issue of what kinds of signals are required to achieve various levels of adequacy.

With this information we should be able to draft a standard having an equal level of adequacy at all points for a specified amount of input wattage. By simple extrapolation, I think we can also estimate the increase or decrease of adequacy resulting from the addition or removal of electrical energy.

All in all, I think we have had a very good experiment and are in a position to move forward in the creation of meaningful standards.

Page 2

Comparison of Vehicles

Cincinnati Demos
4/6/93

Vehicle Moving and Calling for the Right of Way

		Engine 1	Engine 2	Engine 3	Engine 4
B1a.	Front	79%	93%	90%	95%
B2a.	35 Deg	88%	86%	95%	86%
B3a.	75 Deg	83%	67%	83%	81%
	AVERAGE OF 3 POINTS	83%	82%	89%	87%

Vehicle Stopped and Blocking the Right of Way

		Engine 1	Engine 2	Engine 3	Engine 4
B1b.	Front	68%	69%	85%	63%
B2b.	35 Deg	88%	64%	90%	64%
B3b.	75 Deg	70%	50%	89%	70%
B4	Side	53%	60%	63%	69%
B5	45 Deg	81%	56%	68%	68%
B6	Rear	81%	73%	88%	90%
	AVERAGE OF 6 POINTS	74%	62%	81%	71%
	AVERAGE OF ALL 9 POINTS	77%	69%	83%	76%
A1	OVERALL PERFORMANCE	73%	82%	89%	92%

WKM
4/17/93

CODE 3®
PUBLIC SAFETY EQUIPMENT, INC.

10986 N. Warson Road
St. Louis MO 63114-2029
Phone (314) 426-2700
FAX (314) 426-1337

April 19, 1993

NFPA Safety Subcommittee Task Force for Conspicuity:
Kenneth W. Menke, Fire Service Resource Institute
Gregory A. Sink, Federal Signal Corporation
Andrew Olson, Whelen Engineering, Inc.
Scott Sikora, Tomar Electronics, Inc.
Andrew G. Smith, Public Safety Equipment

Gentlemen:

Attached is a summary of the comments written on the data sheets used at the NFPA demonstration on April6, 1993. The comments have been summarized by truck, by both written comments and by quantitative answers. Also included is a one-page summary of the quantitative data and a one-page summary of the qualitative data.

Task Force Consensus (we all agreed to the following):

1. The trucks need some basic midship lighting, even a simple flashing light somewhere midship would be adequate.

2. All systems appear to meet a "minimum' requirement (with the addition of the midship lighting).

3. The consensus of the task force and the safety committee was to go to a 48-amp current limit.

4. “Activity” seemed to rate higher than flash energy (“activity” includes flash rate, change in colors, and change in location of the light source).

Personal Observations:

1. The impression several people had was that the crowd didn't seem to understand why we were turning the white light on and off. It doesn't appear as if this crowd or the public in general will ever identify a white flashing light as indicating that an emergency vehicle is moving and the lack of a white light as indicating that the emergency vehicle is stopped. However, for the purposes of current conservation while the vehicle is stopped, it would seem w make sense w provide a recommendation in the standard for traffic clearing lights to be dropped off while the vehicle is stopped. I recommend that we include a provision for a manual override if this is done automatically so that in situations where the emergency crew wanted to provide full lighting while topped they could easily do that and at other times benefit from the conservation when the vehicle is not moving.

NFPA Safety Subcommittee Task Force for Conspicuity
April 19, 1993
Page 2 of 2

2. The votes for trucks I and 2 seemed to group pretty closely together, likewise the votes for trucks 3 and 4 seemed to group together (often within one vote of each other). The exception to this was when Tomar’s front facing white strobe light was turned on. I suspect this was because of its high activity, given its two white strobe lights alternating with each other for a combined high activity level and their apparent high directional flash energy levels.

3. Based on the written comments submitted in order of priority, it appears as if:

- Amber light is needed to the rear
- Midship lighting is needed
- Better trucks had more activity associated with the light signals

4. More thoughts on Tomar’s white strobe light: Looking at the s data for Part II, when the Tomar white light was on, that system received far more votes than any other system in any other category. When it was off, it tied for second exactly with Whelen's system, and the rotating light system clearly rated higher. It suggests to me that perhaps the center white light is most effective when it is used as a high activity, single directional warning light covering a fairly narrow, front-only area of protection. Once a moderate off-angle is achieved, the higher activity rotating signal takes over as superior.

5. Looking at the summary of the Part II data, it becomes very clear that the high activity level of trucks 3 and 4 (truck 3’s high flash rate, truck 4’s high number of signal sources) clearly rate higher than trucks 1 and 2, which in many viewing angles had higher flash energy levels than trucks 3 and 4. Again, the single exception is when Tomar’s white traffic clearing light is on. I suspect this is because of its high combined flash rates more than anything.

Please review the attached data. If you have any comments or corrections that should be made, please contact our secretary, Rhonda Femmer (314-426-2700, ext 1332). Our primary focus in data summary was collating the written qualitative comments. Ken Menke is performing a much more exhaustive analysis of the quantitative comments.

Sincerely,

PUBLIC SAFETY EQUIPMENT, INC.

Robert E. Kreutzer
Manager, Mechanical Engineering

AGS2/rmf/477
Cc; Robert Tutterow
Robert Barraclough
Carl Peterson

NFPA DEMONSTRATION - APRIL 6, 1993

Sponsor	Truck No.	Percent Yes
Federal Signal & Ken Menke 1	1	74.4
Tomar	2	79.1
Public Safety Equipment	3	85.7
Whelen Engineering	4	88.1

Forms/NFPAREPT

NFPA DEMONSTRATION

APRIL 6, 1993

TRUCK #1 (Federal Signal & Ken Menke)

Question No.		Yes	No
A.	1	32	11

A. 2 Comments:

- Long dead time
- Headlight and taillight would help
- Minimum level
- No headlights or direction or S.T.
- White light is a must
- Could be confused with construction lighting at night
- Dead spot in center of vehicle
- Rotation too slow
- Midships: empty - front could use light in center, rear center there is a void
- Low level lights ineffective
- Midship lights needed
- Could not determine type of light (halogen, etc.)
- Poor light output, good for stopped, too weak for operation
- Midship views (side) is very deficient Forward view in daylight washes out the red lights
- Warning lights too dim, too long between flashes, nothing midships
- Minimum adequate to subjective
- Not much activity
- Good system - can see from far away
- Side visibility somewhat marginal
- Clear center top light very visible
- Lights at bumper level did not appear as predominant as those on top of cab
- But too much red
- Minimum
- Looks effective to me

Question No.		Yes	No	Comments
B.	1a	34	9	

Question No.		Yes	No	Comments
B.	1b	30	12	• Should leave white on • Lower front lifes (lites?) too dim

Forms/NFPAREPT

Truck 1 (Federal Signal & Ken Menke)
Page 2 of 2

Question No.	Yes	No	Comments
B. 2a	37	6	• More lights – small area

Question No.	Yes	No	Comments
B. 2b	36	6	• Leave white on

Question No.	Yes	No	Comments
B. 3a	34	8	

Question No.	Yes	No	Comments
B. 3b	29	12	• Leave white on

Question No.	Yes	No	Comments
B. 4	22	21	• No mid truck coverage

Question No.	Yes	No	Comments
B. 5	35	8	

Question No.	Yes	No	Comments
B. 6	35	8	

B. 7 Comments:

- Marginal on side
- Major overkill for wildland applications - too expensive and will be damaged off-road
- No intersection lights 2A & 2B. No stop tail or directional 2A & 2B. A & 2A if headlights on would be improved. 4 would be OK with intersection light
- Need something in the middle of the truck
- Dark spot above rear wheels, rear is dark
- 2A/2B void in midship and 4 - 3A/3B & 5. #6 - void in center
- Needs a midpoint light
- Amber lights needed (preferably directional)
- Overall not too bad - improved over existing standards - lower lights rear help
- Very
- Like low key rear lights - let's get 'em!
- White could use higher flash rate
- Low lights very effective from rear
- Visible in all positions
- Good as minimum only
- A light in the middle of unit would assist #4, color mix
- Lower rear lights are a big asset
- Overall lighting effect looked adequate

Forms/NFPAREPT

NFPA DEMONSTRATION
APRIL 6, 1993

TRUCK #2 (Tomar Electronics)

Question No.	Yes	No
A. 1	34	8

A. 2 Comments:

- Looks effective to me No midship lights
- White light drowns out top 2 red lights
- Low strobes less effective
- Good
- Low lights better than #I
- Better than #I, void in midships and rear
- Improvement over vehicle #I - frequency of flashes improves, but midships is seriously lacking
- Think that another light at bottom rear would be better
- Not ass effective as first one
- 100% strobe is effective (cross flashing helps)
- Strobes very effective
- Intensity seems a little low
- Not enough definition - lights blend - need different speeds – possible
- Good only in front
- No body side lights
- Frontal view better than truck 2, white is still a must (white was brighter)

Question No.	Yes	No	Comments
B. 1a	41	2	• Need something at middle height • Fair • Fair

Question No.	Yes	No	Comments
B. 1b	30	13	• Would be adequate if all lights Were working • Need lower strobes

Question No.	Yes	No	Comments
B. 2a	36	7	• White light weak

Forms/NFPAREPT

Truck 2 (Tomar Electronics)
Page 2 of 3

Question No.	Yes	No	Comments
B. 2b	29	14	• Marginal • Would be adequate if all lights were working • Need lower rear strobe to be visible

Question No.	Yes	No	Comments
B. 3a	30	13	• Needs middle light • Weak rear lower corner • Fair • Marginal • Can't see white strobe

Question No.	Yes	No	Comments
B. 3b	22	21	• But lower rear could be better • Would be adequate if all lights were working • Need lower rear strobe to be visible

Question No.	Yes	No	Comments
B. 4	26	0	• No mid-range coverage • Need light mid-vehicle if Blocking • Marginal

Question No.	Yes	No	Comments
B. 5	23	18	• Not as good as #1 • Could be better • Missed viewing • Can' t see front left and right rear lower

Question No.	Yes	No	Comments
B. 6	30	11	• Fair • Missed viewing

Forms/NFPAREPT

Truck 2 (Tomar Electronics)
Page 3 of 3

B. 7 Comments:

- Better than #1, but not much!
- Overall not as good as #1
- Could use midship stationary flashing light as an option
- Corner positioning important to visibility with vehicle at various angles
- 3A & 3B could not see rear bottom lights
- Lower lights not as effective as upper lights
- 75º white hidden, needs center light, front lights good, rears good only direct rear
- Generally not as good as #1
- Void midships and rear
- #1 was better - lower placement of strobes had tremendous effect
- In 2a, 2b, 3a, and 3b, could not see bottom, rear light. In 5, could not see bottom front light
- The strobes were only good when straight on
- 2a, 3a, 4, and 5 - intersection lights
- Needs fender well lights
- 2b - no lower light for close-in warning (white light off)
- Lower lights don't seem w have enough intensity
- Dark above rear wheels
- More lights needed (amber and directional)
- Overkill for wildland applications - off road damage
- Need something in the middle

Forms/NFPAREPT

NFPA DEMONSTRATION
APRIL 6, 1993

TRUCK #3 (Public Safety Equipment, Inc.)

Question No.	Yes	No
A. 1	36	4

A. 2 Comments:

- Not bad, as good as #1 and #2. White light a must, but not as noticeable as 1 and 2.
- Lower rotators are very effective
- Alt (alternate?) flash more effective than simult (simultaneous?) - even to avoid simo
- Usefulness of "combination" of lights would improve gradings
- Needs midship light, eye level, front of rear wheels
- Barely. Does need something at midship, eye level, just forward of the rear wheel
- More front lights needed above headlights
- About same as 1 and 2
- Most noticeable
- Longer duration definitely a plus
- Best for getting attention
- A lot of flashes - good signal
- Bumper lights seemed best of the four samples
- Best moving display of the four
- Lightbar signal could be brighter

Question No.	Yes	No	Comments
B. 1a	39	4	• More at mid level

Question No.	Yes	No	Comments
B. 1b	38	5	• Leave white on

Question No.	Yes	No	Comments
B. 2a	41	1	• Good

Question No.	Yes	No	Comments
B. 2b	29	14	

Question No.	Yes	No	Comments
B. 3a	36	5	• High rotators great

Question No.	Yes	No	Comments
B. 3b	35	5	

Forms/NFPAREPT

Truck 3 (Public Safety Equipment, Inc.)
Page 2 of 2

Question No.	Yes	No	Comments
B. 4	28	14	• Fair • More in middle • Very minimal on lower installation, need intermediate light • Need light(s) near middle of truck

Question No.	Yes	No	Comments
B. 5	27	15	• Cab bar light poor or useless • Front beacon not effective • Need light(s) near middle of truck

Question No.	Yes	No	Comments
B. 6	37	5	• Fine • Lost lightbar • Low lights seemed small

B. 7 Comments:

- Need something in the middle of the truck, lower fit, rear lights a must
- Need mid-truck light
- Need center light
- Need lighting mid-vehicle
- White - little effect at 35º front/dark over rear wheels, light bar little effect at 45º rear
- Generally need more high lighting to side and mid range (ahead of rear wheels)
- Lover revolving lights do a good job - all trucks need something in center
- Midship - front center mid to lower section - poor rear - void in center
- Body side lights needed, amber directional lights needed in rear
- Overkill for wildland agencies - too costly and will be damaged off road
- Overall better than 1, 2, and 4
- Needs center light
- More influence and pulses faster
- Very good! Probably the best
- Midship - lacking warning
- A light fixture mounted on the bumper is highly unlikely in a red setup. Very breakable
- The best lights
- Front bar light weak in 5
- Rotating lights seem to grab your eye

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NFPA DEMONSTRATION
APRIL 6, 1993

TRUCK #4 (Whelen Engineering)

