Proposed Updated Language: AASHTO Guidelines for the Selection and Application of Vehicle Markings and Warning Lights on Roadway Operations Vehicles and Equipment

**Introduction**

Vehicle- and equipment-mounted warning lights and retroreflective markings are important tools for attracting driver attention and eliciting safe driving behavior while approaching and passing work activities on or near roadways. In certain situations, the markings and lights provide supplemental information to an overall temporary traffic control (TTC) system deployed at the site; while in other situations, the markings and lights themselves are the primary components of the TTC system. Whereas the retroreflective markings and warning lights must attract attention and convey clear information to motorists, they must also not interfere with driver abilities to detect and recognize any other TTC devices at a site nor inhibit driver ability to perceive workers or other pedestrians who may be present on foot in and around the work activity.

Traditionally, amber has been the primary warning light color used on roadway operations vehicles and equipment. However, more and more agencies have begun using other colors in addition to amber on certain types of vehicles and equipment when such usage has not violated state law. Advancements in light-emitting diode (LED) technology now allows warning light manufacturers to offer a multitude of flash patterns and colors to choose from. Options also exist for retroreflective markings with regards to colors, patterns, type and amount of material used, and the location of its placement on the vehicles or pieces of equipment.

These guidelines have been developed to aid agencies and companies in selecting and using retroreflective markings and warning lights on their roadway operations vehicles and equipment. The guidelines are based on results of multiple human factors and observational field studies. These research results indicate that there is not a single set of vehicle markings and warning light attributes that will work best for all roadway operations vehicles and pieces of equipment. Rather, the vehicle marking and warning light attributes need to be tailored to the operating conditions, work activities, and safety risk factors under which they will be used. Conditions to be considered when determining the marking and warning light attributes to use include the following:

* Will workers or pedestrians on foot typically be located around the vehicle or piece of equipment? Certain marking and warning light attributes reduce driver abilities to quickly detect those workers or pedestrians.
* Will the vehicle markings and warning lights be the main TTC devices first encountered by approaching motorists, or will other TTC devices (signs, channelizing devices, etc.) be present to provide positive guidance to approaching motorists?
* Related to the previous bullet, will the vehicle sometimes be located in a travel lane as the first warning device presented to approaching drivers, such as for service patrol or incident response activities?

Although vehicle and equipment color have an influence upon driver abilities to detect and recognize them in an overall visual environment, recommendations on vehicle or equipment color are not included in these guidelines. Vision science indicates that colors that contrast the most with other vehicles or surroundings will be more easily detectable than those that are similar to other vehicles in the traffic stream or with their surroundings (e.g., a green vehicle in a rural environment with significant roadside greenery present). Given that popular vehicle colors tend to change over time, as does the overall visual environment where roadway operations vehicles and equipment are used, it is not realistic to identify a single vehicle or equipment color to recommend. In addition, past research has not shown a single vehicle color to have significant safety benefits relative to other colors.

**Effectiveness of Retroreflective Marking and Warning Light Attributes**

**Retroreflective Markings**

Retroreflective vehicle markings increase the conspicuity of roadway operations vehicles and equipment. Evidence suggests that drivers also learn over time to associate certain markings with certain work activities. For example, yellow and black inverted V markings are typically associated with roadway construction and maintenance vehicles and activity. Markings that differ from what drivers commonly encounter (and thus expect to see) will naturally attract more attention than markings that are commonly encountered. However, research also suggests that making markings too salient can adversely affect driver ability to quickly detect and recognize the presence of workers, pedestrians, or other nearby hazards during daytime viewing conditions. Compared to a typical yellow and black inverted V pattern, use of a checkerboard (i.e., Battenburg or half-Battenburg) pattern and/or the use of red and white marking colors resulted poorer recognition of a worker.

Retroreflective vehicle markings do not have the same attention-getting capabilities as flashing warning lights. However, the presence of retroreflective markings on a roadway operations vehicle has been shown to improve driver perception of the visibility of workers on foot and the roadway operations vehicle at night compared to no vehicle marking conditions. In addition, the presence of retroreflective markings reduces driver perceptions of discomfort glare at night created by flashing warning lights. It appears that the retroreflected light from the markings helps to “soften” the contrast between warning lights and the dark background, making the overall visual scene easier to view by approaching drivers.

