# Study of Protecting Emergency Responders on the Highways and Operation of Emergency Vehicles

## A Review of First Responder Agencies Who Have Adopted Emergency Lighting and Vehicle Conspicuity Technology

Cumberland Valley Volunteer Firemen's Association — Emergency Responder Safety Institute

June 2018

## Acknowledgements

The Cumberland Valley Volunteer Firemen's Association's Emergency Responder Safety Institute thanks Grady Carrick and Jack Sullivan for their expertise in writing this report. CVVFA/ERSI also acknowledges the cooperation and support of the organizations and personnel who assisted by sharing their experiences and knowledge. Finally, CVVFA/ERSI thanks Cathleen Corbitt-Dipierro, writer/producer from Stonehouse Media Incorporated, for editing this report.

This project was supported by Interagency Agreement No.2016-IJR-4008 and awarded by the National Institute of Justice (NIJ), Office of Justice Programs (OJP), U.S. Department of Justice (DOJ) to the U.S. Fire Administration (USFA).The opinions, findings, and conclusions or recommendations expressed in this publication/program/ exhibition are those of the author(s) and do not necessarily reflect those of the DOJ.

# Table of Contents

## Executive Summary

The primary objective of this report is to study first responder agencies that have adopted new lighting and conspicuity technology and practices to examine how the changes were implemented and to identify successes, obstacles, and lessons learned. Therefore, this report reviews literature related to emergency response vehicle lighting and conspicuity, discusses examples of current emergency lighting technology and conspicuity best practices related to law enforcement vehicles and fire apparatus, draws conclusions from that literature review and examples, and makes recommendations based on those conclusions for departments considering changes to their vehicles' emergency lighting and/or conspicuity measures.

This report identified the following conclusions and made corresponding recommendations:

| **Conclusion** | **Recommendation** |
|---|---|
| There is little consistency among state statutes regarding emergency lighting specifications, including light color. | A conversation about a consistent, nationwide standard has the potential to improve safety of responders. |
| Red and blue lights are most visible in different ambient lighting conditions (red for day, blue for night and for fog and smoke conditions at all hours). | Emergency vehicles should be equipped with both red and blue lights for optimal effectiveness in all conditions. |
| Bright white lights facing drivers can cause visibility problems. | Bright white lights should only be used to illuminate the work area and should be pointed downward onto that area. |
| Using emergency lighting patterns to differentiate between a vehicle that is moving ("calling for right-of-way") and one that is stationary ("blocking right-of-way") is helpful for drivers to discern how to react. | Differentiation can be achieved through different means, including strobe pattern, light pattern, and light color. |
| Light intensity affects driver vision in different ambient conditions. | Lighting intensity should be adjusted according to ambient conditions, preferably automatically via sensor or similar device. |
| Warning lights have best visibility when mounted as high and as close to corner points as practical, but not higher than the maximum height recommended by the manufacturer. | Warning lights should be mounted according to these best visibility findings. |
| Some Industry standards for emergency vehicles lack an upper limit on light intensity. Without an upper limit, lights that are "too bright" can cause visibility problems for drivers. | Standards-making bodies should review their standards to address upper limits on light intensity. |
| Some industry standards for emergency vehicles do not include guidance on new technology, such as flash patterns. | Standards-making bodies should incorporate guidance on new technology, such as flash patterns, into emergency lighting standards. |
| Several departments have outfitted their emergency vehicles with lit amber/yellow arrow sticks to improve visibility and give clear direction to approaching motorists. | Emergency vehicles should be equipped with amber/yellow arrow sticks. |

| | |
|---|---|
| Many emergency lighting packages have different settings that can be used to maximize visibility in different ambient conditions. | Department policy should:<br>• Provide for training of personnel in emergency lighting package capabilities and usage<br>• Direct personnel to:<br>  ○ Use emergency lights to provide warning and promote move over behavior<br>  ○ Reduce forward-facing lights to mitigate opposite direction distractions and delays, as well as minimize potential blinding effects for oncoming motorists<br>  ○ Only display lights on vehicles blocking travel lanes and/or only on the rear-most vehicle when multiple vehicles are on the shoulder when multiple responder vehicles are on the scene |
| Retroreflective markings improve conspicuity of emergency vehicles.<br>• Retroreflective materials, contrasting colors, and fluorescent colors are the hallmarks of strong conspicuity.<br>• Large marking elements like lettering are more conspicuous than small elements, especially when retroreflective.<br>• Cream, white, and yellow are the most visible colors in the highway environment and are therefore strong choices for emergency vehicle body colors.<br>• Rear markings like chevrons and retroreflectivity are of paramount importance. Side markings are also important for visibility when in an angled blocking position. | Departments should implement these recommended conspicuity methods. In addition, retroreflective markings should be added to interior vehicle surfaces that are exposed to view when opened, such as doors and liftgates, to improve conspicuity when these compartments are accessed. |
| Use of high visibility apparel prompts drivers to give pedestrians greater clearance. | Department policy should require high visibility apparel to be worn at all times when working on or near the roadway. |
| Multiple departments have created specialty large blocking and advance warning units from de-commissioned large vehicles like dump trucks and fire apparatus. These units include emergency lighting, arrow boards, and conspicuity measures. | Departments should be encouraged to be innovative and craft traffic incident management solutions that meet local needs using available resources. |
| Emergency lighting and conspicuity measures work best when used in tandem, as each complements the other. | Departments should consider using a combination of emergency lighting and conspicuity measures to maximize the visibility of vehicles and personnel. |

Forward-thinking departments, many of whom had one of their personnel struck at a roadway incident response, have undertaken extensive reviews of their emergency lighting and vehicle conspicuity designs. These reviews have resulted in the adoption of many new measures like those recommended here that have improved visibility, and include use of reflective tape, light bars with a low power setting, adjustable flash patterns, high visibility chevrons in contrasting colors, arrow boards, high-rise or multi-level lighting rigs, ambient light sensors, automatic adjustment of lighting based sensor readings or parking brake position, and having both red and blue lights available.

## Introduction

Responders operating at roadway incident scenes are confronted with unique dangers, particularly on high-speed roadways where the laws of physics make motor vehicles deadly. Whether driving to an emergency call, seated in a stationary responder vehicle at roadside, or exposed to traffic while on foot, responders are extremely vulnerable to vehicular traffic. Increasing safety for responders begins with making them and their vehicles more noticeable to other road users. Equipping responder vehicles with emergency lights and high visibility markings and outfitting responders with high visibility safety apparel (HVSA), allows motorists to identify and safely react to emergency vehicles and personnel..

Emergency vehicle lighting is an important tool for responders to visually communicate with approaching motorists. While that communication has historically largely been a message of “look at me” to encourage cautious driving, advances in lighting and conspicuity technology now provide an opportunity to communicate a clearer message that also directs or reminds motorists of an obligation to slow down and move over.

Passive treatments like emergency vehicle markings (often called “conspicuity” as an umbrella term) can complement lighting to make responder vehicles stand out against complex backgrounds and, consequently, draw attention to their presence. The objective of both lighting and marking is to reduce the chance that response vehicles will be struck by other vehicles.