Question No.		Yes	No
A.	1	37	3

A. 2 Comments:

- Mid side light improved 900 visibility
- This is the minimum I would want to see
- Just barely
- Not as visible as #1 and #2, white drowns out red very much
- Need lower rear lights
- Rear bottom lights on side too far forward, rear yellow strobes too high
- Better than first strobe unit
- Rear lower light (on sides) would be better located closer to rear
- Could use more definition
- Better than 1 and 2 - midship very improved, could be increased
- But needs lower rear lights and front not as good as 1 or 2
- Up and down strobes in grille were good
- All strobe lights are definitely not the answer - yellow at rear is effective
- Lights too small
- Very good - effective lighting combination
- Like the side light location
- Poorer from a distance - blue doesn't show up very well

Question No.		Yes	No	Comments
B.	1a	40	2	• Close without white • Missing front corner identification

Question No.		Yes	No	Comments
B.	1b	26	16	• Marginal • If lower whites stay on, it would be okay • Hall (all?) whites were out • Need outboard reds • Not enough low levels

Question No.		Yes	No	Comments
B.	2a	36	6	• White light mix-up, couldn't turn it off, assume red on in place of white • Fair

Forms/NFPAREPT

Truck 2 (Whelen Engineering)
Page 2 of 3

Question No.	Yes	No	Comments
B. 2b	27	14	• Fair

Question No.	Yes	No	Comments
B. 3a	35	7	• Fair

Question No.	Yes	No	Comments
B. 3b	28	13	• Need lower front red • More mid'-range • OK with clears in grille, red grilles are too dim

Question No.	Yes	No	Comments
B. 4	29	13	• For longer wheel base vehicle, move lower red strobe forward of rear wheel • Midships light should be forward of rear wheels • More mid-range • Red intersector to dim, ok with clear • Rear top marginal

Question No.	Yes	No	Comments
B. 5	28	13	• Need lower rear red • Lower rear locking lights

Question No.	Yes	No	Comments
B. 6	38	4	• Need lower reds • With yellow? with red? • Amber very effective • We need yellow at rear

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Truck 4 (Whelen Engineering)
Page 3 of 3

B. 7 Comments:

- Not set up right to offer "accurate" comparison
- Strobe duration time definitely a negative factor - worst of #1, #2, and #4
- Blinking too fast, position (placement) good
- Overkill for wildland applications, too costly, closest possibility to meeting off-road but still too much for wildland agencies
- Arrangement of lights could be better, some should be lower
- The strobes were fair, compared to others, amb rear lights very visible
- Size of the lights seem to make a substantial difference
- To many strobes – blinding on scene
- Lower rear - lacking, 2b & 3b - midship needs lights, upper 60% of rear great - outstanding
- In general to narrow beam (refers to questions 5 & 6)
- Need white lights on front, red not as stable in rear, light on rear side should be moved to front of rear wheels
- White and color (yellow) are good
- Small light make vehicle appear to be farther away, amber lights at rear are good, two more needed at rear
- Outstanding lighting arrangement
- 75º front top inadequate - rear low inadequate
- White light drowned color
- Need lower level rear warning - I disregarded the yellow rear lights
- Diamond plate adds to rear 45º visibility
- Side intersection light is good - front side cab lights effective - rear diamond plate appears to add to effective
- Best unit lighting in this setting - bright daylight???
- Lowlights were not very effective - yellow at a rear is needed
- But not as good as #1 and possibly only slightly better than #2

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NFPA DEMONSTRATION - APRIL 6, 1993

PART II – OVERALL OBSERVATIONS

Bold Type = Best *Italic* Type = Poorest

Section/Subject	Question No.	Question Topic	Truck #1	Truck #2	Truck #3	Truck #4
A – Moving	1.a	Engines(2)				
		Better	7	11	16	**18**
		Poorer	*17*	8	9	7

2. Comments

- Better trucks had more activity
- More activity is better
- #4 lost
- #1, #2, and #3 need light between headlights and windshield, #4 needs lights at comer of front bumper
- Code 3 (on #3) bar light seems most effective from front. Amber lights are important. #3 bar light ineffective side and rear angles.
- Yellow very effective at rear
  #4 better below, #2 better on cab above
- #3 is close to #1 and #2, just behind #3
  Faster frequency lights better. All need midships lights, eye level, front of rear wheels
- The increased frequencies on 3 and 4 make a substantial improvement. Midship height at driver's eye level, forward of the rear wheel, would make #2, #3, and #4 acceptable.
- Like the faster flash on 3 over 1
- #1 has long "off ' times front view

Section/Subject	Question No.	Question Topic	Truck #1	Truck #2	Truck #3	Truck #4
A – Stationary	1.a	Front Calling for Right of Way				
		Better	10	**23**	17	18
		Poorer	*22*	2	10	10
		Comments: • Good mid-level coverage - use of mirrored bar adds more warning without adding amp draw • #1 very bright but slower, 2 dimmer but faster, 4 red lower too dim, 3 lightbar no dead time • No lower lights on #2				
		Front, Blocking Right of Way				
		Better	10	13	**20**	13
		Poorer	15	7	5	7

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NFPA Demonstration
Part II – Overall Observations

Section/Subject	Question No.	Question Topic	Truck #1	Truck #2	Truck #3	Truck #4
	2.a	Front, 35º, Calling for Right of Way				
		Better	7	7	**13**	11
		Poorer	*8*	8	4	4
	2b.	Front, 35 º, Blocking Right of Way				
		Better	5	7	9	**11**
		Poorer	*8*	6	6	3
	3a.	Front 75 º, Calling for Right of Way				
		Better	5	6	**11**	**11**
		Poorer	*7*	6	2	5
		Comments: • One was not running for test				
	3b.	Front 75 º, Blocking for right of Way				
		Better	5	6	**11**	**11**
		Poorer	*8*	7	3	4
	4.	Side, Blocking right of Way				
		Better	4	5	**13**	10
		Poorer	*7*	4	2	6
		Comments: • The longer the light the more effective. • Some mid-range One was not running for the test				
	5.	Rear 45 º, Blocking right of Way				
		Better	3	4	**14**	10
		Poorer	*10*	6	3	6
		Comments: • One was not running for the test				
	6.	Rear, Blocking right of Way				
		Better	3	4	**20**	**20**
		Poorer	*11*	10	5	7
		Comments: • Assuming amber lites were red but very good with amber • Poor or no lights down low at rear • #4 amber good, #2 low could be brighter				

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7. Comments

- Size of light source is important and activity midship stationary lighting required
- One, two, and three need lights on side about mid-way. #4 seems best in every category.
- Body side lights needed, rear amber needed with directional, all four comers need 270º visible lights
- The lights located on corners are important for exiting and entering intersections. Need lights like #4 in grille to shine in rear windows of vehicles when approaching from rear.
- #1 lower lights best, roof light on #3 may be a little better, still need midship lights. #1, #2, and #3 are all somewhat close, #4 was off
- Rear yellow strobes effective (?)
- #4 intensity a problem - flashing pattern good amber to rear
- Front grille lights should be up in cowl, white lights would (should?) not be turned off at scene, not necessary to outline 4 corners of truck at front
- Lower revolving lights are very effective; yellow rear lights are needed
- #4 dwell time too short! Yellow rear lights good. Rating 3, 2, 1, 4
- Yellow strobes on 4 impressive
- Faster flash frequency on the low front lights on truck 1 would make it even better
- All vehicles - rear window auto viewing height illumination poor - void in rear center and midship
- Tests extremely confusing
- #4 is best overall, 3's lightbar is best overall, amber on rear excellent - lightbar height critical from rear
- On front, #3 needs minor improvement at other driver's eye level to catch a rear view mirror
- 4 needs lower lights in rear
- Even the poorest is too much - all lights need to be protected - most applications are off-road and not city oriented
- #2 and #3 appear best of the four samples and about equal. #1 suffered from bumper level being "weak," #4 suffered from placement too centered on front view
- I like the effect of rotating lights down low at front and rear. Yellow at rear helps.
- #3 truck is the best
- #2 has long off time on side, need stationary light midship, multi colors have good impact amber to
  the rear good

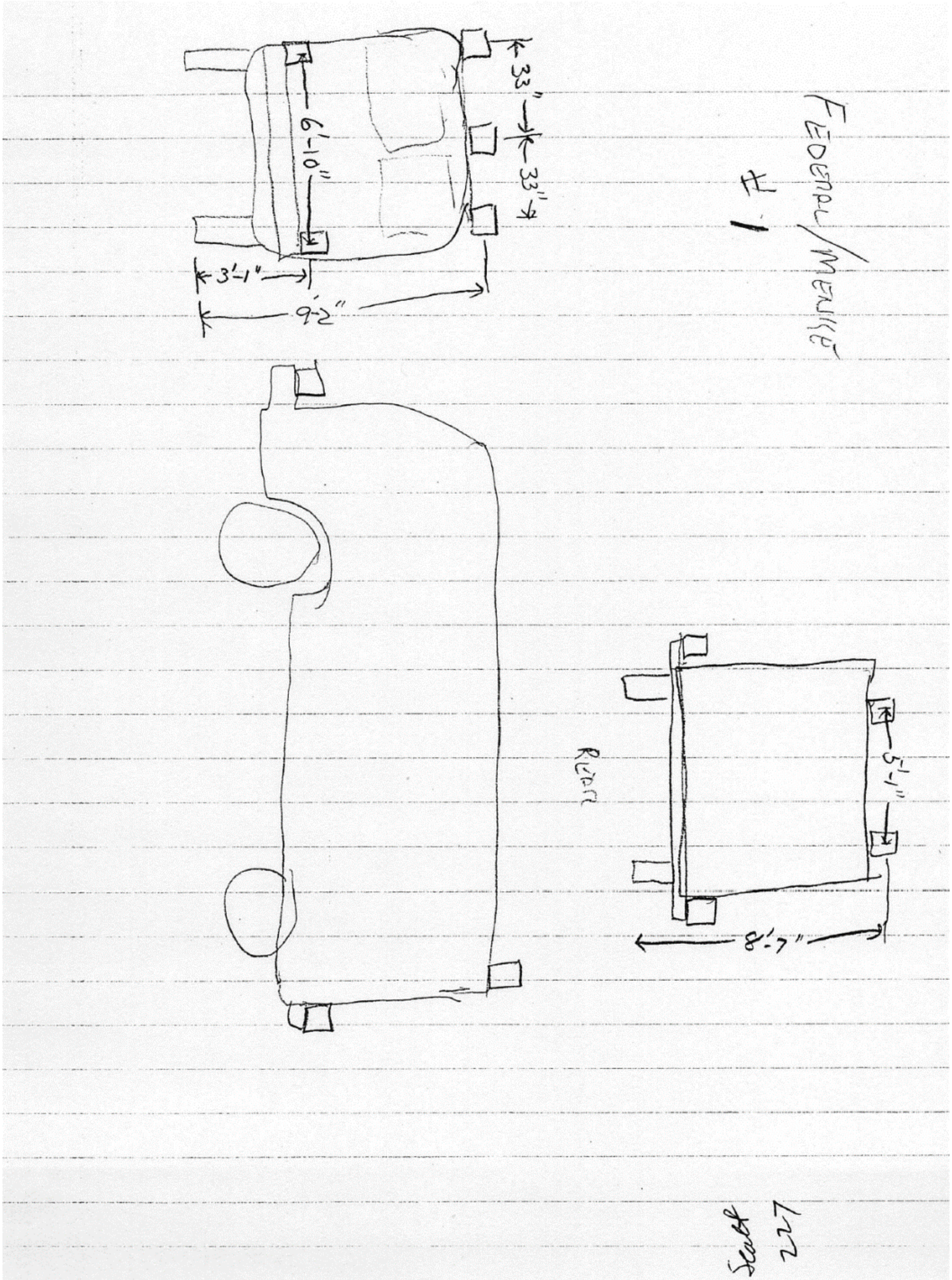
Forms/NFPAREPT

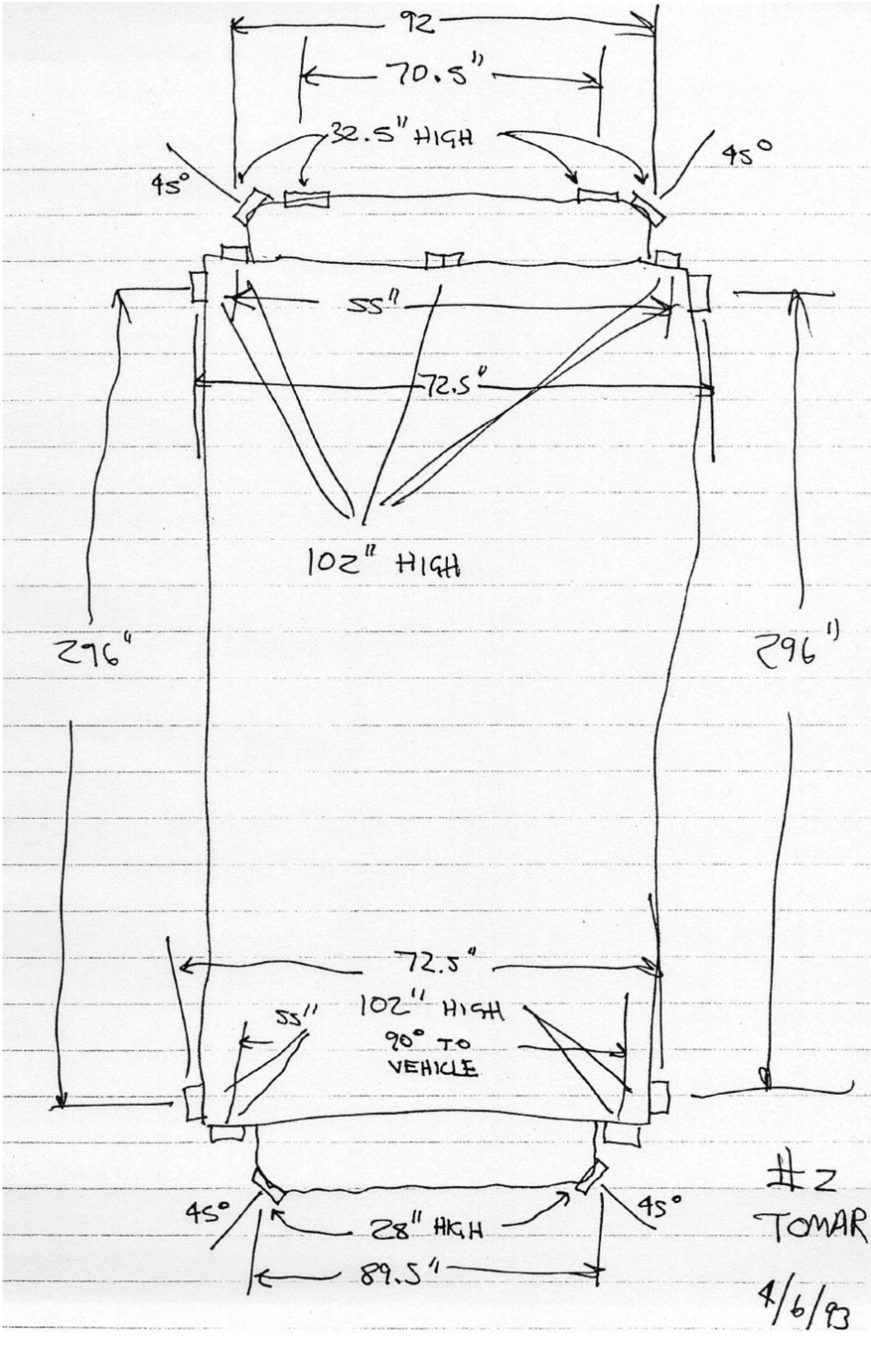
NFPA Demonstration
Part II – Overall Observations