**Warning Lights**

During daytime viewing conditions, emphasis is on having enough photometric output from the warning lights to make the roadway operations vehicle or equipment conspicuous to approaching drivers. However, at night, excessive glare that inhibits driver abilities to see the work activity, workers or other pedestrians on foot, or other hazards is the primary concern. Vehicle- and equipment-mounted warning light manufacturers utilize warning light classifications based on Society of Automotive Engineers (SAE) recommended practices for flashing optical warning devices. SAE specifies minimum optical power requirements (the integration of the luminous intensity of the light over a 60 second period) measured in units of candela-seconds per minute and peak luminous intensity requirements (measured in candela) for white, amber (yellow), blue, and red colored lights. SAE Class 1 warning lights are intended for use on authorized emergency vehicles responding to emergency situations, whereas Class 2 warning lights are intended for authorized maintenance or service vehicles to warn of traffic hazards. However, many agencies utilize Class 1 warning lights on their maintenance or service vehicles.

Drivers associate greater numbers of warning lights flashing on a vehicle or piece of equipment with increased urgency or level of hazard of the work activity in which the vehicle or equipment is participating. At the same time, higher levels of aggregate light intensity and optical power are associated with significant or severe discomfort glare ratings by drivers when viewed at night. Fortunately, controllers for most LED warning light systems now come with light dimming capabilities (i.e., pulse width modulation) for nighttime operations.

Amber only or amber and white is the most common warning light color used for most roadway operations vehicles and equipment. Most jurisdictions limit by law the use of certain warning light colors (typically red and blue) on vehicles to authorized emergency vehicles, although a few states allow one or more of those colors to also be used on certain roadway operations vehicles. Use of other colors in addition to amber on roadway operations vehicles and equipment increases driver perceptions of urgency or level of hazard being approached. For this reason, some agencies have incorporated green (a color not typically regulated by law) with amber warning lights on certain roadway operations vehicles and equipment. Drivers rate green and amber lights as somewhat more distracting and causing more discomfort glare than the same number of amber lights. In addition, studies indicate that use of amber and green lights in combination with a fast flash speed reduces driver abilities to correctly identify the arrow indication being displayed on an arrow board at night. In contrast, field studies verified that drivers react more significantly to multi-colored than to amber only lights, reducing their speed traveling past a work vehicle and being slightly more likely to move over a lane if available.

Warning light flash speed is another attribute that has competing consequences on drivers. Drivers rate arrow board visibility at night poorer when viewed in the vicinity of a faster warning light flash speed (2.5 Hz) as compared to a slower (1.25 Hz) flash speed, most likely because the faster flash speed is much different than the speed of the arrow board flashes and attracts more attention away from the arrow board display. A fast flash speed also results in higher ratings of distraction and discomfort glare compared to a slow flash speed. However, drivers perceive a fast flash speed as indicating they are approaching a more urgent or hazardous situation than a slower flash speed. Some warning light manufacturers offer configurations that switch automatically between a fast and a slow flash rate. However, drivers tend to rate such an alternating fast-slow-fast flash speed as more distracting and less desirable than either a consistent slow or a fast flash speed.

Whereas there are trade-offs to be considered when deciding on how many warning lights to install on a vehicle, the colors of those lights, and the flash speed at which to operate them, similar trade-off concerns do not exist with respect to the coordination of the flashes of the individual warning lights. Relative to a synchronized alternating flash pattern, an asynchronous flash pattern where the individual lights flash independently from one another decreases driver ability to correctly recognize worker presence at night. The asynchronous flash pattern also increases discomfort glare, especially for younger drivers. Finally, drivers perceive an asynchronous flash pattern as indicating slightly less urgent or hazardous conditions ahead than an alternating flash pattern.

**Categories of Roadway Operations Vehicles and Equipment Retroreflective Markings and Warning Light Needs**

As noted above, certain vehicle marking and warning light attributes enhance the salience of the work vehicle or equipment, increase detection and recognition distances, elevate driver expectations of the urgency or level of hazards being approached, and affect driver speed and lane choice decisions. However, those same attributes can also degrade driver ability to quickly detect workers or other pedestrians who may be on foot around the work vehicle or equipment and make it more difficult to scan the visual scene for other hazards due to increased distraction or discomfort glare that the attributes create. Therefore, the research suggests that vehicle markings and warning light attributes be tailored to the types of activities that different roadway operations vehicles and equipment typically perform, where those activities are performed, and when those activities are performed (day or night). Six different categories of vehicles and equipment are identified:

* Service patrol and incident response vehicles and equipment
* Temporary traffic control vehicles (set-up and take down vehicles, truck-mounted arrow board and attenuator trucks)
* Winter treatment vehicles and winter response (snowplow) operations
* Project inspector or manager vehicles
* Construction, maintenance, and utility work vehicles
* Construction, maintenance, and utility work equipment

Key characteristics for each category are presented in Table 1. Roadway operations vehicles used for service patrols or incident response are perhaps the most challenging for which to develop recommendations. These vehicles are often the first on scene of an incident and so have no other TTC present other than their vehicle markings and warning lights to provide notification and warning to approaching drivers. At the same time, workers are out on foot performing various tasks in the vicinity of the vehicle. The situation argues for vehicle markings and warning lights that maximize driver detection and recognition of the vehicle, that imply a high degree of urgency or level of hazard, and that result in changes to driver speed and lane choice decisions. Unfortunately, the attributes that best meet these needs also tend to inhibit driver abilities to detect workers on foot.