The primary objective of this report is to review first responder agencies that have adopted new lighting and conspicuity technology and practices to look at how the changes were adopted, successes, obstacles, and lessons learned.

## Literature Review

A review of relevant literature establishes a foundation for evaluating agency experiences with emergency vehicle lighting and conspicuity.

The seminal work on this topic is the “Emergency Vehicle Visibility and Conspicuity Study” produced by the Federal Emergency Management Agency in conjunction with the U.S. Fire Administration.[1] The study found that retroreflective materials, contrasting colors, and fluorescent colors were critical features of vehicle markings. Incorporating these characteristics into vehicle decals and marking were recommended. Also recommended was using contour markings to silhouette the side profile of vehicles. Additionally, the opportunity to specifically concentrate markings on the rear of law enforcement vehicles was also noted as important.

[1] *Emergency Vehicle Visibility and Conspicuity Study*. U.S. Fire Administration. Federal Emergency Management Agency. U.S. Department of Homeland Security, 2009, *Emergency Vehicle Visibility and Conspicuity Study*,

Flannagan, Blower, and Devonshire examined non-blinding vehicle lighting in their report "Effects of Warning Lamp Color and Intensity on Driver Vision."[2] The field experiment examined various colors and intensities of light in daytime and nighttime conditions. In the study, groups of participants viewed four light colors (white, yellow, blue, and red) across various light intensities with the objectives of identifying the presence of lamps, spotting pedestrian responders, and rating the subjective conspicuity of the lamps. The study's recommendations centered on using different intensity levels for day and night, but also asserted that the color blue should be incorporated into warning lamp design for both daytime and nighttime use. Using different colors to differentiate stationary vehicles that are blocking travel lanes was another recommendation.

Flannagan and Devonshire also authored "Effects of Warning Lamps on Pedestrian Visibility and Driver Behavior," a 2007 study for the U.S. Department of Homeland Security, FEMA, USFA, and the U.S. Department of Justice, Office of Justice Programs. The study focused on evaluating three areas: how warning lamp characteristics affect the visibility of pedestrian responders on the scene, how visual characteristics of warning lamps affect driver behavior when passing a parked emergency vehicle, and nighttime photometry. The study used LED sources that were blue and red, with both low and high intensity lamps. Warning lamps did not affect lateral clearance afforded to on-scene pedestrians; however pedestrian high-visibility apparel did.

In a lighting study for the Texas Department of Transportation, "Texas DOT Vehicle Fleet Warning Light Policy Research," Ullman and Lewis point out that, in the traffic engineering community, highway signage is consistently colored across jurisdictions in ways that categorize the information and purpose of the sign, such as regulatory, warning, or guidance. In contrast, assignment of vehicle emergency lighting color varies state to state.[3] The research found that drivers were able to differentiate responder vehicle type and relative hazard based on the color of lights displayed. The findings were that yellow color alone was not sufficient to appropriately convey hazard across the wide range of operating conditions for DOT activities.

In "Move Over Law: Role of Emergency Vehicle Lighting in Compliance on Florida Freeways," Carrick and Washburn studied the move over behavior of more than 9,000 vehicles as they approached staged enforcement stops where various lighting combinations were used. The study found that when red and blue lights were displayed, four out of five drivers complied with move over laws, but that number dropped significantly when only an amber deck light was used.[4] Adding a yellow directional component to blue and red top lights did not change move over compliance.

In a Florida Highway Patrol (FHP) White Paper entitled "Enhancing Rear-Approach Conspicuity of Police Vehicles," Carrick and Spears reviewed progress in vehicle markings and used NFPA 1901 as the basis for

[2] Flannagan, Michael J, et al. *Effects of Warning Lamp Color and Intensity on Driver Vision.* . SAE International, 2008

[3] Ullman, Gerald L, and Don Lewis. "Texas DOT Vehicle Fleet Warning Light Policy Research." TRB Transportation Research E-Circular E-C013.

[4] Carrick, Grady, and Scott Washburn. "The Move Over Law: Effect of Emergency Vehicle Lighting on Driver Compliance on Florida Freeways." Transportation Research Record: Journal of the Transportation Research Board, vol. 2281, 2012, pp. 1–7.

recommend changes to the FHP vehicle fleet.[5] Recommendations included using red and fluorescent yellow-green retroreflective chevrons on the rear bumper. The recommendations of the white paper were adopted by the Director of the Florida Highway Patrol for all new vehicles, effective in the spring of 2013.

## The IACP LESS Subcommittee

The International Association of Chiefs of Police (IACP) established a Law Enforcement Stops and Safety Subcommittee in 2003 to examine officer safety issues related to traffic stops.[6] With more than two dozen experts from law enforcement, vehicle manufacturers, and safety groups, the IACP LESS Subcommittee examined law enforcement vehicle crashes at roadside. While the efforts focused on enforcement stops, the subcommittee's work product readily translates into all types of traffic incident management across all responder disciplines.

The staff study produced by the IACP LESS Subcommittee focused on vehicle, highway/environment, and policy/procedure topics. Of particular value for this report is the extensive work done in the area of vehicle lighting. Color, intensity, flash rate, and vehicle markings were all included in the IACP LESS report.

**Color.** Color plays an important role for legal reasons, but different colors also have different effectiveness where human perception is concerned. In darkness, blue is more effective. During daylight, red is more effective. Blue has the advantage at night of standing out better among a variety of red light sources, notably vehicle brake lights. However, during nighttime conditions of smoke, fog, or haze, blue loses its advantage and red is better because it, "scatters less, travels farther, and retains greater intensity at a distance than blue light."[7] Color also has an impact on drivers' ability to judge distance and motion, where blue is perceived to be advancing and red as receding under low light conditions.

**Intensity.** Intensity is an element of brightness for emergency lights. Strobe and other lights appear to have different brightness because of the length of time that they are "on."

**Flash rate.** Faster flash rates draw more attention than slower flash rates. However, there is general disagreement about the ideal flash rate; engineers have determined that faster flash rates produce a message of urgency, distraction, and eye discomfort.

**Vehicle markings.** Markings are an important complement to emergency vehicle lighting and the IACP LESS Subcommittee study identified efforts by the Arizona DPS to modify vehicle markings to make vehicles more conspicuous. The study noted that research suggests cream, white, and yellow are the

[5] Carrick, Grady, and K. Spears. "Enhancing Rear-Approach Conspicuity of Police Vehicles." Florida Highway Patrol White Paper. 10 March 2013.
[6] *LESS Wants More Safe Traffic Stops.* Law Enforcement Stops and Safety Subcommittee, International Association of Chiefs of Police.
[7] *Staff Study 2004.* Law Enforcement Stops and Safety Subcommittee, International Association of Chiefs of Police, 2004.

most visible colors in the highway environment and are, therefore, good choices for emergency vehicle body color.[8]

## National Fire Protection Association Standards

### NFPA 1901 - Standard for Automotive Fire Apparatus

The standard provides guidance on the location of warning lights on new automotive fire apparatus and trailers, the flash rate and color of the lights (in accordance with applicable state and local laws and regulations), and references SAE J578 for the color specifications for red, blue, yellow or white.