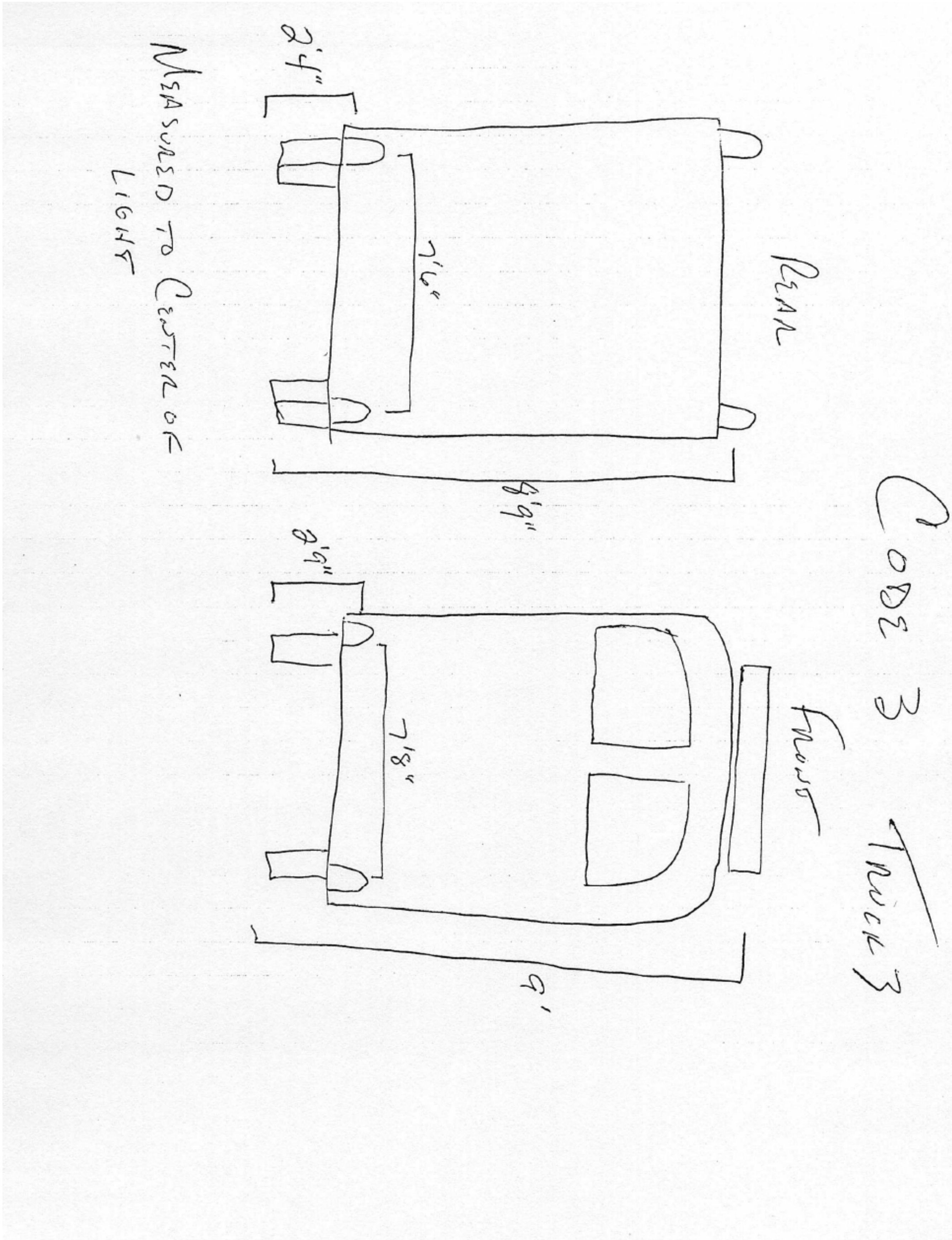
Comment Summary:

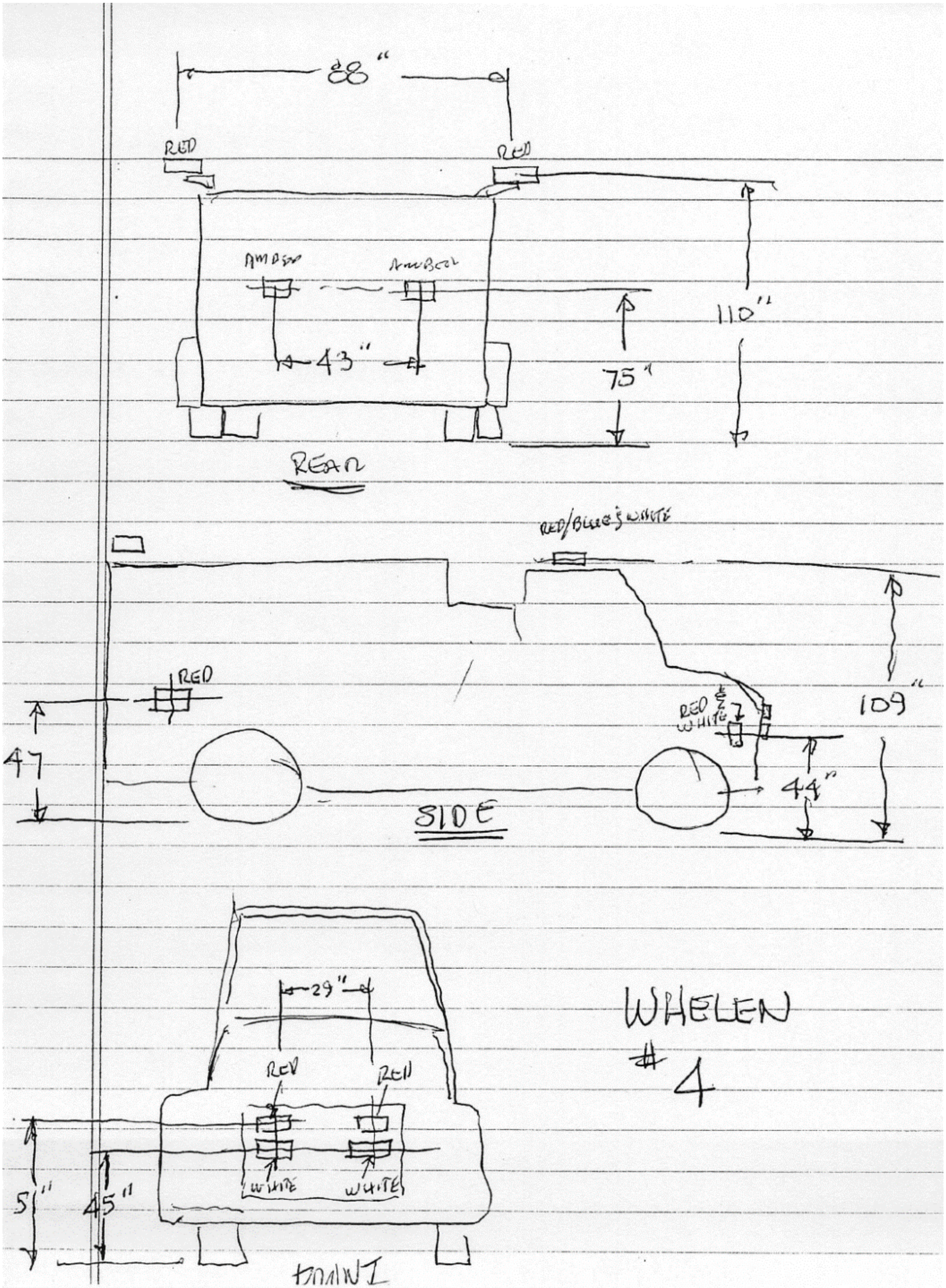
Comment	No. of Times Comment Expressed
1. Rear amber needed	14
2. Midship light needed	7
3. Better trucks had more activity	6
4. Size of lighthead is important	2
5. Need lights in grill to shine in windows of approaching vehicles	2
6. Lower revolving lights are very effective	2
7. Number 4 seemed best overall	1
8. Light needed between headlights and windshield	1
9. All four corners need 270º lights	1
10. Lights on vehicle corners are important	1
11. Not necessary to outline four corners of truck at front	1
12. White lights should be left on at scene	1
13. Test extremely confusing	1
14. Even the poorest is too much	1
15. Multi color have good impact	1

Forms/NFPAREPT


33"
33"
6'-10"
3'-1"
9'-2"
#1
Rear
5'-1"
8'-7"


92
70.5"
32.5" HIGH
45°
45°
55"
72.5"
102" HIGH
296"
296"
72.5"
102" HIGH
55"
90° TO
VEHICLE
45°
45°
28" HIGH
89.5"
#2
TOMAR
4/6/93


CODE 3 TRUCK 3
REAR
FRONT
24"
7'6"
8'9"
8'9"
7'8"
9'
MEASURED TO CENTER OF LIGHT


88"
RED
RED
AMBER
AMBER
43"
75"
110"
REAR
RED/BLUE & WHITE
RED
47
RED & WHITE
109"
44"
SIDE
29"
RED
RED
WHITE
WHITE
51"
45"
FRONT
WHELEN
#4

Fire Service Research Institute

ADVANCING THE STATE OF THE ART WHILE REMEMBERING THE TRADITION OF THE PAST

A NON-PROFIT AGENCY

To: Terry Dawson
Andy Olson
Scott Sikora
Greg Sink|Ed Stanuch
Drew Smith/Bob Kreutzer

From: Ken Menke

Date: May 3, 1993

Subject: Photometric Plots of the Data from the Cincinnati NFPA demos held at Riverfront Stadium April 6, 1993

Enclosed are plots of the individual devices and my estimate of the combined performance for Engine 1, 2, and 3. I have received no data for Engine 4.

I am about to leave for the West Coast. If Whelan wishes to have Engine 4 considered, they will have to bring data plotted in a manner consistent with the enclosed plots to Scottsdale.

Combining the individual device plots to form a vehicle composite requires a number of assumptions and judgements. I have tried to be very conservative. If you wish to do your own calculations, the red lower rotators on Engine 1 generated 11,000 CdS/M and ran at a rate of 90 F/M and those on Engine 3 generated 10,000 CdS/M and ran at a rate of 180 F/M.

Scott Sikora has pointed out that under real world conditions, either the upper or lower red lights may be the critical element in vehicle performance. I think he is correct and have plotted the performance separately.

Clearly, there is a large experimental error possible at any point. With this in mind, I am going to suggest at Scottsdale that we consider any point with a rating of 80% or more adequate, any point of 70% or less inadequate, an points between 71% and 79% inconclusive.

See you in Scottsdale.

58 Lincoln Avenue • Webster Groves, Missouri 63119 • 314 - 961 - 8893

APPENDIX 1
Report on Development of 1996 Changes

Summary Data by Zone
1993 Optical Power
Test Engines 1, 2, and 3
Upper Level

	Zone A	Zone B	Zone C	Zone D	Total
Engine 1					
Responding	2,280,000	624,000	569,000	624,000	4,097,000
Blocking	655,000	624,000	569,000	624,000	2,472,000
Engine 2					
Responding	958,000	544,000	544,000	544,000	2,590,000
Blocking	566,000	544,000	544,000	544,000	2,198,000
Engine 3					
Responding	767,000	428,000	418,000	428,000	2,041,000
Blocking	301,000	415,000	418,000	415,000	1,549,000
Engine 4 Responding	No Data - Whelen Claims Data is Proprietary				
Engine 4 Blocking	No Data - Whelen Claims Data is Proprietary				

Min. Requirements Adopted for Use in NFPA 1901 and SAE 2498 Standards for Large Vehicles[1]

	Zone A	Zone B	Zone C	Zone D	Total
Responding	1,000,000	400,000	400,000	400,000	2,200,000
Blocking	400,000	400,000	800,000	400,000	2,000,000

1. These standards also contain +/-5 degree requirements and lower minimum requirements for smaller vehicles. Please refer to NFPA 1901 and related standards or SAE 2498 for complete information.