Vehicles used for TTC (truck-mounted attenuators, shadow vehicles) experience many of the same challenges as those by service patrol or incident response vehicles. They are the first vehicle encountered when approaching a mobile work operation. The vehicle may be stopped or moving slowly and may be positioned either in a travel lane or on a shoulder. Workers will typically not be out on foot around these types of vehicles if it is a continuously moving work operation but may be on foot for other work activities. TTC vehicles will often include an arrow board in addition to its warning lights and vehicle markings. These vehicles may support the response to major traffic incidents. However, they are used most often in conjunction with construction and maintenance work operations.

The next category of roadway operations vehicles/equipment are those used for winter pre-treatment and snowplowing or snow removal purposes. These vehicles typically move continuously along the roadway at reduced, but not excessively low, travel speeds. They also operate without TTC devices providing advance warning or channelization to approaching motorists. Workers are not typically out on foot around these types of vehicles/equipment. However, they often operate under degraded visibility conditions (rain, snow) that can mask light-colored vehicles, markings, and amber or white warning lights.

**Table 1. Vehicle markings and Warning Light Attribute Recommendations**

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| --- | --- |
| **Type of Vehicle or Equipment** | **Operating Characteristics** |
| Service Patrol/Incident Response | * Intermittent stops, may be in travel lane or on shoulder * Workers out on foot * Operate both daytime and nighttime * Often first on scene, no advance warning TTC may be present |
| TTC Vehicles (Truck- or Trailer-Mounted Attenuators, Shadow Vehicles, etc.) | * Typically the first vehicle of a work operation encountered by approaching motorists * May be mobile or stopped * May be in a travel lane or on a shoulder * Workers on foot are not typically positioned around the vehicle when moving continuously, may be present when stationary * May operate during the day or at night |
| Winter Pre-Treatment Vehicles/ Snowplowing Operations | * Continuously moving operation (speeds > 30 mph) * No advance warning TTC typically in use * Vehicle-mounted arrow boards typically used when on multi-lane roadways * Workers remain in vehicle/equipment * Operate during both daytime and nighttime * Can operate in degraded visibility conditions that can mask light-colored vehicles |
| Project Inspector/Project Manager Vehicles | * Stopping on shoulder or within a designated workspace or activity area * Personnel may be out on foot around vehicle |
| Construction/Maintenance/Utility Work Vehicles | * May be only vehicle on site * May also be within a defined workspace with other TTC devices present * Workers may or may not be moving and working around vehicle * May be stopped/parked unless traveling to or from work site * May also be moving slowly along a shoulder or on the roadside (e.g., mowing, herbicide spraying) |
| Construction Equipment | * Always positioned within a workspace with other TTC devices present * Workers may or may not be moving and working around the equipment |

The fourth category addressed are vehicles used by construction project inspectors and managers. These vehicles are typically pickup trucks or sport-utility vehicles, usually parked when present at a work site either on a shoulder or within a workspace demarcated with TTC devices. The inspectors and managers themselves will be out on foot in the vicinity of the vehicle.

The fifth category are construction, maintenance, or utility work vehicles. These vehicles may be the only one(s) on site or be used within a work zone bounded by TTC devices. Workers may possibly be on foot performing various tasks near these vehicles if the work operation is a stationary one. However, these vehicles may also be moving slowly along the roadway or roadside for certain work activities (e.g., moving, herbicide spraying, debris removal).

The final category are the various types of roadway construction equipment that are used for roadway resurfacing, rehabilitation, and reconstruction. These pieces of equipment will always be positioned within a workspace that has other TTC associated with it. Workers on foot may or may not be located around the equipment. Vehicle markings and warning lights on this type of equipment are very much supplemental to the overall TTC set up at a work site.