*NFPA 1901* section 13.8, "Optical Warning Devices," provides guidance on emergency warning light installations on new fire apparatus. According to the standard, each optical warning light system should have an upper and lower warning level. Upper level warning lights should be mounted as high and as close to corner points as practical, but not higher than the maximum height specified by the lighting manufacturer. Lower level lights should be mounted with the optical center of the device between 18 inches and 62 inches above ground level. Further guidance is provided for midship optical warning devices and there is also specific guidance for smaller fire apparatus. Additionally, each vehicle is divided into four zones (front, rear, and two sides) and the optical warning devices should be capable of displaying two separate signaling modes during emergency operations. One mode is used to signal an emergency response while the vehicle is moving and the second mode is used to signal that the apparatus is stationary and blocking the right of way.

Table 13.8.13.5 in *NFPA 1901* provides minimum optical power requirements for large apparatus and is divided by mode of operation: calling for the right-of-way or signaling blocking the right-of-way. The table lists minimum power requirements in candela-seconds/minute, which is the basic unit of luminous intensity or how bright/intense the human eye perceives the light in a given direction. There is no maximum power listed in the table. The lack of a maximum power value in applicable emergency lighting standards has allowed high intensity lights, particularly LED, to be employed without limitation.

Motorists approaching an incident scene can be distracted and/or temporarily "blinded" by the high intensity warning lights, making it impossible to see emergency personnel working around the emergency vehicles on scene. In some cases, this has contributed to secondary crashes at an incident scene. Moreover, many drivers, including public safety personnel, have noted the confusing nature of multiple optical warning lights operating at the same time at an incident scene.

Mr. Scott Potter, managing partner of Patriot Fleet Group, LLC in New England, says, "Today's warning light technology, particularly LED, provides much longer life and efficient warning signals and it brings a high level of light intensity never seen before. These new levels of intensity inherently create new

[8] *LESS Wants More Safe Traffic Stops.* Law Enforcement Stops and Safety Subcommittee, International Association of Chiefs of Police.

conditions that may actually lower the overall safety of the vehicle and an incident scene. The NFPA standards can be improved to reduce these risks and align themselves better with current technology."[9]

In NFPA 1901, light output requirements are only minimum accepted light measures. In the automotive industry, Federal Motor Vehicle Safety Standards, SAE International, and even KKK-A-1822F (Federal Specification for the Star of Life Ambulance) have maximum caps placed on acceptable light measures. Light output from brake lights, turn signals, parking lights, and even headlights have a cap that they are not to exceed. The *NFPA 1901* Technical Committee should consider following suit with maximum light output caps.

### Possible Solutions

Possible solutions for the issue of high intensity lighting creating visibility issues for drivers include:

- In certain instances, create a window of acceptable light output, such as minimum $X_1$ candela seconds/minute and maximum $X_2$ candela seconds/minute, where the $X_1$ and $X_2$ represent the suitable numeric lower and upper limit values, respectively, based on research findings.
- Tie the acceptable range numbers to ambient light values. Today's technology allows for light intensities to directly correspond to ambient light so the intensity adjusts automatically to ambient light conditions.
- Acknowledge that the light output cap may or may not be appropriate for all operating modes and create exceptions accordingly.

NFPA 1901 Section 13.8.13.5*, reads, "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." The table shows minimum light output requirements, specifically to the rear of the apparatus, as 400,000 candela-seconds/minute while responding and 800,000 candela-seconds/minute while stationary, or "Blocking Right-of-Way. Today, the optical power of warning light fixtures far exceeds what was available in 1996 when this section of the standard was originally adopted. This results in overly bright lights facing the rear of the apparatus that far exceed the minimum requirement that could potentially pose a distraction to first responders and motorists following behind the emergency vehicle, particularly at night. In addition, these same light intensity increases may now contribute to unsafe conditions at emergency scenes during times of low ambient light. One possible solution is to remove the intensity language requirements during times of low ambient light from the NFPA 1901 standard. Most of the warning light manufactures now have "low power" features built into the light fixtures that presently cannot be used in these applications according to NFPA 1901, as this might cause the lights to fall below these output figures. With the intensity requirement removed for nighttime or low ambient light operation, it would allow for the low power setting to be applied, thus creating a safer response and incident work area.

[9] Potter, Scott. Email received by Jack Sullivan, 4 Dec. 2017.

In the blocking right-of-way mode, or while parked at an emergency scene, studies have shown that light intensity that may be appropriate during daylight hours could be distracting during nighttime operations.[10] Today's technology allows for intensity variation to correspond directly to ambient light. Therefore, one possible solution is to apply a high ambient light intensity requirement and a low ambient light intensity requirement that would be automatically controlled by ambient light sensors on emergency vehicles.

In addition to light intensity, the lack of a flash sequencing requirement could potentially create a hazard. On a large apparatus, small flash bursts from random positions around the vehicle may be compliant, but do little to define the overall size of the vehicle. Synchronizing the light bursts would provide a visual warning signal that directly corresponds to the vehicle's size by providing an outline of the apparatus. This outline may also help approaching motorists determine its position on the roadway. KKK-A-1822F, the Federal Specification for the Star-of-Life Ambulance, has a flash sequence requirement, but *NFPA 1901* does not. Calling for right-of-way and blocking right-of-way may or may not have the same flash sequence requirement depending on the standard. Technology exists now to allow for fast flashes while calling for the right of way when responding and a slower flash or flicker when parked on scene to cut down on the distraction and glare issues. Today's technology allows for these adjustments to be made automatically based on the parking brake position. Therefore, one possible solution is to insert language into the standard that requires alternating rapid flashes (example >75 fpm) either synchronized or asynchronous while calling for right-of-way, and a slower fully synchronized in/out flash pattern (example between 40 and 60 fpm) while blocking right-of-way.

To address intense warning light flashes facing the incident scene that could impair one's night vision and contribute to distraction and/or temporary night blindness, one possible solution is to allow for "scene side" warning lights to be reduced or cancelled completely during the blocking right of way mode, while 'traffic side' warning lights resume.

Emergency lighting manufacturers have started to address these issues by incorporating ambient light sensing technology in new warning light packages, as well as offering reduced light intensity modes, slower flash rates, and automatic sensing features so that operators don't have to manually adjust warning lights under different circumstances. Some of these features cannot currently be installed in new fire apparatus because they conflict with *NFPA 1901's* requirements, specifically in the Minimum Optical Power Requirement table.

Similar emergency lighting concerns exist in *NFPA 1906: Standard for Wildland Fire Apparatus*, *NFPA 1917: Standard for Automotive Ambulances*, and *NFPA 1912: Standard for Fire Apparatus Refurbishing.* Any changes to *NFPA 1901* for optical warning device standards should also be considered for adoption in *NFPA 1906, 1912, and 1917*.