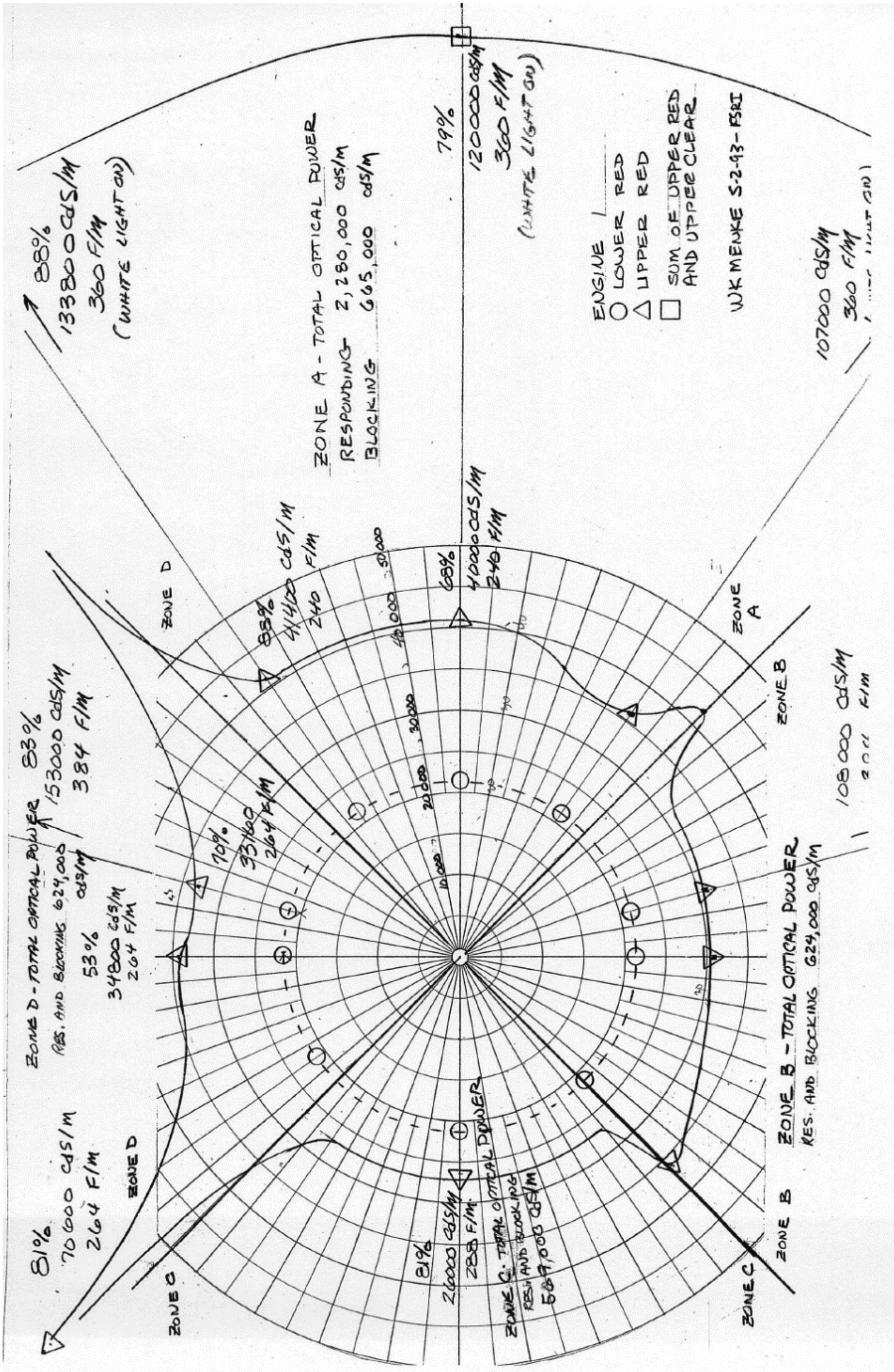
Summary Data by Zone
1993 Optical Power
Test Engines 1, 2, and 3
lower Level

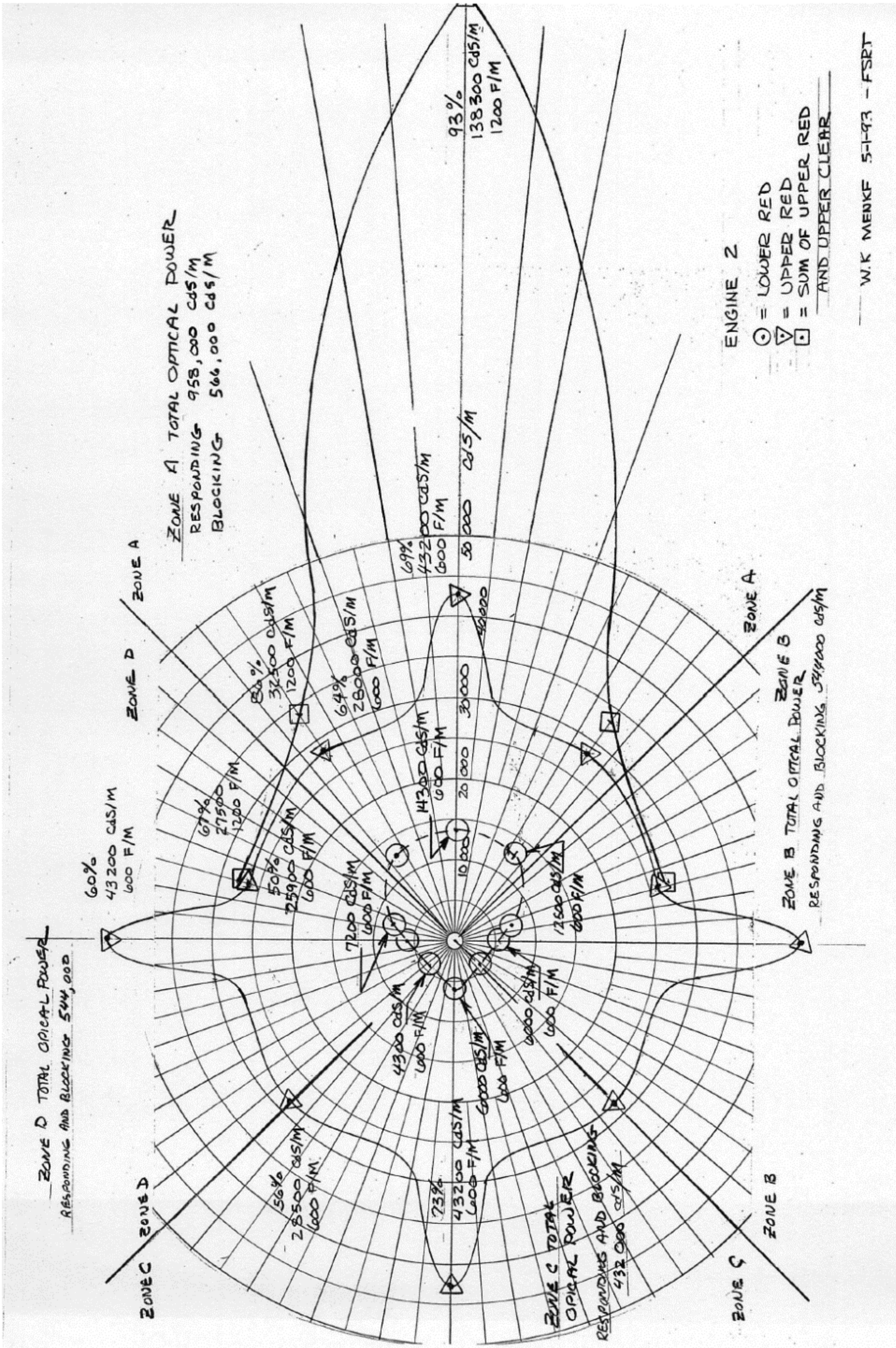
	Zone A	Zone B	Zone C	Zone D	Total
Engine 1					
Responding	437,000	437,000	437,000	437,000	1,748,000
Blocking	437,000	437,000	437,000	437,000	1,748,000
Engine 2					
Responding	250,000	143,000	95,000	143,000	631,000
Blocking	250,000	143,000	95,000	143,000	631,000
Engine 3					
Responding	418,000	418,000	418,000	488,000	1,672,000
Blocking	418,000	418,000	418,000	418,000	1,672,000
Engine 4 Responding	No Data - Whelen Claims Data is Proprietary				
Engine 4 Blocking	No Data - Whelen Claims Data is Proprietary				

Min. Requirements Adopted for Use in NFPA 1901 and SAE 2498 Standards for Large Vehicles[1]

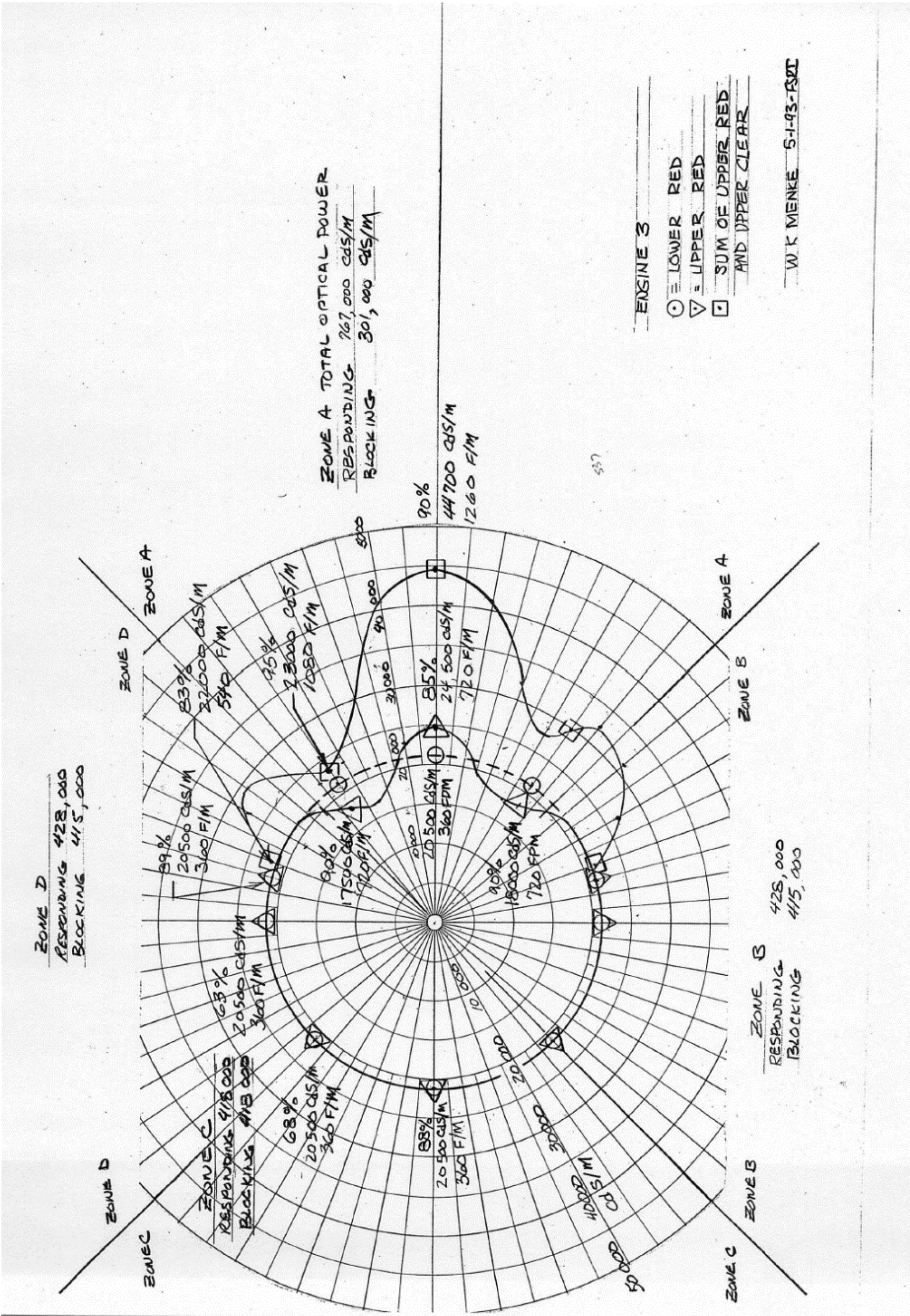
Responding	150,000	150,000	150,000	150,000	600,000
Blocking	150,000	150,000	150,000	150,000	600,000

1. These standards also contain +/-5 degree requirements and lower minimum requirements for smaller vehicles. Please refer to NFPA 1901 and related standards or SAE 2498 for complete information.


ZONE A - TOTAL OPTICAL POWER
RESPONDING 2,280,000 cdS/M
BLOCKING 665,000 cdS/M
ENGINE
LOWER RED
UPPER RED
SUM OF UPPER RED AND UPPER CLEAR
WK MENKE 5-2-93-FSRI
88%
133800 cdS/M
360 F/M
(WHITE LIGHT ON)
79%
120000 cdS/M
360 F/M
(WHITE LIGHT ON)
107000 cdS/M
360 F/M
ZONE D - TOTAL OPTICAL POWER
RES. AND BLOCKING 624,000 cdS/M
83%
153000 cdS/M
384 F/M
53%
34800 cdS/M
264 F/M
70%
33100
264 F/M
88%
41400 cdS/M
240 F/M
68%
40000 cdS/M
240 F/M
ZONE B - TOTAL OPTICAL POWER
RES. AND BLOCKING 624,000 cdS/M
108000 cdS/M
81%
70600 cdS/M
264 F/M
81%
26000 cdS/M
288 F/M
ZONE C - TOTAL OPTICAL POWER
RES. AND BLOCKING
587,000 cdS/M
ZONE A
ZONE B
ZONE C
ZONE D


ZONE A TOTAL OPTICAL POWER
RESPONDING 958,000 cds/m
BLOCKING 566,000 cds/m
ZONE D TOTAL OPICAL POWER
RESPONDING AND BLOCKING 544,000
ZONE B TOTAL OPTICAL POWER
RESPONDING AND BLOCKING 549,000 cds/m
ZONE C TOTAL OPICAL POWER
RESPONDING AND BLOCKING 432 000 cds/m
93%
138300 cds/m
1200 F/M
ENGINE 2
= LOWER RED
= UPPER RED
= SUM OF UPPER RED AND UPPER CLEAR
ZONE A
ZONE B
ZONE C
ZONE D

APPENDIX 1
Report on Development of 1996 Changes



APRIL 6, 1993
NFPA WARNING LIGHT DEMOS
CINCINNATI, OHIO

9-8 Optical Warning Devices. Each apparatus shall have a system of optical warning devices that meets or exceeds the requirements of this section.