**Vehicle Marking and Warning Light Recommendations**

In terms of the photometric output provided by warning lights on roadway operations vehicles, past research had indicated the need for a minimum of two SAE Class 2 lights, mounted as high and as far apart laterally as possible, during both daytime and nighttime conditions. During daytime conditions, there is less of a need to identify a maximum light output threshold since driver eyes adapt to the high ambient light levels and have little issues with glare from the warning lights. However, excessive warning light output concerns at night were investigated as part of this research. Based on the studies performed, it is recommended that roadway operations vehicles and equipment limit the aggregate output from their warning light systems to a peak luminous intensity of 1200 candela (cd). The use of warning light controllers that provide dimming capabilities of lights are recommended to ensure that as the aggregate peak luminous intensity of 1200 cd at night is not exceeded. Other flash patterns not examined under this research, such as sequencing light sticks, should also limit the aggregate peak intensity of their operation to 1200 cd or less. Asynchronous flash patterns should not be used on roadways operations vehicles and equipment.

Attracting the attention of motorists approaching roadway operations vehicles and equipment from the rear (and to a lesser extent from the front) is a fundamental goal of a vehicle marking and warning light system. However, certain work activities occur within roadway intersections, driveways, and other access points where motorists may also approach and view those vehicles and equipment from the side. Although not specifically evaluated as part of this research, it is recommended that warning lights also be installed so that at least one flashing light is visible from each side of the vehicle. The installation of more than one light visible from the sides is also acceptable, so long as the maximum peak intensity of the overall system when viewed from the side does not exceed 1200 cd as recommended above. This includes the use of perimeter flashing warning light systems that help identify the lateral and vertical extent of the vehicle or equipment being approached (perimeter lighting on the rear or front of the vehicle or equipment is also acceptable).

It is important to keep in mind that flashing lights mounted at or near the eye height of approaching drivers may increase discomfort glare and further degrade driver abilities to detect workers or other roadway hazards near the vehicle or equipment. For this reason, installation of any warning lights at or near driver eye height is discouraged.

The same warning light characteristics (color, flash speed, flash pattern) displayed to the rear or front of the vehicle should be used on lights displayed to the sides. Use of vehicle markings on the side of the vehicle or equipment is at the discretion of the owner.

Table 2 presents recommendations for vehicle markings and warning lights by roadway operations vehicle/equipment category. Roadway operations vehicles used for service patrols or incident response should use vehicle markings that are different than those typically used for traditional work zone operations, such as a red and white inverted pattern or a yellow and black checkerboard (Battenburg or half-Battenburg) pattern. Service patrol or incident response vehicles should use multi-color flashing warning lights if they are the only vehicle on scene and the vehicle is in a travel lane but should use amber lights only if located on a shoulder or if other emergency response vehicles with multi-colored warning lights are present. Service patrol or incident response vehicles should use a fast or an alternating fast-slow-fast flash speed that implies an urgent hazardous situation being approached and should use an alternating flash pattern.

For TTC vehicles, it is recommended that the warning light attributes used for service patrol/incident response vehicles also be used on TTC vehicles, but with yellow and black inverted V vehicle markings on the rear of the vehicle to help differentiate between roadwork operations and incident response/service patrol activities. TTC vehicles should use multi-color flashing warning lights if they are the first vehicle encountered by approaching motorists in a mobile work operation but should use amber lights only if in a stationary operation with other TTC devices present to designate the workspace. TTC vehicles should use a slow or an alternating fast-slow-fast flash speed and an alternating flash pattern.

Winter pre-treatment and snowplowing or snow removal vehicles and equipment should utilize yellow and black vehicle markings or similar colors that contrast more with snow or sleet conditions. The marking pattern should differ from a typical work zone situation (e.g., a checkerboard [Battenburg or half-Battenburg] pattern should be used). Multi-colored warning lights which also contrast more with sleet or snow are also recommended. Based on the nature of the work operation, a slow or alternating fast-slow-fast flash speed that is less distracting to drivers and which drivers perceive to make it easier to judge the speed of the work vehicles are also recommended.

**Table 2. Recommended Vehicle Marking and Warning Light Attributes for Different Roadway Operations Vehicle and Equipment Types**