[10] Potter, Scott. "Police Vehicle Warning Signals — An Innovative Approach to Officer Safety." *Police Chief Magazine*, 2 May 2018, www.policechiefmagazine.org/warning-signals-officer-safety/.

# Examples of Emergency Lighting and Conspicuity Innovations on Law Enforcement Vehicles

## Arizona Department of Public Safety

The Arizona DPS was among the first agencies in the U.S. to experiment with the concept of enhanced markings on the rear of vehicles, notably the use of chevrons on the rear of the vehicle.[11] The Arizona DPS added blue bumper chevrons to their vehicle fleet, which was comprised of all white vehicles. Additionally, they also inversed the color of the "HIGHWAY PATROL" lettering on the rear, displaying it as white letters on a rectangular blue decal instead of blue letters on a white-body vehicle, thus creating a "billboard effect." The DPS added contour markings on the sides of marked vehicles to silhouette the outline of the vehicle, enhancing existing retroreflective stripes and side decals. A blue stripe on the traditional white vehicle was added to the vehicles' markings. Figure 1 is an example of how the changes made to Arizona DPS vehicle markings appear in daytime and nighttime conditions, circa early 2000's. These changes were fairly significant for a law enforcement agency, particularly a state agency where tradition is a strong barrier to change. The impact of the change illustrated by these photos is readily apparent to both the practitioner and the layperson.


**Figure 1. Comparison of conspicuity of "new" vs. "old" retroreflective vehicle markings on the rear of Arizona Highway Patrol cruisers. Image from the National TIM Training Program (Rev 7/13). *Photo Credit: Federal Highway Administration.***

[11] *Staff Study 2004.* Law Enforcement Stops and Safety Subcommittee, International Association of Chiefs of Police, 2004.

In 2016, the ADPS made dramatic changes to their vehicle color scheme, forgoing the traditional white with blue markings for silver with reflective black markings.[12] Extensive use of contrasting color on the sides and the addition of the bold "STATE TROOPER" further the objective of making the vehicle conspicuous. The DPS noted that the black markings on the vehicle have significantly higher retroreflectivity when compared to the blue decals they replaced, because the blue was actually dyed into white material to achieve the exact color used by the agency. The side silhouette feature was carried over from the former design; however the application is now on the body of the vehicle instead of on the molding, due to durability issues. The large diagonal reflective stripe on the side of the vehicle diminishes the need for the silhouette outline, but the concept endures because of its value to making the side profile more visible at night.

Black and white chevrons on the rear continue the enhancements from the earlier modifications, including the "billboard effect." The white and black combination creates contrast, which is a fundamental element of conspicuity. As with all other markings on the vehicle, these decals are also retroreflective. Because some sport utility vehicles have a larger rear-facing surface, the agency uses stacked chevrons in these cases to create a larger conspicuity marking.

The red and blue emergency light bar on top of the vehicle is complemented with an amber arrow stick. The bottom surface of the rear liftgate is equipped with red and blue emergency lights so that, when opened, those lights are rear-facing. This compensates for the rear liftgate obscuring the top lights. The lighting system is equipped with a sensor that dims the intensity of the lights during nighttime conditions. As with most lighting systems, forward facing lights can be turned off as a traffic incident management strategy to reduce opposite direction traffic delays due to bright white lights affecting vision. Figure 2 is a photograph of the 2016 ADPS vehicle markings.


**Figure 2. Arizona DPS 2016 vehicle markings.** ***Photo credit: Arizona State Troopers Association.***

[12] Fernandez, Craig. "DPS Evolves with New Branding and a New Image." *Arizona State Troopers Association*, 1 July 2016.

More modern examples of changes to vehicle markings are seen in the plethora of police, fire, EMS, towing, and transportation agencies that are now introducing conspicuity elements into vehicle markings. Vehicle markings are known as passive treatments that augment emergency vehicle lighting. Many examples of the application in law enforcement, towing, and safety service patrols are being implemented across the country. The National TIM Responder Training Program includes several examples of different approaches to encourage their application.[13]


**Figure 3. Examples of emergency vehicle markings form the Florida version of the National TIM Training Program.** ***Photo credit: Federal Highway Administration.***

## Massachusetts State Police

In 2010, five Massachusetts state troopers were struck by vehicles while on duty in a five-week period of time. One of those troopers was killed in the line of duty after being struck by a vehicle while he was sitting inside a patrol car during a traffic stop on the side of Interstate 95.[14]

In response to those crashes, the Massachusetts State Police (MSP) initiated a review of safety procedures, equipment and policies to determine what could be done to improve the safety of troopers working roadway incidents. That review included an analysis of the emergency warning lights on MSP patrol vehicles and testing the addition of reflective tape placed in strategic locations on test vehicles.[15]

---

[13] "National Traffic Incident Management Training." Federal Highway Administration. Mar. 2017.

[14] Potter, Erik. "In Wake of Taunton Crash, State Police Seek Ways to Improve Trooper Safety." *Taunton Daily Gazette*, 23 July 2010.

[15] Marsh, Stephen. "Roadside Safety: Retro-Reflective Cars and Auto-Dimmed Lightbars." *Police Fleet Manager*, Hendon Media Group, 2011.

The testing included modified warning lightbars that allowed for low power to reduce the intensity of LED lights in the bar and different flash patterns than what had been used traditionally. Those two features allowed the lightbar to be dimmed and the flash rate to be reduced, which helped make the patrol car profile more visible because approaching motorists faced far less glare from the warning lights when they were at these lower and slower settings. Those changes made it easier for other motorists driving near the patrol car to see troopers walking and working around the patrol vehicle.[16]

Additional testing of retroreflective tape installed on test vehicles demonstrated improved nighttime conspicuity of the patrol vehicles. Motorists were able to better discern the profile of the patrol vehicle at nighttime with the addition of the retroreflective tape.[17]

Since that earlier testing and experimentation, MSP has adopted a set of conspicuity changes for their patrol vehicles. Patrol vehicles now have lightbars equipped with blue LEDs, ambient light sensors, and the ability to display “steady burn” flash patterns at night. The ambient light sensors automatically determine the amount of ambient light available at any given time and then automatically adjust the intensity of the warning lights and the frequency of the flash pattern. The daytime flash rate is 75 flashes per minute. The night mode or low power setting is 82% less than the daytime setting and there is a three second delay between the flickers of the steady flash pattern.

MSP has also added high visibility, lime-green retroreflective tape on the inside of the driver door, passenger doors, and rear hatch that is visible when the doors are in the open position.

---

[16] Marsh, Stephen. “Roadside Safety: Retro-Reflective Cars and Auto-Dimmed Lightbars.” *Police Fleet Manager*, Hendon Media Group, 2011.

[17] Marsh, Stephen. “Roadside Safety: Retro-Reflective Cars and Auto-Dimmed Lightbars.” *Police Fleet Manager*, Hendon Media Group, 2011.

Figure 4: Retroreflective tape inside emergency vehicle doors and liftgate. *Photo credit: Massachusetts State Police.*

White retroreflective material has been added to the exterior of the rear of the vehicle in a mini-chevron pattern.