9-8.1* The optical warning system shall consist of an upper and a lower warning level.

9-8.2 For the purpose of defining and measuring the required optical performance, the apparatus shall each be divided into four warning zones. The four zones shall be determined by drawing lines through the geometric center of the apparatus at 45 degrees to a line drawn lengthwise through the geometric center of the apparatus. The four zones shall be designated A, B, C, and D in a clockwise direction with zone A to the front of the apparatus. (*See Figure 9-8.3.2.*)

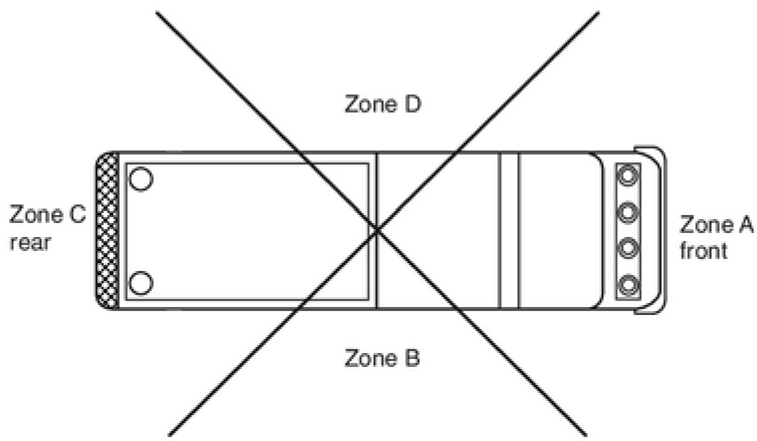


FIGURE 9-8.3.2 Warning Zones for Optical Warning Devices.

9-8.3 Each optical warning device shall be installed on the apparatus and connected to the apparatus's electrical system in accordance with the requirements of this standard and the requirements of the manufacturer of the device.

9-8.4 A master optical warning device switch that energizes all of the optical warning devices shall be provided.

9-8.5 The optical warning system on the fire apparatus shall be capable of two separate signaling modes during emergency operations. One mode shall signal to drivers and pedestrians that the apparatus is responding to an emergency and is calling for the right-of-way. The other mode shall signal that the apparatus is stopped and is blocking the right-of-way.

9-8.6* Switching shall be provided that senses the position of the parking brake or the park position of an automatic transmission. When the master optical warning system switch is closed, and the parking brake is released or the automatic transmission is not in park, the warning devices signaling the call for the right-of-way shall be energized. When the master optical warning system switch is closed, and the parking brake is on or the automatic transmission is in park, the warning devices signaling the blockage of the right-of-way shall be energized. The system shall be permitted to have a method of modifying the two signaling modes.

9-8.7 The optical warning devices shall be constructed or arranged so as to avoid the projection of light, either directly or through mirrors, into any driving or crew compartment(s).

9-8.8 The front optical warning devices shall be placed so as to maintain the maximum possible separation from the headlights.

9-8.9 The optical sources on each level shall be of sufficient number and arranged so that failure of a single optical source does not create a measurement point in any zone without a warning signal at a distance of 100 ft (30 m) from the geometric center of the apparatus.

9-8.10 Flashers.
9-8.10.1 The minimum flash rate of any optical source shall be 75 flashes per minute and the minimum number of flashes at any measurement point shall be 150 flashes per minute.
9-8.10.2 The flasher of any current-interrupted flashing device shall otherwise meet the requirements of SAE J1054, Warning Lamp Alternating *Flashers*.
9-8.11 Permissible colors or combinations of colors in each zone, within the constraints imposed by applicable laws and regulations, shall be as shown in Table 9-8.11. All colors shall be as specified in SAE J578, *Color Specification*, for white, red, yellow, or blue.

Table 9-8.11 Zone Colors

Color	Calling for Right-of-Way	Blocking Right-of-Way
Red	Any zone	Any zone
Blue	Any zone	Any zone
Yellow	Any zone except A	Any zone
White	Any zone except C	Not permitted

9-8.12 Requirements for Large Apparatus. If the apparatus has a bumper-to-bumper length of 22 ft (6.7 m) or more, or has an optical center on any optical warning device greater than 8 ft (2.4 m) above grade, the requirements of 9-8.12.1 through 9-8.12.6 shall apply.
9-8.12.1 The upper-level optical warning devices shall be mounted as high and as close to the corner points of the apparatus as is practical in order to define the clearance lines of the apparatus. However, these optical warning devices shall not be mounted above the maximum height, specified by the device manufacturer, that gives an intensity value at 4 ft (1.2 m) above level grade and 100 ft (30.5 m) from the optical warning device of less than 50 percent of that required at the optical center.
9-8.12.2 The lower level optical warning devices shall be mounted as close to the front corner points of the apparatus as is practical with the optical center of the device at a distance of 18 in. to 62 in. (457 mm to 1575 mm) above grade.
9-8.12.3 A midship optical warning device shall be mounted on both the right and the left sides of the apparatus with the optical center of the device at a distance of 18 in. to 62 in. (457 mm to 1575 mm) above grade. Additional midship optical warning devices shall be required where necessary to maintain a horizontal distance between the centers of adjacent lower-level optical warning devices of 15 ft (4.6 m) or less.
9-8.12.4 For each operating mode, the combined optical power of all the optical sources shall meet or exceed the zone total optical power requirements shown in Table 9-8.12.4.
9-8.12.5 No individual measurement point shall be less than that shown in Table 9-8.12.4.
9-8.12.6* The minimum optical warning system shall require no more than an average of 45 amps for the operation of the upper level and lower level devices. On apparatus whose length requires two midship lights per side, the optical warning system shall require no more than an average of 50 amps for operation of the upper level and lower level devices. On apparatus whose length requires three midship lights per side, the optical warning system shall require no more than an average of 55 amps for the operation of the upper and lower level devices.

Table 9-8.12.4 Minimum Optical Power Requirements for Large Apparatus

Zone	Level	Mode of Operation					
		Clearing Right-of-Way			Blocking Right-of-Way		
		H	At Any ***H*** Point	At Any Point 5 Degrees Up or 5 Degrees Down from ***H***	***H***	At Any ***H*** Point	At Any Point 5 Degrees Up or 5 Degrees Down from ***H***
A	Upper	1,000,000	10,000	3,500	400,000	10,000	3,500
B	Upper	400,000	10,000	3,500	400,000	10,000	3,500
C	Upper	400,000	10,000	3,500	800,000	10,000	3,500
D	Upper	400,000	10,000	3,500	400,000	10,000	3,500
A	Lower	150,000	3,750	1,300	150,000	3,750	1,300
B	Lower	150,000	3,750	1,300	150,000	3,750	1,300
C	Lower	150,000	3,750	1,300	150,000	3,750	1,300
D	Lower	150,000	3,750	1,300	150,000	3,750	1,300

Note: All values are in candela-seconds/minute.
H = Horizontal plane passing through the optical center.

9-8.13 Requirements for Small Apparatus. If the apparatus has a bumper-to-bumper length of less than 22 ft (6.7 m) and has the optical center of all optical warning devices at 8 ft (2.4 m) or less above grade, the requirements of 9-8.13.1 through 9-8.13.5 shall apply.

9-8.13.1 The upper-level optical warning devices shall be mounted as high as practical, but not over 8 ft (2.4 m), at the optical center. They shall be permitted to be combined in one or more enclosures and shall be permitted to be mounted on the cab roof or any other convenient point.

9-8.13.2 The lower-level optical warning devices shall be mounted as close as practical to the front corner points of the apparatus with the optical center of the device at a distance of 18 in. to 48 in. (457 mm and 1220 mm) above grade.

9-8.13.3 For each operating mode, the combined optical power of all the optical sources mounted on both the upper and lower levels shall meet or exceed the zone total optical power requirements shown in Table 9-8.13.3.

9-8.13.4 No individual measurement point shall be less than that shown in Table 9-8.13.3.

Table 9-8.13.3 Minimum Optical Power Requirements for Small Apparatus						
	Mode of Operation					
	Clearing Right-of-Way			Blocking Right-of-Way		
Zone	***H***	At Any ***H*** Point	At Any Point 5 Degrees Up or 5 Degrees Down from ***H***	***H***	At Any ***H*** Point	At Any Point 5 Degrees Up or 5 Degrees Down from ***H***
A	1,000,000	10,000	3,500	400,000	10,000	3,500
B	200,000	8,000	3,500	200,000	8,000	3,500
C	400,000	10,000	3,500	800,000	10,000	3,500
D	200,000	8,000	3,500	200,000	8,000	3,500

Note: All values are in candela-seconds/minute.
H = Horizontal plane passing through the optical center.

9-8.14 Tests of Optical Warning Devices.
9-8.14.1 Mechanical and Environmental Test. All optical warning devices including those normally tested under SAE J595, *Flashing Warning Lamps for Authorized Emergency, Maintenance, and Service Vehicles*, and SAE J1318, *Gaseous Discharge Warning Lamp for Authorized Emergency, Maintenance, and Service Vehicles*, shall be tested in conformance with SAE J845, *Optical Warning Devices for Authorized Emergency, Maintenance, and Service Vehicles*. All devices shall comply with the following performance requirements of that standard
Vibration
Moisture
Dust
Corrosion
High temperature
Low temperature
Durability
Warpage
Exception: Optical devices and components designed for mounting only in weatherproof, interior spaces shall be required to comply only with the vibration test and the warpage test for plastic components.
9-8.14.2 Photometric Test Procedures for Optical Devices. Testing shall be performed by, or on behalf of, the device manufacturer to ensure compliance with the requirements of 9-8.14.2.1 through 9-8.14.2.4. The results of the testing shall be used by the apparatus builder or purchaser to determine compliance with this standard. The goniometer, integrating photometer, and other equipment used to take the test measurements shall meet the requirements of SAE J1330, *Photometry Laboratory Accuracy Guidelines*.
9-8.14.2.1 The optical source shall be mounted in a goniometer and operated as it would be in a normal system application. The minimum distance between the light-emitting surface of the source being tested and the front face of the photometer detector shall be 59 ft (18 m). The

goniometer shall be oriented to the appropriate point, and the integrating photometer shall be set to integrate light pulses from the source for 20 seconds.

9-8.14.2.2 For all tests performed with the power applied, the lighting system, or component thereof, shall be operated at 12.8 V + 0.1 V for 12-V rated equipment and 25.6 V + 0.2 V for 24-V rated equipment measured at the point of entry into the component. If the equipment is rated for operation on both 12 volts and 24 volts, the tests shall be performed at both voltages.

9-8.14.2.3 The technique described in 9-8.14.2.1 shall be performed along the horizontal plane that passes through the optical center, beginning at the optical center and repeated at 5 degree intervals to the left and right of the optical center throughout the active horizontal angle of light emission of the optical source.

9-8.14.2.4 Measurements shall be repeated at 5 degrees up and 5 degrees down from the horizontal plane that passes through the optical center, beginning at a point on a line passing through the optical center, and perpendicular to the horizontal plane and passing through the optical center. The measurements shall be repeated at 5-degree intervals to the left and right of this line throughout the active horizontal angle of light emission of the optical source. If the optical warning device contains more than one optical source, the test shall be repeated for each optical source.

9-8.15* Certification of Compliance. The apparatus manufacturer shall demonstrate compliance of the warning system by one of the following methods:

(a) Certification that the system was installed within the geometric parameters specified by the manufacturer of the system, and referencing the optical source test reports provided by the manufacturer of the system;

(b) Certification that a mathematical calculation performed by a qualified person demonstrates that the combination of individual devices as installed meets the requirements of this standard. This calculation shall be based on test reports for individual optical sources provided by the manufacturer of the device;

(c) Actual measurement of the lighting system after installation on the apparatus.