| **Type of Vehicle or Equipment** | **Vehicle Marking and Warning Light Attributes** |
| --- | --- |
| Service Patrol/Incident Response | * Vehicle Markings: Yellow and black if using checkerboard pattern; red and white or similar colors if using inverted V pattern * Peak Light Intensity: 1200 cd minimum daytime, 1200 cd maximum nighttime * Warning Light Color: Multi-color (green and amber, blue and amber or red and amber where allowed, etc.) if first on scene and incident vehicle is located in a travel lane; amber only if the vehicle is located on the shoulder or roadside or if other emergency vehicles are already on site * Warning Light Flash Speed: Fast or alternating fast-slow-fast * Warning Light Flash Pattern: Alternating |
| TTC Vehicles (Truck- or Trailer-Mounted Attenuators, Shadow Vehicles, etc.) | * Vehicle Markings: Yellow and black inverted V pattern * Peak Light Intensity: 1200 cd minimum daytime, 1200 cd maximum nighttime * Warning Light Color: Multi-color if the first vehicle in a mobile operation; amber only if in a stationary operation with other TTC devices present * Warning Light Flash Speed: Slow or alternating fast-slow-fast * Warning Light Flash Pattern: Alternating |
| Winter Pre-Treatment Vehicles/ Snowplowing Operations | * Vehicle Markings: Yellow and black or other colors that contrast with a white background checkerboard (Battenburg or half-Battenburg) pattern * Peak Light Intensity: 1200 cd minimum daytime, 1200 cd maximum nighttime * Warning Light Color: Multi-color to ensure good contrast with the white ambient background * Warning Light Flash Speed: Slow or alternating fast-slow-fast * Warning Light Flash Pattern: Alternating |
| Project Inspector/Project Manager Vehicles | * Vehicle Markings: Yellow and black inverted V pattern * Peak Light Intensity: 1200 cd minimum daytime, 1200 cd maximum nighttime * Warning Light Color: Amber * Warning Light Flash Speed: Slow or alternating fast-slow-fast * Warning Light Flash Pattern: Alternating |
| Construction/Maintenance/Utility Work Vehicles | * Vehicle Markings: Yellow and black inverted V pattern * Peak Light Intensity: 1200 cd minimum daytime, 1200 cd maximum nighttime * Warning Light Color: Amber * Warning Light Flash Speed: Slow * Warning Light Flash Pattern: Alternating |
| Construction Equipment | * Vehicle Markings: None needed (if agencies desire to have them, a yellow and black inverted V pattern should be used) * Peak Light Intensity: Minimum 300 cd (single Class 2 warning light); maximum 1200 cd nighttime * Warning Light Color: Amber * Warning Light Flash Speed: Slow * Warning Light Flash Pattern: Alternating |

cd = candela

Slow flash speed = 1-1.25 Hertz; Fast flash speed = 2.5-3 Hertz

Vehicles used by construction project inspectors and managers should also utilize yellow and black inverted V vehicle markings that are recognized as indicating a work zone situation by most motorists. Because there are other TTC devices present, use of amber (or amber and white) warning lights that are more associated with work zone operations and which interfere less with recognizing the presence of workers on foot or other TTC devices such as arrow boards, is recommended. It is also recommended that the warning lights operate at either a slow flash speed or an alternating fast-slow-fast flash speed.

As far as the work vehicles used in a typical construction, maintenance, or utility work zone, more traditional vehicle markings and warning lights are recommended. Although these vehicles may be the only one(s) on site at work zones on lower-volume, lower-speed roadways, work activities on higher-volume, higher-speed roadways will almost always have other TTC present. Workers may possibly be on foot performing various tasks near these vehicles. Thus, markings and warning light attributes that attract increased attention to the vehicle and away from any workers on foot should be avoided. Use of yellow and black inverted V markings is recommended for these types of vehicles, along with amber or amber and white warning lights that operate at a slow flash speed.

Roadway construction equipment that are used for roadway resurfacing, rehabilitation, and reconstruction will always be positioned within a workspace that has other TTC associated with it. Workers on foot may or may not be located around the equipment. Vehicle markings and warning lights on this type of equipment are very much supplemental to the overall TTC set up at a work site. It does not seem necessary for this type of equipment to be outfitted with vehicle markings. In addition, a single SAE Class 2 warning light affixed to the top of the equipment is likely sufficient as well.

It is important to acknowledge that agencies may not be able to accommodate all of the recommendations presented. For example, some agencies rely on the same vehicles to perform multiple types of work operations, such that the recommended vehicle markings and warning light attributes for one type of operation may contradict the recommended markings and warning light attributes for another operation where the same vehicle is used. In these situations, agencies must decide for themselves which marking is most appropriate for their needs. A similar concern exists with regards to warning light configurations. Fortunately, newer warning light technology makes it easier to offer different configurations and select them through the controls and switches installed in the vehicle cab. Agencies that provide multiple warning light configuration options to vehicle operators will need to ensure that adequate training is provided about which configurations are allowable for the various situations for which the vehicle is being used, and to adjust their warning lights if conditions change (such as at incident locations as multiple additional emergency response vehicles arrive).