Figure 5: White retroreflective material in a chevron pattern on the rear of an MSP vehicle. *Photo credit: Massachusetts State Police.*

Graphic markings on the sides of the vehicles are now also retroreflective.


**Figure 6: Side markings of MSP vehicles are retroreflective.** ***Photo credit: Massachusetts State Police.***

A thin strip of retroreflective material has been added around the front bumper, sides, and rear bumper of the vehicles.


**Figure 7: Thin strip of retroreflective material is visible above the front bumper of this MSP vehicle.** ***Photo credit: Massachusetts State Police.***

Results of the changes to date have been positive and the enhanced conspicuity features have been implemented on the majority of the fleet.

## Florida Highway Patrol

The Florida Highway Patrol evaluated a number of potential lighting system changes in 1999. That evaluation resulted in adopting a number of changes to the emergency vehicle lighting systems on their fleet in 2005.[18] Notable changes to the lighting system included the addition of the color red to their traditionally all-blue lighting system. Blue light is more effective at night and red during daylight,[19] except for atmospheric conditions like smoke, haze, and fog, where red is more efficient because it, "scatters less, travels farther, and retains greater intensity at a distance than blue light".[20] In addition, FHP adopted the use of a sensor to determine daytime and nighttime ambient light and trigger different light intensity and the selective use of either red (daytime) or blue (nighttime) accordingly. Later, the agency chose to forego the use of only red during the day and only blue during the night to maximize the available lighting options, choosing instead to display red and blue during all periods. The agency did maintain a "red override" switch to display all red during smoke, fog, and haze. Different flash patterns were implemented for moving and stationary modes, and the agency policy was to equip all vehicles with a rear deck amber arrow stick for directional warning display. Separating the amber arrow from the red and blue emergency light was viewed as a way to enhance the visibility of the directional arrow. In addition to the traditional ability to extinguish forward facing emergency lights, the agency also included a similar feature that allowed for rear-facing emergency lights to be selectively turned off.

The lighting system changes that were implemented by the FHP have served the agency well for more than a decade. With the refresh of lighting equipment in July 2017, the FHP has revisited some of the changes resulting from their 1999 lighting study. Advances in emergency vehicle lighting technology continue to allow the agency to explore new ways to maximize safety. There remains a strong sentimentality to the uniqueness that the agency enjoyed among Florida police agencies when using only blue and white lights on their top lightbar. To distinguish itself among more than 400 Florida police and sheriff's agencies that largely employ red and blue lights, the FHP chose to revert to an emergency vehicle lighting system that predominantly uses blue and white. Because the new lighting systems are more efficient, the agency believes that integrating lights that display predominantly blue and white will not cause a loss of effectiveness. Wig-wag red lights were maintained in the taillight systems of the vehicles, along with a red flashing halo at the rear of the vehicle, which extends to the full width of the vehicle. In addition, the next generation lighting system is based on technology that will allow for more red lights via software changes, should the agency choose to do so. The agency has maintained the use of an amber arrow stick in the rear deck. FHP has added additional lighting to the side skirt of its vehicles consisting of blue flashing lights and solid white lights when activated for nighttime visibility.

The latest lighting technology also allows programming with the vehicle's factory lighting systems. This feature allows the vehicle's rear deck bar to display red lights when the driver applies the brakes. The vehicles also now display red lights on either side of the license plate when the brakes are applied.

---

[18] Wells, Jim. "Florida Highway Patrol Experimental Lighting Study." *Police Fleet Manager*, Hendon Media Group, 2005.
[19] Garber, J., & Patel, S. T. (1992). The effect of trailer width and length on large-truck crashes. Charlottesville: Virginia Transportation Research Council.
[20] *A Policy on Geometric Design of Highways and Streets.* 6th ed., American Association of State Highway Officials, 2011.

Since the 2005 lighting changes, the FHP added passive rear conspicuity markings to complement its emergency lighting package. The FHP began using *NFPA 1901*-type markings on patrol vehicles in the spring of 2013. All new marked patrol vehicles were equipped with red and high visibility yellow-green chevrons on the rear bumper. The sides of the vehicles were treated with black reflective tape that matched the body color of the vehicle during daytime, but is highly reflective at night. The FHP was the first state law enforcement agency to implement the use of high visibility markings that comprised all three elements of conspicuity: contrasting colors, fluorescent colors, and retroreflective material. Side "silhouette" markings are still being applied to the vehicle.

FHP sedans were marked with the red and high visibility yellow-green chevrons until 2017, when the agency decided to reduce markings on sedans. Marked sedans now use "subdued" chevrons on the rear bumper, which are retroreflective but keyed to match the body color of the vehicle (chevrons are black when not illuminated and gold when illuminated). Figure 8 shows the black appearance of the chevrons in daytime. The change means the agency marking strategy for sedans no longer employs contrasting or fluorescent colors; however the added conspicuity remains for nighttime settings. The recent reversion to predominantly blue lighting and subdued chevrons by FHP on sedans demonstrates the strong role that tradition plays among law enforcement agencies. This is probably true with law enforcement more than any other responder discipline because the agencies are steeped in history and the unique identity that agencies have in their community.


**Figure 8: "Subdued" chevrons on the rear bumper of a Florida State Patrol sedan.** ***Photo credit: Grady Carrick.***

According to the agency, Florida Highway Patrol SUV markings continue to use the original red and high visibility yellow-green chevron markings because of the daytime these vehicles spend on roadway shoulders performing activities like commercial motor vehicle inspection/enforcement, traffic homicide investigations, and contraband interdiction. Figure 9 is an example of the current FHP markings on SUVs.

On SUVs, these markings were applied to the liftgate, as well as on the utility box inside the rear compartment for when the door was open. Inside-mounted emergency lights are visible from the rear in both the closed and open positions.


**Figure 9: Florida Highway Patrol SUV with conspicuity markings inside and outside the liftgate.** ***Photo credit: Florida Highway Patrol.***

## NYPD Highway Patrol

The NYPD Highway Patrol Unit has used an elevated lighting system for several decades. The multi-level vehicle lights are a fixture on NYPD Highway Patrol vehicles and their use is considered an integral part of their vehicle emergency lighting approach. NYPD officers commonly refer to the lights as “high-rise” lights, and when elevated, they are best described as lighted football goal posts on top of the cruiser. At rest, they are poles that sit on the vehicle roof, behind and parallel to the top light bar. Hinged at the outside edges above the “B pillar,” the motorized system elevates the 58-inch light poles to a vertical position above each “B pillar.” The multi-level units have multiple LED lights on the front and rear of each arm. The systems have been used by the NYPD for decades, and are also popular with other law enforcement agencies, as well as in applications on fire and EMS SUVs, utility vehicles, and some federal law enforcement vehicles.

The concept of the multi-level or high-rise light system is to create visible lights from a farther distance as vehicles approach, essentially enhancing the advance warning to approaching motorists. By moving emergency lights higher from the vehicle and ground, they can also be seen in situations where other response vehicles may obstruct the view of lights that are mounted lower, or where the vehicle trunk lid or SUV liftgate might obscure the lights when opened. The lights are particularly effective where vertical

curves in the roadway or a complex roadside environment make distinguishing a traditional emergency lighting system difficult. Figure 10 is a photograph of the multi-level lighting system used by the NYPD.