13.8 Optical Warning Devices. Each apparatus shall have a system of optical warning devices that meets or exceeds the requirements of this section.
13.8.1* The optical warning system shall consist of an upper and a lower warning level.
13.8.2 The requirements for each level shall be met by the warning devices in that particular level without consideration of the warning devices in the other level.
13.8.3 For the purposes of defining and measuring the required optical performance, the upper and lower warning levels shall be divided into four warning zones.
13.8.3.1 The four zones shall be determined by lines drawn from the vehicle centerline out through the corners of the apparatus at 45 degrees to a line drawn lengthwise through the geometric center of the apparatus.
13.8.3.2 The four zones shall be designated A, B, C, and D in a clockwise direction, with zone A to the front of the apparatus. *(See Figure 13.8.3.2.)*

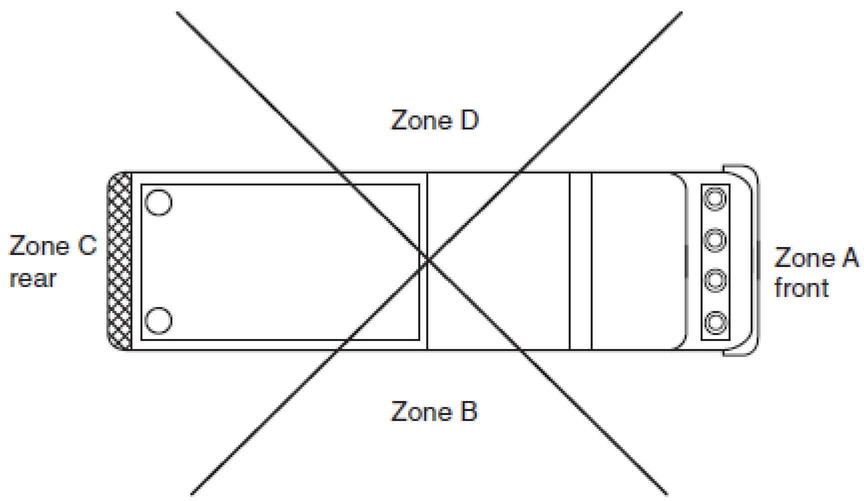


Figure 13.8.3.2 Warning Zones for Optical Warning Devices

13.8.4 Each optical warning device shall be installed on the apparatus and connected to the apparatus's electrical system in accordance with the requirements of this standard and the requirements of the manufacturer of the device.
13.8.5 A master optical warning system switch that energizes all the optical warning devices shall be provided.
13.8.6 The optical warning system on the fire apparatus shall be capable of three separate signaling modes during emergency operations.
13.8.6.1 One mode shall signal to drivers and pedestrians that the apparatus is responding to an emergency and is calling for the right-of-way.
13.8.6.2 One mode shall signal that the apparatus is stopped and is blocking the right-of-way under daytime lighting conditions.
13.8.6.3* A third mode shall signal that the apparatus is stopped and is blocking the right-of-way at night or in limited ambient light conditions.
A.13.8.6.3 There is a mounting body of evidence that optical warning devices may cause distraction, discomfort, and reduced visibility due to glare for drivers passing emergency apparatus parked along an active roadway, especially at night. These same issues apply to the emergency responders working alongside the apparatus in close proximity to the lights. Research

has shown that this problem can be greatly reduced by reducing intensity, reducing flash rates, synchronizing light flashes, and changing colors to predominantly amber lights in place of predominantly red and/or blue lights. This especially applies to rear-facing lights. Purchasers, apparatus manufacturers, and warning light manufacturers are encouraged to take advantage of this research and the ability of modern LED lighting systems to control intensity, flash rate, flash patterns, synchronization, and even color of lighting systems based on conditions.

13.8.6.4 The use of some or all of the same warning lights shall be permitted for multiple modes provided the other requirements of this chapter are met.

13.8.7 Mode Selection

13.8.7.1 A switching system shall be provided that senses the position of the parking brake or the park position of an automatic transmission.

13.8.7.2 When the master optical warning system switch is on and the parking brake is released or the automatic transmission is not in park, the warning devices signaling the call for the right-of-way shall be energized.

13.8.7.3 An optical sensor shall be provided to sense day/night conditions.

13.8.7.3.1 If a mechanism is provided to force the nighttime or daytime mode, it shall reset to automatic when the master optical warning switch is turned off.

13.8.7.4 When the master optical warning system switch is on, the parking brake is on or the automatic transmission is in park, and the optical sensor is sensing daylight light levels; the warning devices signaling the daytime blockage of the right-of-way shall be energized.

13.8.7.5 When the master optical warning system switch is on, the parking brake is on or the automatic transmission is in park, and the optical sensor is sensing nighttime light levels; the warning devices signaling the nighttime blockage of the right-of-way shall be energized.

13.8.7.6* The system shall be permitted to have a method of modifying the three signaling modes.

13.8.8 The optical warning devices shall be constructed or arranged so as to avoid the projection of light, either directly or through mirrors, into any driving or crew compartment(s).

13.8.9 The optical warning devices shall be placed as far as practicable from the headlights, turn signals, brake lights, and scene lights.

13.8.10* The optical sources on each level shall be of sufficient number and arranged so that failure of a single optical source does not create a measurement point in any zone on the same level as the failed optical source without a warning signal at a distance of 100 ft (30 m) from the geometric center of the apparatus.

13.8.11 Flashing

13.8.11.1 Flash Rate. The minimum flash rate of any optical source shall be 60 flashes per minute, and the minimum number of flashes at any measurement point shall be 120 flashes per minute.

13.8.11.1.1* In the blocking the right-of-way mode, the flash rate shall be 60 to 75 flashes per minute.

A.13.8.11.1.1 Lower flash rates have been shown to reduce driver distraction. This does not change the requirement to mark the upper and lower corners of the vehicle, but the lights flash in synchronization

13.8.11.1.2 Steadily burning, nonflashing optical sources shall be permitted to be used.

13.8.11.1.3 The optical energy provided by nonflashing optical sources shall not be included in the calculations of the zone's total optical power.

13.8.11.2 Flash Pattern In the blocking the right-of-way modes, the flashing of all optical warning devices shall be synchronized according to 13.8.11.2.1 through 13.8.11.2.5
13.8.11.2.1 In each zone, the upper corner optical warning devices shall flash together, alternating with the lower optical warning devices which shall flash together.
13.8.11.2.2 If there is more than one optical warning device on each side in zone C upper, or a center upper optical warning device, they may flash with either the upper or lower optical warning devices.
13.8.11.2.3 If there are more than 4 non-white optical sources in zone A upper, the inner optical sources may flash with either the upper outer optical sources or the lower optical warning devices.
13.8.11.2.4 Midship optical warning devices shall flash with the upper optical warning devices in the same zone.
13.8.11.2.5 It shall be permissible for the light bar to not be synchronized with the other lights if it is synchronized within itself and meets the other flash pattern requirements.
13.8.12* Color of Warning Lights.
13.8.12.1 Permissible colors or combinations of colors in each zone, within the constraints imposed by applicable laws and regulations, shall be as shown in Table 13.8.12.1.
Table 13.8.12.1 Zone Colors

Color	Calling for Right-of-Way	Blocking Right-of-Way
Red	Any Zone	Any Zone
Blue	Any Zone	Any Zone
Yellow	Any zone except A	Any Zone
White	Any zone except C	Not Permitted

13.8.12.2 All colors shall be as specified in SAE J578, *Color Specification*, for red, blue, yellow, or white.
13.8.13* Requirements for Large Apparatus.
13.8.13.1 If the apparatus has a bumper-to-bumper length of 25 ft (7.6 m) or more or has an optical center on any optical warning device greater than 8 ft (2.4 m) above level ground, the requirements of 13.8.13.2 through 13.8.13.8.4 shall apply.
13.8.13.2 Upper-Level Optical Warning Devices.
13.8.13.2.1 The upper-level optical warning devices shall be mounted as high and as close to the corner points of the apparatus as is practical to define the clearance lines of the apparatus.
13.8.13.2.2 The upper-level optical warning devices shall not be mounted above the maximum height, specified by the device manufacturer, that gives an intensity value at 4 ft (1.2 m) above level ground and at 100 ft (30.5 m) from the optical warning device of less than 50 percent of that required at the optical center.
13.8.13.3 Lower-Level Optical Warning Devices.
13.8.13.3.1 To define the clearance lines of the apparatus, the optical center of the lower-level optical warning devices in the front of the vehicle shall be mounted on or forward of the front axle centerline and as close to the front corner points of the apparatus as is practical.
13.8.13.3.2 The optical center of the lower-level optical warning devices at the rear of the vehicle shall be mounted on or behind the rear axle centerline and as close to the rear corners of the apparatus as is practical.

13.8.13.3.3 The optical center of any lower-level device shall be between 18 in. and 62 in. (460 mm and 1600 mm) above level ground.
13.8.13.3.4* It shall be permitted for red zone C lower flashing lights to switch to steady-on lights when the service brakes are applied and the optical warning light system is on in the "Clearing Right-of-Way" mode.
13.8.13.4 Midship Optical Warning Devices.
13.8.13.4.1 A midship optical warning device shall be mounted on both the right and the left sides of the apparatus if the distance between the front and rear lower-level optical devices exceeds 25 ft (7.6 m) at the optical center.
13.8.13.4.2 Additional midship optical warning devices shall be required, where necessary, to maintain a horizontal distance between the centers of adjacent lower-level optical warning devices of 25 ft (7.6 m) or less.
13.8.13.4.3 The optical center of any midship mounted optical warning device shall be between 18 in. and 62 in. (460 mm and 1600 mm) above level ground.
13.8.13.5* For each operating mode, the combined optical power of all the optical sources shall meet or exceed the zone total optical power requirements shown in Table 13.8.13.5.
13.8.13.6 No individual measurement point shall be less than that shown in Table 13.8.13.5.
13.8.13.7 In the nighttime blocking the right-of-way mode the combined optical power of all the flashing optical sources shall not exceed the zone maximum total optical power requirements shown in Table 13.8.13.5.

Table 13.8.13.5 Optical Power Requirements for Large Apparatus

		Mode of Operation									
		Calling for Right-of-Way			Daytime Blocking Right-of-Way			Nighttime Blocking Right-of-Way			
Zone	Level	Minimum H Total	At Any H Point	At Any Point 5 Degrees Up or 5 Degrees Down from H	Minimum H Total	At Any H Point	At Any Point 5 Degrees Up or 5 Degrees Down from H	Minimun H Total	Maximun H Total	At Any H Point	At Any Point 5 Degrees Up or 5 Degrees Down from H
A	Upper	2,000,000	20,000	7,000	1,000,000	10,000	3,500	400,000	750,000	7,500	2,500
B	Upper	750,000	20,000	3,500	400,000	10,000	3,500	400,000	750,000	7,500	2,500
C	Upper	750,000	20,000	3,500	1,500,000	10,000	3,500	400,000	750,000	7,500	2,500
D	Upper	750,000	20,000	3,500	400,000	10,000	3,500	400,000	750,000	7,500	2,500
A	Lower	400,000	7,000	3,000	400,000	7,000	3,000	75,000	150,000	1,875	1,000
B	Lower	400,000	7,000	3,000	400,000	7,000	3,000	75,000	150,000	1,875	1,000
C	Lower	400,000	7,000	3,000	400,000	7,000	3,000	75,000	150,000	1,875	1,000
D	Lower	400,000	7,000	3,000	400,000	7,000	3,000	75,000	150,000	1,875	1,000

Notes:
1. All values are in candela-seconds/minute.
2. H = Horizontal plane passing through the optical center.
3. The values in the H Total columns are the total of 19 data point values for each light, with data points on the boundary between zones counted in both zones.

13.8.14* Requirements for Small Apparatus.
13.8.14.1 If the apparatus has a bumper-to-bumper length of less than 25 ft (7.6 m) and has the optical center of all optical warning devices at 8 ft (2.4 m) or less above level ground, the requirements of 13.8.14.2 through 13.8.14.8.3 shall apply.
13.8.14.2 Upper-Level Optical Warning Devices.
13.8.14.2.1 The upper-level optical warning devices shall be mounted as high as practical, but not over 8 ft (2.4 m), at the optical center.
13.8.14.2.2 The upper-level optical warning devices shall be permitted to be combined in one or more enclosures and shall be permitted to be mounted on the cab roof or any other convenient point.

13.8.14.3 Lower-Level Optical Warning Devices.
13.8.14.3.1 One or more lower-level optical warning devices shall be visible from the front and the side of the apparatus.
13.8.14.3.2 The optical center of the lower-level optical warning devices in the front of the vehicle shall be mounted on or forward of the front wheel centerline and as close to the front corner points of the apparatus as is practical.
13.8.14.3.3 The optical center of the device(s) shall be between 18 in. and 48 in. (460 mm and 1220 mm) above level ground.
13.8.14.3.4* It shall be permitted for red zone C lower flashing lights to switch to steady-on lights when the service brakes are applied and the optical warning light system is on in the "Clearing Right-of-Way" mode.
13.8.14.4 For each operating mode, the combined optical power of all the optical sources mounted on both the upper and lower levels shall meet or exceed the zone's total optical power requirements shown in Table 13.8.14.4.
13.8.14.5 No individual measurement point shall be less than that shown in Table 13.8.14.4.
13.8.14.6 In the nighttime blocking the right-of-way mode the combined optical power of all the optical sources shall not exceed the zone maximum total optical power requirements shown in Table 13.8.13.5.

Table 13.8.14.4 Optical Power Requirements for Small Apparatus

	Mode of Operation									
	Calling for Right-of-Way			Daytime Blocking-Right-of-Way			Nighttime Blocking-Right-of-Way			
Zone	Minimum H Total	At Any H Point	At Any Point 5 Degrees Up or 5 Degrees Down from H	Minimum H Total	At Any H Point	At Any Point 5 Degrees Up or 5 Degrees Down from H	Minimum H Total	Maximum H Total	At Any H Point	At Any Point 5 Degrees Up or 5 Degrees Down from H
A	2,000,000	20,000	7,000	800,000	10,000	3,500	200,000	400,000	5,000	1,750
B	200,000	8,000	3,500	200,000	8,000	3,500	100,000	200,000	4,000	1,750
C	400,000	10,000	3,500	800,000	10,000	3,500	200,000	400,000	5,000	1,750
D	200,000	8,000	3,500	200,000	8,000	3,500	100,000	200,000	4,000	1,750

Notes:
1. All values are in candela-seconds/minute.
2. H = Horizontal plane passing through the optical center.
3. The values in the H Total columns are the total of 19 data point values for each light, with data points on the boundary between zones counted in both zones.

