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Work Vehicle Warning Lights: Color Options and Effectiveness

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Work Vehicle Warning Lights: Color Options and Effectiveness

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16. Abstract

KTC reviewed existing regulations, guidance, and practices to assess the Kentucky Transportation Cabinet's warning lights program on highway work vehicles. The Kentucky Revised Statutes categorizes KYTC vehicles as "public safety vehicles" and requires their use of amber lights. Because the use of red can be confused with emergency vehicles, KYTC prohibits the use of red on work vehicles. At the national level, standards for warning light colors do not exist. Rather, AASHTO provides guidance on roadway operations equipment and recommends the use of amber and white lights as the primary warning light colors for highway vehicles. AASHTO guidance also prescribes the use of slow, asynchronous flash frequencies; LED light sources; and placement of lights at high elevations and against solid-colored backgrounds. The MUTCD provides little guidance in terms of warning light specifications, including color preferences. A review of existing state agencies, including DOTs, concluded that amber and white are the primary light colors currently in use across highway operations vehicles.

KTC conducted two external surveys to assess warning light products and practices within the U.S. The first survey reviewed vendor LED products and revealed that LED lights are primarily available in the colors of amber, blue, green, red, and white. Fluorescent yellow-green is not available. The second survey requested state DOT information related to lighting systems' colors, sources, intensity, and placement; responding agency names and policies; and previous state DOT studies related to warning lights. Survey responses indicated 100 percent use of the color amber (as a color type) as well as use of LED light sources. More than 75 percent of reporting agencies place warning lights on their highway work vehicle's roof to maximize visibility to motorists. Survey results varied dramatically on the differentiation of warning light colors by vehicle type and the differentiation of light intensities for daytime versus nighttime conditions. KTC researchers recommend the use of amber and white colors for KYTC work vehicles, an asynchronous flashing pattern with slow flash frequencies, and LED bulbs. Other recommendations include placement of warning lights at high elevations on the vehicle, placement of warning lights against a solid-colored background, and investigation on feasibility of yellow-green LED lights.

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Executive Summary

State DOTs and highway agencies use a range of fleet vehicles to accomplish operational, maintenance, and construction activities. Safety protocols have been established at each of these organizations to ensure highway workers conduct their activities under the safest conditions possible. One commonly used safety measure is the installation of warning lights on highway agency vehicles. Warning lights are available in many colors and patterns and notify the traveling public that they are approaching highway work-related activities. Drivers should be able to see the lights at a sufficient distance to let them perceive and react to the upcoming activity. Because the use of red can be confused with emergency vehicles, KYTC prohibits the use of red on work vehicles. National standards on warning lights for highway agency vehicles do not exist. Therefore, state DOTs and highway agencies have discretion to use a wide array of color arrangements, light sources, locations, and other related factors when establishing their respective warning light programs.

Currently, the Kentucky Transportation Cabinet (KYTC) relies on a combination of regulations, guidelines, and internal policies to govern its vehicle warning light program. The primary source of authority stems from legislative requirements contained within the Kentucky Revised Statutes (KRS). In addition, KYTC has developed internal policies and guidelines that dictate how warning lights are installed and operated on its vehicles. Another guidance document, the Manual on Uniform Traffic Control Devices (MUTCD), frequently guides the oversight of traffic control devices, such as signs and signals, but it contains limited guidance pertaining to warning lights on work vehicles.

The Kentucky Transportation Center (KTC) reviewed vehicle warning light practices found at other state DOTs across the U.S. As part of this effort, KTC researchers reviewed studies conducted by the American Association of State and Highway Transportation Officials (AASHTO), which publishes the best single-source document on warning lights. Various state DOTs and/or affiliated research agencies were studied as well. Most often, these studies examined the colors used in warning light installations. Sometimes they identified other factors of interest, such as the light source, form of light signaling (i.e., flashing or rotating), what times of day the lights were used, and where lights were positioned on vehicles. A majority of studies indicated that amber was the primary vehicle warning light color used by state DOTs on highway agency vehicles, although other colors were sometimes used. Other warning light characteristics, such as duration and placement, varied across state DOTs.

KTC researchers conducted two external surveys to identify existing practices, trends, and options for vehicle warning light systems. In the first survey, KTC conducted an online survey to identify the LED light colors commonly used in vehicle warning light systems. This online survey relied upon three approved LED vendors from KYTC's approved vendor list. This survey revealed that LED lights are primarily available in the colors of amber, blue, green, red, and white. KTC followed up the online survey with phone calls to approved KYTC LED vendors and learned that the fluorescent yellow-green color does not exist as a product option. In the second survey, KTC researchers gathered more information on state DOT warning lights practices and procedures. The research team then analyzed survey results to identify usage trends and best practices. KTC distributed this survey to state DOTs and other highway agencies through the State Highway Safety Engineers LISTSERV database. The survey contained 16 questions asking about various facets of warning lights' usage on highway agency vehicles and specifically, information related to lighting system colors, sources, intensity, and the placement of lights. The survey also collected data on the responding agency's name, the type of organization, and its warning light policies and regulations. Furthermore, it asked respondents to identify any previous studies conducted on highway vehicle warning lights. KTC received 16 responses. All of the responding agencies reported using amber lights as part of their overall warning light ensemble, with LEDs as a primary light source. All agencies relied upon internal policies and regulations to guide their warning light program

efforts. Many state DOTs also placed warning lights on the rooftops of highway vehicles to provide 360-degree visibility. Finally, state DOTs often tried different approaches to differentiate among vehicles: varying colors by highway vehicle type and requiring different light source intensities during daytime and nighttime conditions.