**Figure 10: Multi-level or high-rise lighting system in deployed mode.** ***Photo credit: Richard Pepe, NYPD Retired.***

The New York State Police have started assigning personnel to New York City and have followed suit by equipping vehicles with high-rise units. They look and function identically to the NYPD units, but are provided by a different manufacturer. The high-rise system used by the NYSP is integrated with, not separate from, the top light. In addition, the lighting system is integrated with the vehicle electronic systems to detect when the vehicle is placed in gear so that a warning can be given to the driver when the unit is in the upright position.

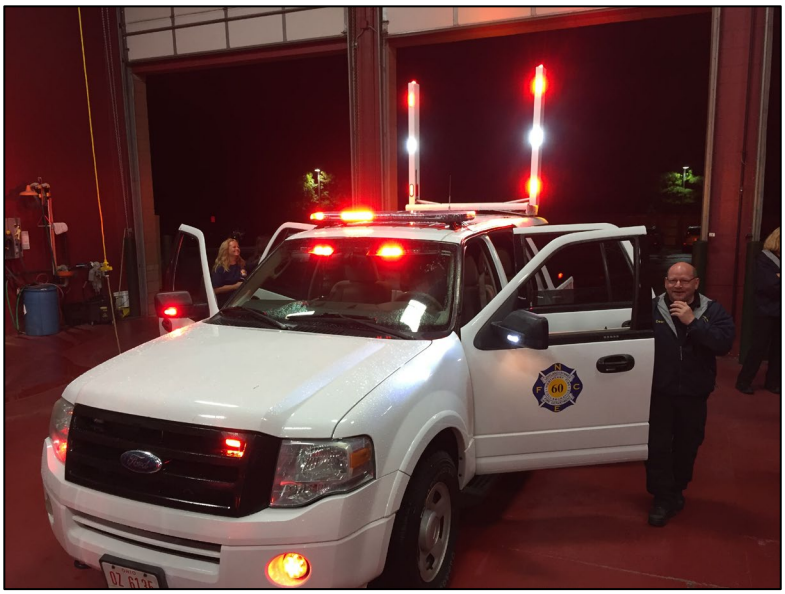

**Figure 11: Another example of a high-rise light bar, this one on a vehicle from the Loveland-Symmes Fire Department.** ***Photo credit: Loveland-Symmes Fire Department.***

## Examples of Innovative Fire Service Apparatus Emergency Lighting and Conspicuity Features for Roadway Incident Scene Safety

### Grand Rapids Fire Department

In August 2011, the Grand Rapids, Michigan Fire Department (GRFD) unveiled a new fire apparatus identified as "Utility 2." Utility 2 is a dump truck originally used by the Grand Rapids Water Department that was modified specifically to assist the fire department with temporary traffic control at roadway incidents. The fire department modified the truck and placed it in service after three separate fire apparatus were struck by vehicles within a short period of time while parked at different traffic incidents along the highway. The estimated damage to those fire apparatus equated to around $150,000 for repairs, in addition to the rigs being out of service for an extended period of time.

**Figure 12: Front and back views of GRFD Utility 2.** ***Photo credit: Grand Rapids Fire Department.***

Utility 2 was equipped with emergency warning lights, high visibility chevrons on the rear, a full size arrow board, and a paint job to match other GRFD fire apparatus. The Michigan Department of Transportation funded an attenuator trailer for the truck so it could be used as a blocking unit[21] at roadway incident scenes. The unit provides the initial block and advance warning before motorists approach fire apparatus working the actual emergency. The large arrow board is especially effective at helping motorists understand which way they have to go to pass the incident scene safely. The attenuator trailer has been struck several times with minimal damage. Since being put in service, Utility 2 has responded to hundreds of roadway incidents each year at the same time fire and EMS units are dispatched to emergency incidents on the highways in the city. The unit has been successful in protecting incident scenes and preventing distracted motorists from striking firefighters or fire apparatus at the incident scenes where it has been deployed.[22]

## City of Wyoming, Michigan

In February 2018, the City of Wyoming, Michigan unveiled a new traffic control vehicle modeled after the Grand Rapids FD Utility 2. The City of Wyoming was able to repurpose a city dump truck that had reached the end of its service life as a dump truck. It was modified with funding obtained through a grant and equipped to provide advance warning and blocking at traffic incident scenes. The Michigan Municipal Risk Management Authority provided a $20,000 grant to fund the project.[23]

City of Wyoming "Utility 3" is dispatched to emergency scenes at highway incidents to establish a physical block to protect emergency responders and vehicles working various types of incidents. It is equipped with warning lights, siren, flashing traffic arrow, temporary traffic control devices and an attenuator device on the rear to absorb the force of any striking vehicle. The primary purpose of the unit

[21] A blocking unit positions upstream of a roadway incident scene across closed lanes of traffic to provide a protected work area for responders.

[22] Tunison, John. " Grand Rapids Fire Department Unveils Truck to Block Freeway Traffic, Absorb Potential Crashes." *MLIVE*, 1 Aug. 2011.

[23] "Retired City of Wyoming Dump Truck Sees New Life as Crash Attenuator." *City of Wyoming, MI*, 13 Feb. 2018.

is to protect personnel and emergency vehicles from being struck by distracted drivers approaching incident scenes.


**Figure 13: Front and back views of City of Wyoming Utility 3.** ***Photo credit: City of Wyoming, Michigan.***

## Irving Fire Department

In October 2017, the Irving Fire Department in Texas deployed the first of several repurposed fire apparatus as "blocker" units for the purpose of protecting emergency responders and vehicles at roadway incident scenes. Again, the Irving FD implemented the idea after experiencing nine struck-by-vehicle incidents involving fire apparatus over a five year period. In one case, an Irving FD ladder truck that was blocking at a crash scene was struck by a tractor trailer traveling at highway speeds. The truck overturned and was totaled and the driver of the striking vehicle was killed in the secondary crash.

The first two "blocker" trucks were deployed with some modifications from their original use as front line fire engines. Although the units still carry water in the tanks to add weight, [24] all firefighting equipment was removed from the apparatus and large amber traffic arrow devices were installed on both sides of the trucks and on the rear. The large arrow devices on the sides of the units help drivers approaching an incident to see the unit from a distance when it is parked on an angle as a blocking unit. Additionally, other temporary traffic control devices are stored on the unit including cones and flares to help direct traffic around the incident scene.

[24] Matthews, Peter. "Texas Department Places 'Blocker' Apparatus in Service." *Firehouse*, 17 Jan. 2018,


Figure 14: Views of Irving Fire Department "Blocker" 3. *Photo credit: Firehouse.com*

In the future, the City of Irving plans to deploy a blocker unit from each of the five fire stations that house ladder trucks. When dispatched to an emergency, one of the personnel assigned to the ladder company will drive the blocker unit to the incident and position it as a blocking vehicle. That operator then joins up with the ladder crew for the duration of the incident.