13.8.15 Tests of Optical Warning Devices.
13.8.15.1 Mechanical and Environmental Test.
13.8.15.1.1 All optical warning devices shall be tested to the requirements of SAE J595, *Directional Flashing Optical Warning Devices for Authorized Emergency, Maintenance, and Service Vehicles*; SAE J845, *Optical Warning Devices for Authorized Emergency, Maintenance, and Service Vehicles*; or SAE J1889, *L.E.D. Signal and Marking Lighting Devices*.
13.8.15.1.2 Optical devices and components designed for mounting only in weatherproof, interior spaces shall be tested in conformance with the applicable SAE standard listed in 13.8.15.1.1 and shall comply with the vibration test and the warpage test for plastic components.
13.8.15.1.3 Optical devices and components designed for mounting on the exterior of the apparatus or in non-weatherproof interior spaces shall be tested in conformance with SAE J845 and shall comply with the following performance requirements of that standard:
(1) Vibration
(2) Moisture

(3) Dust
(4) Corrosion
(5) High temperature
(6) Low temperature
(7) Durability
(8) Warpage

13.8.15.2 Photometric Test Procedures for Optical Devices.

13.8.15.2.1 Testing shall be performed by, or on behalf of, the device manufacturer to ensure compliance with the requirements of 13.8.15.2.2 through 13.8.15.2.5.2.

13.8.15.2.1.1 The results of the testing shall be used to determine compliance with this standard, and all required photometric data shall be available, upon request, from the optical warning device manufacturer.

13.8.15.2.1.2 The goniometer, integrating photometer, and other equipment used to take the test measurements shall meet the requirements of SAE J1330, *Photometry Laboratory Accuracy Guidelines*.

13.8.15.2.2 The optical source shall be mounted in a goniometer and operated as it would be in a normal system application.

13.8.15.2.2.1 The minimum distance between the light emitting surface of the source being tested and the front face of the photometer detector shall be 59 ft (18 m).

13.8.15.2.2.2 The goniometer shall be oriented, and the integrating photometer shall be set to integrate light pulses from the source to accurately read, or read and convert to, candela-seconds/minute.

13.8.15.2.3 For all tests performed with the power applied, the lighting system, or component thereof, shall be operated at 12.8 V ±0.1 V for 12 V nominal equipment, 25.6 V ±0.2 V for 24 V nominal equipment, and 38.4 V ±0.3 V for 42 V nominal equipment.

13.8.15.2.3.1 If the equipment is rated for operation on multiple voltages, the tests shall be performed at each of the rated voltages used by the equipment.

13.8.15.2.3.2 Voltage shall be measured at a point 12 in. ± 1 in. (300 mm ± 25 mm) from the entry into the component.

13.8.15.2.4 The technique described in 13.8.15.2.2 through 13.8.15.2.2.2 shall be performed along the horizontal plane that passes through the optical center, beginning at the optical center and repeated at 5-degree intervals to the left and to the right of the optical center throughout the active horizontal angle of light emission of the optical source.

13.8.15.2.5 Measurements shall be repeated at 5 degrees up and 5 degrees down from the horizontal plane that passes through the optical center, beginning at a point on the vertical plane passing through the optical center.

13.8.15.2.5.1 The measurements shall be repeated at 5-degree intervals to the left and to the right of this vertical plane throughout the active horizontal angle of light emission of the optical source.

13.8.15.2.5.2 If the optical warning device contains more than one optical source, the test shall be repeated for each optical source.

13.8.15.2.6 Each LED optical source shall be tested to verify that the drop in light output from initial turn on with the optical source at room temperature to photometric stability (per SAE J1889) is not more than 25%.

13.8.16* Compliance Documentation. The apparatus manufacturer shall demonstrate compliance of the warning system by one of the following methods:

(1) Certification that the system was installed within the geometric parameters specified by the manufacturer of the system referencing the optical source test reports provided by the manufacturer of the system

(2) Certification that a mathematical calculation based on test reports for individual optical sources provided by the manufacturer of the devices and performed by a qualified person demonstrates that the combination of individual devices as installed meets the requirements of this standard

(3) Actual measurement of the lighting system after installation on the apparatus

Lighting Change Evaluation Study
Harrisburg, PA May 16, 2019
Design of Experiment

This Design of Experiment was developed with advice from Dr. Michael Flannagan of the University of Michigan Transportation Research Institute. Thanks to Dr. Flannagan for his assistance.

Observers

Potential changes to the NFPA 1901/1906 emergency lighting requirements will be evaluated in Harrisburg, PA on Thursday evening, May 16, 2019 in conjunction with the Fire Expo 2019. The evaluation study will be conducted by showing multiple lighting configurations presented by multiple emergency lighting manufacturers and evaluated using written or online questionnaires filled out by volunteers. The invited evaluators will include:

- All members for the NFPA Fire Department Apparatus Committee, Principals and Alternates.
- Other people associated with the NFPA Fire Department Apparatus Committee.
- Members, associates, and contacts of the Emergency Responder Safety Institute.
- Others with interest in the subject of firefighter safety.

This population does have a potential bias. The people who chose to participate in the study are probably people who have the build in bias that the current lighting is too intense and so would be likely to estimate intensity and glare higher than a randomly selected population.

Lighting Displays

There will be several lighting configurations representing fire apparatus rear views (Zone C). The lighting configurations will be mounted on tripods. The lights, controls, and wiring will be provided by the emergency lighting manufacturer. AC power will be available provided by the study. **For each lighting configuration and each mode shown**, the lighting manufacturer will provide to the study:

- Model number of each light and control device used.
- Color of each light.
- The photometric data for the configuration (both upper and lower zones separately) in accordance with the NFPA testing process including:
  - Candela-Seconds/Minute at 19 H points from -45º to +45º.
  - Candela-Seconds/Minute at 38 points from -45º to +45º H at +5ºV and -5ºV.
  - Total Candela-Seconds/Minute for 19 H points from -45º to +45º.
- Description of flash rate and flash pattern.

APPENDIX 4
Design of Experiment

For the various dimmed levels, the photometric data can be a percentage of a single table if all intensities use the same fixtures and LED sources. It is preferable that the data be provided in an excel spreadsheet to simplify analysis.

The location host, the Fire Expo, required that the lighting vendors must be companies that were also exhibitors at the Fire Expo. That gave three lighting manufacturers that could possibly provide lighting equipment. All three, Code 3, Federal Signal, and Whelen Engineering, were invited to provide equipment for the study. After discussions about what was needed, Code 3 and Federal Signal decided not to provide equipment for the study. Whelen Engineering offered to provide the study with hardware and data for the study. All manufacturers (including others not asked to provide hardware) were invited to be observers in the data collection process, and all will be included in the review process for the proposed language for NFPA 1901 and NFPA 1906, being the hardware provider produces no advantage in the final process.

Parameters
The following parameters were selected as independent variables for the study. Within each group, data points were selected to provide evaluation data relevant to the objective of the study, helping provide information on what changes should be made to the emergency lighting requirements in NFPA 1901 and NFPA 1906 to address the issue of too-bright lighting when parked.

Intensity selected from the following list. Intensity will be varied by dimming the LED light output using variable Pulse Width Modulation (PWM).

1) Current typical high intensity lighting configuration at full intensity.
    - The intensity of the lighting package will vary between manufacturers.
2) Intensity at about the current minimum required.
    - Upper zone H total 800,000-1,000,000 Cd-Sec/Min
    - Lower zone H Total 150,000-185,000 Cd-Sec/Min
3) Intensity at about 50% the current minimum required.
    - Upper zone H total 400,000-500,000 Cd-Sec/Min
    - Lower zone H Total 75,000-95,000 Cd-Sec/Min
4) Intensity at about 10% the current minimum required (simulates 45º off angle).
    - Upper zone H total 80,000-100,000 Cd-Sec/Min
    - Lower zone H Total 15,000-18,5000 Cd-Sec/Min
5) Intensity at about 5% the current minimum required (simulates 45º off angle).
    - Upper zone H total 40,000-50,000 Cd-Sec/Min
    - Lower zone H Total 7,500-9,000 Cd-Sec/Min

The first level, 1), represents the current state of the market, which is reported to be felt by many as “too bright”. This gives a basis for comparison.

The second level, 2), represents the current minimum blocking mode rear view, and was the state-of-the-art when the current standard language was developed in the early 1990’s.

The third level, 3), represents the current minimum blocking mode side view and the minimum responding mode rear view. It would be a reduction from the current minimum blocking mode rear view.

Many flashing lights designed to be mounted on the side or rear of fire apparatus have a very significant difference in the intensity between straight out and 45º off to the side. This difference is often as much as a factor of 1/10. When fire apparatus is placed in a blocking position on the highway, the approaching motorist may see the rear and side lighting at close to the dimmest point. The fourth level, 4), represents the intensity that would be seen when level 2 is observed at the worst-case angle.

The fifth level, 5), represents the intensity that would be seen when level 3 is observed at the worst-case angle.

Flash pattern selected from:

6) Random flashing of the lights with maximum “activity”
   - This represents the typical high activity random flash pattern.
   - Use multi-flash and other high activity patterns
7) Alternating Up/Down and/or In/Out pattern
   - Half of the lights flash alternating with the other half of the lights.
   - Corresponding lights on left and right are on together.
   - Single flash
8) Synchronized All On/All Off
   - All lights go on and off together
   - Single flash
9) Diagonal “X” alternating flash
   - Upper left and lower right together alternating with
   - Upper right and lower left together
   - Single flash

The first flash pattern. 6), is a current state-of-the-art LED flash pattern with lights flashing randomly, often with double or triple flashes or changing flash characteristics. This pattern is highly attention getting but can be distracting or glare producing. It provides the baseline from which to compare other flash patterns.

The second flash pattern, 7), is a calmer flash pattern. In the simplest case with 2 upper and 2 lower lights, the upper lights flash a single flash then the lower lights flash a single flash. When there are more that 2 lights in a zone and level (especially with a light bar with many optical sources), they still use single flashes with approximately half of the lights on at once, but they can give both up/down and in/out visual images.

The third flash pattern, 8), has all lights flashing a single flash together. This gives a totally dark time between flashes. This may improve the visibility of other objects but may also create difficulty tracking the location and size of the parked truck.

The fourth flash pattern, 9), presents a different image by lighting diagonals. Other reports have suggested that this pattern makes it harder for the approaching driver to visualize the width of the parked truck.

Modulation depth. Requires control of background glow when "Off".

10) Full-on/Full-off single flash
    - Lights go On to full intensity for the case 1-5 above.
    - Lights go full off when Off.
11) Full-on/10%-on single flash
    - Lights go On to full intensity for the case 1-5 above.
    - For the Off part of flash, lights remain on at 10% of "On" intensity.
    - Could be done with a separate adjacent light 10% as bright as the main light.

The first case, 10), is the standard case now with LED lights, the light goes on to full, or a specific reduced, intensity and then goes off completely.

The second case, 11), has the light coming on fully or to a specific reduced intensity but then, rather than going completely off, goes down to about 10% of the "On" intensity. This residual glow has been shown in previous studies to provide better tracking by the approaching driver. The bright flash attracts attention and then the glow allows the driver's eye to continue to track where the light is. Historically lights that used a rotating light source or rotating mirror would display some of this effect because light bounced around inside the lens providing a background light. With LED lights this can be done by retaining some PWM power to the light all the time, or placing a smaller, dimmer, light next to the main light.

Test Cases

With 5 intensities, 4 flash patterns, 2 modulation depths, and 2 distances; there are theoretically 80 displays to show and evaluate. This is more than redundancy that needed to evaluate the several parameters. desired to do in a reasonable time. Since the study is being done all at once in a single evening, the audience must be willing to observe and evaluate all the cases shown. For this reason, a selected subset of display configurations is selected.

The study needs to determine two basic questions. The first is what lighting intensities are too bright, just right, or too dim. There is, of course, no exact or perfect answer to this question. In real life, the answer is different for each observer, lighting condition, environment, and lighting configuration. The second question is what changes to flash characteristics (pattern and modulation depth) can improve the display. There is an interconnection to these two questions, changing flash pattern probably changes how different intensities will be perceived. At the same time, improvements in the flash pattern should be better across the lighting intensity spectrum. The table below lists all the cases to be displayed and observed. All the displays at 100 meters will be done first. In this scenario the key question is the ability to see, recognize, and respond to the parked fire apparatus. The group of observers will then move to 10 meters from the light displays and additional displays will be shown. Here the key question is the ability to navigate past the parked fire apparatus. Glare and distraction are a more significant issue at close distances.

One case is duplicated to allow the results to be compared between the two times the same display is shown. Comparing the results with a t-test will give an indication of how consistent the observers are over time. In most cases, both manufacturers will display the same scenario of lighting intensity and flash characteristics. This will give the same kind of redundancy to the data. Manufacturer will be treated as a fixed effect since both manufacturers are displaying a configuration based on identical parameters that will be used to define the standard.

Test Cases to Display at 100 meters First randomized and then in a logical sequence stepping through patterns				
Intensity	**Flash Pattern**	**Modulation**	**Total Cases**	**Comments**
1-5	6	10	5	Current flash pattern, all intensities
1-5	7	10	5	Proposed flash pattern, all intensities
2	8	10	1	On/Off flash
2	9	10	1	X flash
1-5	7	11	5	Proposed flash with glow, reduced intensities
			17	Total 100 m
Test Cases to Display at 10 meters First randomized and then in a logical sequence stepping through patterns				
Intensity	**Flash Pattern**	**Modulation**	**Total Cases**	**Comments**
1-4	6	10	4	Current flash pattern, upper intensities
1-5	7	10	5	Proposed flash pattern
2	7	11	1	Test background glow
2	8	11	1	
2	8	10	1	On/Off
2	9	10	1	X pattern
			13	Total 10 m

APPENDIX 4
Design of Experiment

The observers will initially be located approximately 100 meters from the light sources. This distance approximates the distance at which a driver traveling at 60 mph would need to detect the warning lights in order to recognize it as a potential hazard and engage in a defensive driving maneuver. A vehicle will be placed on each side of the group of observers with their low-beam headlights on pointing towards the lighting displays.

Another set of displays will be repeated with the observers at 10 meters from the light displays, simulating the conditions of a driver passing the parked vehicle.

All the displays within a distance will be shown in random order. The observers will not know anything about the specifics of which display they are observing. They will not be given information on which manufacturer supplied the hardware they are looking at, the specific intensity, or the characteristics defining the flashes they are seeing.