The procedure of parking large fire apparatus on an angle in advance of an incident scene is standard practice in most areas of the country and is a tactic taught as part of the Federal Highway Administration Strategic Highway Research Program 2 Traffic Incident Management & Responder Safety Training Program that is being deployed nationwide. Although it is not common to see large arrow deices on the sides of fire apparatus, the units in Irving will help demonstrate their effectiveness during the early stages of traffic incidents when it is sometimes difficult for local transportation agencies to respond quickly with work zone trucks and temporary traffic controls.

## Montgomery County, Maryland Fire and Rescue Service

In Montgomery County, Maryland Fire and Rescue Service (MCFRS), some fire apparatus have arrow devices installed on the sides of the rigs for improved visibility to oncoming traffic when parked at an angle at traffic incidents.


**Figure 15: MCFRS apparatus outfitted with an arrow board on the side of the vehicle (at left of photo above the county lettering).** ***Photo credit: Montgomery County (MD) Fire and Rescue Service***

For arrow devices installed on the back of fire apparatus, it is recommended to mount the arrow device as high as possible on the back of the rig, preferably above the hose bed on pumpers. By mounting the arrow device up high, it allows approaching vehicles to see it from a farther distance and the chances of the arrow board being obscured by hose or other equipment is reduced.


**Figure 16: Arrow bar mounted high on the rear of a fire apparatus.** ***Photo credit: Jack Sullivan.***

## Other Departments

Some fire departments in various geographic areas of the country have fire police officers whose job is traffic and crowd control at emergency incident scenes. Some of those fire departments have provided specialty vehicles for their fire police that are equipped with various kinds and quantities of temporary traffic control devices like traffic cones, flares, advance warning signs, and either large arrow boards or variable message signs.


**Figure 17: Rear and side views of a fire police vehicle from Aetna Hook & Ladder Company (Newark, Del.). *Photo credit: Jack Sullivan.***


**Figure 18: Rear view of a Gettysburg Fire Department (Penn.) fire police vehicle. *Photo credit: Jack Sullivan.***

Some fire departments have had success applying for and receiving Department of Homeland Security Federal Emergency Management Agency Assistance to Firefighters Fire Prevention & Safety Grant support for covering the cost of adding high visibility chevrons on in-service fire apparatus, traffic arrow

boards, temporary traffic control devices, and high visibility personal protective equipment. Fire departments that are looking for ways to improve roadway incident scene safety would do well to prepare and submit grant applications to help fund those types of improvements.

Fire departments are taking a more active role in providing resources (e.g., specialty vehicles, temporary traffic control devices, and personnel) for advance warning of incidents ahead for motorists, temporary traffic control devices at incident scenes, and guidance for motorists on which way to go in order to safely navigate past an incident scene.


**Figure 19: Livonia (MI) Fire & Rescue vehicle outfitted with a high-mounted arrow board for traffic control.** ***Photo credit: Livonia (MI) Fire & Rescue.***

Three fire departments report they are now using portable speed bumps to help manage traffic speeds at incident scenes. The Tigerville Fire Department in Greenville County, South Carolina now deploys portable speed bumps to get traffic to slow down while passing by roadway incidents.[25] The North Charleston, South Carolina and Woolwich, Maine fire departments are using similar equipment to manage traffic at incident scenes.[26] Experience to date has been very positive. It's important to note that the portable speed bumps are generally designed for traffic speeds below 45 miles per hour.

[25] Smith, Nickelle. "Speed Bumps Slow Traffic for Roadside Emergency Crews." *WSPA 7 News*, 3 July 2017.
[26] Woolwich Fire/Rescue. Post with video of portable speed bumps in use to slow down traffic at emergency incident scenes. *Facebook*, 31 May 2017.

# Conclusions

Drawing together the many study and experience-based findings highlighted in this report, we have made the following conclusions.

## Emergency Lighting

- Due to state statutes and regulations, the color, intensity, and flash patterns of emergency lights differ widely across states.
- Tradition can be a barrier to change.
- Yellow/amber warning light color alone is not sufficient to indicate all hazards to drivers. Red and blue light combinations were more effective in prompting drivers to move over.
- Red warning light color is more effective in daytime and during times of smoke and fog.
- Blue warning light color is more effective during times of darkness.
- 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).
- For best visibility to drivers, upper level warning lights should be mounted as high and as close to corner points as practical, but not higher than the maximum height recommended by the manufacturer. Lower level lights should be mounted with the optical center of the device between 18 and 62 inches above ground level.
- Outfitting emergency vehicles with lit amber/yellow arrow sticks has been used to good effect by several departments.

## Vehicle Conspicuity

- Retroreflective materials, contrasting colors, and fluorescent colors are the hallmarks of strong conspicuity.
- Large marking elements like lettering are more conspicuous than small elements, especially when retroreflective.

- Cream, white, and yellow are the most visible colors in the highway environment and are therefore strong choices for emergency vehicle body colors.
- Conspicuity markings on the rear of vehicles, particularly rear chevrons and retroreflective elements, are of paramount importance. Side markings, including contour markings, are also important as emergency vehicles are often parked at an angle for blocking purposes.
- Use of high visibility apparel prompts drivers to give pedestrians greater clearance; where warning lamps had no impact.
- Retroreflective markings inside vehicle surfaces that are exposed to view when opened, such as doors and liftgates, improve conspicuity when these compartments are open.
- Multiple departments have created specialty large blocking and advance warning units from de-commissioned large vehicles like dump trucks and fire apparatus. These units include emergency lighting, arrow boards, and conspicuity measures.
- Departments should consider using a combination of emergency lighting and conspicuity measures in tandem, as each compliments the other.

# Recommendations

## Emergency Lighting

- 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.
- Policymakers should consider standardization of emergency lighting conventions across states, as today’s mobile society means drivers are constantly crossing state lines and may not be familiar with the emergency lighting conventions in the state where they are traveling.
- Choices in emergency lighting and vehicle conspicuity should be driven by research and proven practices, not tradition and aesthetics.
- Department policy should:
    - Provide for training of personnel in emergency lighting package capabilities and usage
    - Direct personnel to:
        - use emergency lights to provide warning and promote move over behavior
        - reduce forward-facing lights to mitigate opposite direction distractions and delays, as well as minimize potential blinding effects for oncoming motorists
        - only display lights on vehicles blocking travel lanes and/or only on the rear-most vehicle when multiple vehicles are on the shoulder when multiple responder vehicles are on the scene

- Within the constraints of legal limitations in your state, having a lighting package that includes both use of red and blue lights is beneficial as it enables you to use red lights for daytime and low visibility conditions (e.g.: smoke, fog) and blue for nighttime.
- 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.
- White lights facing drivers should be extinguished or repositioned to point downward.

## Vehicle Conspicuity

- Law enforcement should focus efforts on the rear of marked vehicles and they should employ all three elements of conspicuity, contrasting colors, florescent colors, and the use of retroreflective materials.
- All responder vehicles should maximize visibility using side markings and decals that are contrasting and retroreflective, as well as red and yellow or red and yellow-green conspicuity markings on rear vertical surfaces.
- Chosen markings should contrast with vehicle body color.
- For best vehicle body visibility, choose white, cream, or yellow paint color.
- Other responder vehicle types (safety service patrols, towing, transportation, and others) should employ vehicle markings on the rear of vehicles, attached equipment, and/or utility boxes or beds.
- The interior of vehicle openings such as doors, liftgates, and tailgates should be marked for conspicuity with retroreflective contrasting-color elements, particularly when opening these doors obscures other lights or markings.
- Fire vehicles should follow the conspicuity requirements of *NFPA 1901* and ambulances should follow *NFPA 1917* or other accepted standard.
- Personnel should always wear ANSI-compliant high visibility apparel when working at emergency scenes.

- Departments should consider creating special blocking units out of heavy vehicles and outfit them with conspicuity measures, arrow boards, traffic control devices, and emergency lighting.

Forward-thinking departments, many of whom had one of their personnel struck at a roadway incident response, have undertaken extensive reviews of their emergency lighting and vehicle conspicuity designs. These reviews have resulted in the adoption of many new measures like those recommended here that have improved visibility, and include use of reflective tape, light bars with a low power setting, adjustable flash patterns, high visibility chevrons in contrasting colors, arrow boards, high-rise or multi-level lighting rigs, ambient light sensors, automatic adjustment of lighting based on an input like sensor readings or parking brake position, and having both red and blue lights available.

In conclusion, many opportunities for future research exist, including studying emergency vehicle crashes to distinguish differences between vehicles with or without conspicuity markings, further research on lamp characteristics (color, intensity, flash pattern) to determine the best visibility choices and combinations, testing of different flash patterns based on operating mode to determine the optimal choices under different conditions and situations, and studying how changes in lighting and conspicuity by departments have affected struck bys, crashes, and driver perceptions.

# References

*A Policy on Geometric Design of Highways and Streets*. 6th ed., American Association of State Highway Officials, 2011.

Carrick, Grady, and K. Spears. "Enhancing Rear-Approach Conspicuity of Police Vehicles." Florida Highway Patrol White Paper. 10 March 2013.

Carrick, Grady, and Scott Washburn. "The Move Over Law: Effect of Emergency Vehicle Lighting on Driver Compliance on Florida Freeways." *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2281, 2012, pp. 1–7.

*Emergency Vehicle Visibility and Conspicuity Study*. U.S. Fire Administration. Federal Emergency Management Agency. U.S. Department of Homeland Security, 2009, *Emergency Vehicle Visibility and Conspicuity Study*, www.usfa.fema.gov/downloads/pdf/publications/fa_323.pdf.

Fernandez, Craig. "DPS Evolves with New Branding and a New Image." *Arizona State Troopers Association*, 1 July 2016, aztroopers.org/enews/dps-evolves-with-new-branding-and-a-new-image.

Flannagan, Michael J, et al. *Effects of Warning Lamp Color and Intensity on Driver Vision.* . SAE International, 2008, www.sae.org/standardsdev/tsb/cooperative/warninglamp0810.pdf.

Garber, J., & Patel, S. T. The effect of trailer width and length on large-truck crashes. Charlottesville: Virginia Transportation Research Council. 1992.

Gibbons, Ronald B, et al. *Selection and Application of Warning Lights on Roadway Operations Equipment*. National Cooperative Highway Research Program, 2008,*Selection and Application of Warning Lights on Roadway Operations Equipment*.

*LESS Wants More Safe Traffic Stops*. Law Enforcement Stops and Safety Subcommittee, International Association of Chiefs of Police, www.theiacp.org/Portals/0/pdfs/LESS/ACF29B.pdf.

Marsh, Stephen. "Roadside Safety: Retro-Reflective Cars and Auto-Dimmed Lightbars." *Police Fleet Manager*, Hendon Media Group, 2011, www.hendonpub.com/police_fleet_manager/articles/2011/1112/roadside_safety_retro_reflective_cars.

Matthews, Peter. "Texas Department Places 'Blocker' Apparatus in Service." *Firehouse*, 17 Jan. 2018, www.firehouse.com/apparatus/type/pumper/article/12391030/irving-fire-dept-adds-blocker-fire-apparatus-for-roadway-safety-firefighter-news.

"National Traffic Incident Management Training." Federal Highway Administration. Mar. 2017.

*NFPA 1901: Standard for Automotive Fire Apparatus*. 2016 ed., National Fire Protection Association, 2016.

*NFPA 1917: Standard for Automotive Ambulances*. 2016 ed., National Fire Protection Association, 2016.

Potter, Erik. "In Wake of Taunton Crash, State Police Seek Ways to Improve Trooper Safety." *Taunton Daily Gazette*, 23 July 2010, www.tauntongazette.com/article/20100723/News/307239236.

Potter, Scott. Email received by Jack Sullivan, 4 Dec. 2017.

Potter, Scott. "Police Vehicle Warning Signals — An Innovative Approach to Officer Safety." *Police Chief Magazine*, 2 May 2018, www.policechiefmagazine.org/warning-signals-officer-safety/.

"Retired City of Wyoming Dump Truck Sees New Life as Crash Attenuator." *City of Wyoming, MI*, 13 Feb. 2018, www.wyomingmi.gov/About-Wyoming/News/ID/147/Retired-City-of-Wyoming-Dump-Truck-Sees-New-Life-as-Crash-Attenuator.

Smith, Nickelle. "Speed Bumps Slow Traffic for Roadside Emergency Crews." *WSPA 7 News*, 3 July 2017, www.wspa.com/news/speed-bumps-slow-traffic-for-roadside-emergency-crews_20180102082504460/896743881.

*Staff Study 2004*. Law Enforcement Stops and Safety Subcommittee, International Association of Chiefs of Police, 2004, www.theiacp.org/portals/0/pdfs/LESSSManualScreenQuality.pdf.

Tunison, John. "Grand Rapids Fire Department Unveils Truck to Block Freeway Traffic, Absorb Potential Crashes." *MLIVE*, 1 Aug. 2011, www.mlive.com/news/grand-rapids/index.ssf/2011/08/grand_rapids_fires_freeway_blo.html.

Ullman, Gerald L, and Don Lewis. "Texas DOT Vehicle Fleet Warning Light Policy Research." TRB Transportation Research E-Circular E-C013. onlinepubs.trb.org/onlinepubs/circulars/ec013/1cullman.pdf.

Wells, Jim. "Florida Highway Patrol Experimental Lighting Study." *Police Fleet Manager*, Hendon Media Group, 2005, www.hendonpub.com/police_fleet_manager/articles/2011/1112/roadside_safety_retro_reflective_cars.

Woolwich Fire/Rescue. Post with video of portable speed bumps in use to slow down traffic at emergency incident scenes. *Facebook*, 31 May 2017, https://www.facebook.com/Woolwichfire/videos/1498944640125663/. Accessed 19 April 2018.