Each lighting display will be shown for 8 seconds (10 cycles at 75 flashes/minute) and then turned off. The observers will then be given about 20 seconds to answer the three questions and add any comments. When they need to change pages, additional time will be allowed to change pages on their clipboard and verify that they are on the correct page.

Data Collection

Once the observers have arrive they will be welcomed and the process will be explained. Each observer will be given a questionnaire, a pencil, a clipboard, and a flashlight, or they will be able to do the questionnaire on their smartphone. Both a QR code to scan and a URL can be used to access the questionnaire. First, they will be asked to fill out some demographic information:

- Name
- Age range (Under 16, 16-40, 41-64, 65+)
- Gender (Male, Female)
- Association (NFPA Fire Department Apparatus Committee, Emergency Lighting Manufacturer, Firefighter/EMS/Fire Police, Police Officer, Other)
- Wearing glasses (Yes, No)
- Email (if the participant wants status updates)

The observers will be given instruction about the displays they will see, the scenario being demonstrated, and the questions they will be asked to answer about each display. Pre-prepared paragraphs about the scenario and about each question will be read so that everyone understands what the questions mean. They will have an opportunity to ask any questions about the process. For each display, each observer will be asked to fill out several questions:

- What is the visibility of truck at this distance? Scale from 1 to 9, 1=Insufficient warning, 5=ideal to identify, 9=Way to intense.
- What would be the ease of navigating past/around the vehicle with the lights on? Scale from 1 to 9; 1=No problem, 5=Could pass safely but distracting, 9=Difficult to pass.

- What is the level of discomfort glare? Using the DeBoer glare scale (with numbers reversed) on a scale from 1 to 9; 1=just noticeable, 3=satisfactory, 5 just acceptable, 7=disturbing, 9=unbearable.
- Comments?

As the displays are shown, they will constantly be reminded of the display number they are answering questions about. The displays will be numbered sequentially from 1 to 60.

At the conclusion of the light displays, the clipboards and questionnaires will be collected. The participants will be thanked for their participation.

We will take measurements of ambient light, at the beginning and the end of the displays, both with the light meter looking straight up and with the light meter looking the same direction as the observers to get the intensity of light from the background.

Data Analysis

After the demonstrations, all the questionnaire data will be put into an Excel spreadsheet and analyzed. The results from each of the sets of demonstrations will be compared and these results will be used to make changes to the NFPA 1901/1906 emergency lighting standards language, starting from the first draft language already published for public comment. The analysis, along with the historical development of the standard and other research that has been done over the last 30 years, will be published on the Emergency Responder's Safety Institute web site. All the raw survey data will be available, if desired, to the participating manufacturers and members of the NFPA Fire Department Apparatus Committee so they can do their own analysis.

The first step will be determining the average and standard deviation of the responses to each display. Initially the entire population will be used together, and the two manufacturer's displays under the same conditions will be combined.

The following comparisons will be evaluated for potentially significant results:

- Using the current typical flash pattern (6,10), how does changing the intensity change the responses at both near and far distances?
- What is the comparison of flash patterns 6 through 9 at the same intensity at both near and far distances? What is the best pattern?
- For the proposed flash pattern (7), what is the best intensity to balance glare, ease of navigation, and visibility, both at near and far distances?
- Does the 100%/10% modulation depth change responses at the same flash pattern and intensity?
- Are there significantly different responses for any of the demographic groups, age, gender, association, glasses, or between manufacturers?
- Do the results from the pairs of tests done in random vs sequential order show that the data collection remained consistent over time?

Lighting Intensity Study Questionnaire May 16, 2019

Name: (will not be public) ____

Age: Under 16 ____ 16-40 ____ 41-64 ____ 65+ ____

Gender: Male ____ Female ____

Association: NFPA Fire Department Apparatus Committee ____
Emergency Lighting Manufacturer ____
Emergency Vehicle Manufacturer ____
Firefighter/EMS/Fire Police ____
Police Officer ____
Other ____

Wearing Glasses: Yes ____ No ____

Email (if you want to be advised of progress): ____________________________

APPENDIX 5
Lighting Change Evaluation Questionnaire

What is the visibility of truck lights at this distance?
1=Insufficient, 5=Ideal to identify, 9=Way too intense

What would be the ease of navigating past/around vehicle with lights on?
1=No problem, 5=Could pass safely but distracting, 9=Difficult to pass

What is the level of discomfort glare?
1=Just noticeable, 3=Satisfactory, 5=Just acceptable, 7=Disturbing, 9=Unbearable

Display										
1	Visibility?	1	2	3	4	5	6	7	8	9
	Navigating?	1	2	3	4	5	6	7	8	9
	Glare?	1	2	3	4	5	6	7	8	9
	Comments?									
2	Visibility?	1	2	3	4	5	6	7	8	9
	Navigating?	1	2	3	4	5	6	7	8	9
	Glare?	1	2	3	4	5	6	7	8	9
	Comments?									
3	Visibility?	1	2	3	4	5	6	7	8	9
	Navigating?	1	2	3	4	5	6	7	8	9
	Glare?	1	2	3	4	5	6	7	8	9
	Comments?									
4	Visibility?	1	2	3	4	5	6	7	8	9
	Navigating?	1	2	3	4	5	6	7	8	9
	Glare?	1	2	3	4	5	6	7	8	9
	Comments?									
5	Visibility?	1	2	3	4	5	6	7	8	9
	Navigating?	1	2	3	4	5	6	7	8	9
	Glare?	1	2	3	4	5	6	7	8	9
	Comments?									
6	Visibility?	1	2	3	4	5	6	7	8	9
	Navigating?	1	2	3	4	5	6	7	8	9
	Glare?	1	2	3	4	5	6	7	8	9
	Comments?									

The questionnaire continues 6 displays per page through display 60.

APPENDIX 6
Lighting Change Evaluation Raw Results

Distance: 100 Meters

				Visibility		Navigation		Glare	
Display #	Intensity	Flash Pattern	Modulation Depth	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	1 (Full)	7 (Alternate)	11 (100%/10%)	5.41	2.05	4.66	2.35	4.82	2.09
2	2 (100%Min)	9 (X Pattern)	10 (100%/0%)	4.29	1.53	3.50	2.01	3.44	1.74
3	4 (10%Min)	6 (Random)	10 (100%/0%)	3.55	1.55	3.39	1.90	2.97	1.94
4	1 (Full)	6 (Random)	10 (100%/0%)	7.08	1.99	6.65	2.38	6.62	1.68
5	1 (Full)	7 (Alternate)	10 (100%/0%)	6.45	1.81	5.50	2.27	5.84	1.81
6	3 (50%Min)	7 (Alternate)	10 (100%/0%)	3.87	1.39	2.58	1.58	2.79	1.51
7	3 (50%Min)	6 (Random)	10 (100%/0%)	4.58	1.43	3.55	2.01	2.97	1.44
8	2 (100%Min)	6 (Random)	10 (100%/0%)	5.13	1.47	4.21	1.91	3.97	1.50
9	4 (10%Min)	7 (Alternate)	10 (100%/0%)	3.68	1.57	2.71	1.89	2.39	1.20
10	5 (5%Min)	7 (Alternate)	11 (100%/10%)	3.34	1.73	2.21	1.45	2.08	1.18
11	2 (100%Min)	8 (On/Off)	10 (100%/0%)	4.95	1.94	4.42	2.03	5.03	2.07
12	4 (10%Min)	7 (Alternate)	11 (100%/10%)	3.37	1.66	2.43	1.70	2.47	1.25
13	3 (50%Min)	7 (Alternate)	11 (100%/10%)	4.22	1.62	3.35	1.80	3.35	1.63
14	5 (5%Min)	6 (Random)	10 (100%/0%)	3.70	1.46	3.35	2.21	2.70	1.71
15	2 (100%Min)	7 (Alternate)	10 (100%/0%)	5.19	1.47	5.46	8.17	4.22	1.82
16	5 (5%Min)	7 (Alternate)	10 (100%/0%)	3.54	1.65	2.43	1.55	2.51	1.39
17	2 (100%Min)	7 (Alternate)	11 (100%/10%)	5.11	1.48	3.73	2.10	4.08	1.78
18	1 (Full)	6 (Random)	10 (100%/0%)	7.54	2.01	6.89	2.57	6.84	2.09
19	2 (100%Min)	6 (Random)	10 (100%/0%)	5.38	1.60	4.27	2.04	4.38	1.99
20	3 (50%Min)	6 (Random)	10 (100%/0%)	4.84	1.45	4.08	2.20	3.84	1.88
21	4 (10%Min)	6 (Random)	10 (100%/0%)	4.03	1.62	3.41	1.92	3.03	1.72
22	5 (5%Min)	6 (Random)	10 (100%/0%)	3.46	1.57	3.08	2.08	2.86	1.91
23	1 (Full)	7 (Alternate)	10 (100%/0%)	7.59	2.00	7.14	2.37	7.24	1.78
24	1 (Full)	7 (Alternate)	11 (100%/10%)	7.14	1.97	6.41	2.33	6.73	1.83
25	2 (100%Min)	7 (Alternate)	10 (100%/0%)	4.51	1.33	3.41	1.76	3.78	1.71
26	2 (100%Min)	7 (Alternate)	11 (100%/10%)	4.54	1.68	3.19	1.47	3.43	1.35
27	2 (100%Min)	8 (On/Off)	10 (100%/0%)	4.27	1.79	4.49	2.18	4.46	1.82
28	2 (100%Min)	9 (X Pattern)	10 (100%/0%)	4.70	1.37	4.38	1.82	4.08	1.57

29	3 (50%Min)	7 (Alternate)	10 (100%/0%)	4.27	1.61	3.11	1.62	3.00	1.52
30	3 (50%Min)	7 (Alternate)	11 (100%/10%)	4.19	1.39	2.76	1.55	2.89	1.29
31	4 (10%Min)	7 (Alternate)	10 (100%/0%)	3.49	1.33	2.35	1.58	2.38	1.28
32	4 (10%Min)	7 (Alternate)	11 (100%/10%)	3.44	1.52	1.91	1.02	2.19	1.22
33	5 (5%Min)	7 (Alternate)	10 (100%/0%)	3.57	1.58	2.54	1.79	2.27	1.18
34	5 (5%Min)	7 (Alternate)	11 (100%/10%)	3.22	1.52	2.05	1.31	1.95	1.06

Distance: 10 Meters

				Visibility		Navigation		Glare	
Display #	Intensity	Flash Pattern	Modulation Depth	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
35	2 (100%Min)	7 (Alternate)	10 (100%/0%)	5.73	1.65	4.95	2.12	5.73	1.87
36	4 (10%Min)	6 (Random)	10 (100%/0%)	3.84	1.37	3.08	1.57	3.16	1.70
37	2 (100%Min)	6 (Random)	10 (100%/0%)	6.00	1.74	5.39	2.06	5.51	1.70
38	3 (50%Min)	6 (Random)	10 (100%/0%)	5.22	1.39	4.41	2.34	4.41	1.76
39	5 (5%Min)	7 (Alternate)	10 (100%/0%)	3.73	1.66	2.49	1.55	2.57	1.73
40	2 (100%Min)	7 (Alternate)	11 (100%/10%)	5.70	1.55	4.46	2.10	5.14	1.63
41	2 (100%Min)	8 (On/Off)	10 (100%/0%)	6.27	2.13	6.27	2.25	6.30	1.81
42	2 (100%Min)	8 (On/Off)	11 (100%/10%)	5.78	1.85	4.70	2.05	5.24	1.98
43	3 (50%Min)	7 (Alternate)	10 (100%/0%)	4.71	1.74	5.80	8.27	4.20	2.00
44	2 (100%Min)	9 (X Pattern)	10 (100%/0%)	5.16	1.36	3.95	1.97	4.41	1.90
45	4 (10%Min)	7 (Alternate)	10 (100%/0%)	3.68	1.62	3.51	2.04	2.68	1.63
46	1 (Full)	6 (Random)	10 (100%/0%)	8.00	2.30	7.51	2.55	7.70	2.38
47	1 (Full)	7 (Alternate)	10 (100%/0%)	8.00	2.21	7.43	2.54	8.03	1.75
48	1 (Full)	6 (Random)	10 (100%/0%)	8.03	2.07	7.73	2.40	8.00	1.79
49	2 (100%Min)	6 (Random)	10 (100%/0%)	5.57	1.98	4.81	2.00	5.05	2.01
50	3 (50%Min)	6 (Random)	10 (100%/0%)	4.76	1.52	4.03	1.73	3.97	1.87
51	4 (10%Min)	6 (Random)	10 (100%/0%)	3.92	1.58	3.51	1.94	3.08	1.55
52	1 (Full)	7 (Alternate)	10 (100%/0%)	7.95	2.03	7.54	2.31	7.65	1.85
53	2 (100%Min)	7 (Alternate)	10 (100%/0%)	4.73	1.46	3.95	1.66	4.17	1.83
54	2 (100%Min)	7 (Alternate)	11 (100%/10%)	4.35	1.75	3.68	1.53	3.76	1.71
55	2 (100%Min)	8 (On/Off)	10 (100%/0%)	5.42	2.13	5.00	2.24	5.29	2.15

56	2 (100%Min)	8 (On/Off)	11 (100%/10%)	4.95	1.73	4.14	1.80	4.19	1.67
57	2 (100%Min)	9 (X Pattern)	10 (100%/0%)	4.68	1.44	3.76	1.60	4.11	1.57
58	3 (50%Min)	7 (Alternate)	10 (100%/0%)	4.35	1.66	3.59	1.82	3.57	1.72
59	4 (10%Min)	7 (Alternate)	10 (100%/0%)	3.35	1.58	2.78	1.65	2.70	1.49
60	5 (5%Min)	7 (Alternate)	10 (100%/0%)	3.43	1.54	2.57	1.59	2.54	1.48

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