KTC researchers recommend the use of amber and white colors for KYTC work vehicles, an asynchronous flashing pattern with slow flash frequencies, and LED bulbs. Other recommendations include placement of warning lights at high elevations on the vehicle and against a solid-colored background. Continued investigation is required for determining the feasibility of the color yellow-green as a viable warning light color.

Chapter 1: Background

1.1 Introduction

Warning lights on KYTC's work vehicles are a vital component to ensure maximum safety while employees perform activities that expose them to highway traffic conditions. For the past several years, KYTC work vehicles have been equipped with LED warning lights in the form of front and rear flashers as well as "light bars," which are typically placed on the roof of a vehicle. Over this period, LED light colors have consisted of many different color arrangements; typically, they were red, amber, white, or a combination thereof.

1.2 Problem Statement

A number of stakeholders have expressed concern about KYTC vehicles using red warning lights. The fear is that drivers could potentially confuse them with emergency service vehicles, such as fire and rescue services, which have traditionally been equipped with red lights. Because of these concerns, and due to conflicts with KRS Sections 189.20 – 189.50, the Kentucky Transportation Cabinet Secretary released a memo on February 17, 2015, prohibiting the use of red lights on KYTC work vehicle warning light systems. As such, KYTC has requested information on alternative practices and guidelines to follow as it decides how to replace the existing red lights on its work vehicles.

1.3 Objectives

This study synthesizes literature, applicable statutes and regulations, and practices related to warning light systems mounted on highway agency work vehicles. The following tasks have been completed in support this objective:

a. Summarize information related to the use of warning lights on highway work vehicles.
b. Conduct a LISTSERV survey of state highway agencies to determine the warning light colors currently used on work vehicles.
c. Summarize applicable statutes and regulations related to colors of lights permitted on vehicles for warning and emergency notification.
d. Document study results.

Chapter 2: Literature Review

2.1 Synthesis on Warning Lights

State DOTs and other highway-related agencies use a wide assortment of warning lights in their vehicle fleets. Warning lights are configured to meet the specifications required by each organization's internal policies and standards. These may stipulate the use of specific colors, types of lighting, location, and other factors related to the installation of vehicle warning lights. In many cases, organizational policies and standards are the product of statutes and regulations written by state legislatures. Currently, there are no national standards about warning lights that state DOTs and other highway-related agencies must follow. Thus, the types of warning lights used throughout the United States vary significantly. Several recent research studies have focused on warning lights to identify installation procedures that improve highway worker safety. Key research findings are summarized in the following sections.

2.1.1 AASHTO

In 2009 the American Association of State and Highway Transportation Officials (AASHTO) published *Guidelines for the Selection and Application of Warning Lights on Roadway Operations Equipment*. This guidance manual summarizes NCHRP Report 624, *Selection and Application of Warning Lights on Roadway Operations Equipment*, which assessed motorists' responses to various warning light system installations.[1] In this effort, researchers examined 40 warning light configurations involving multiple driving scenarios. The scenarios focused on a variety of conditions related to adverse weather patterns (e.g., fog, rain, etc.), daytime versus nighttime lighting, and the presence of vehicle traffic, among others.

The researchers' primary objective was to identify the most effective means of enhancing safety for state DOT highway workers and public motorists by examining: 1) state DOT employees actively using a roadway operations vehicle (e.g., snow plow operations), 2) state DOT employees working roadside next to a parked operations vehicle (e.g., roadside sign installation), and 3) public motorists driving through a work zone after they received visual notification from vehicle warning lights. This study provided recommendations on the use of warning lights. It provided guidance and suggestions for the following warning light characteristics and parameters: colors, duration (e.g., flashing, steady, etc.), intensity by light source, placement on vehicle, and layout.

State DOTs use various color arrangements in their vehicle warning light systems. Traditionally, amber has been the most popular color. Other colors commonly used include white, red, and blue. The study's findings revealed that amber and white light sources elicited better responses from motorists than blue or red. In addition, motorists strongly associated amber and white lights with maintenance operations and blue and red lights with emergency services. Consequently, AASHTO recommended that amber and white lights be used as the primary colors for warning lights.

The interval of time that warning lights remain active (i.e., in the "on" mode) impacts the time needed to capture a driver's attention. Warning lights may be steady or flashing. Steady lights have constant illumination and may be confused with regular vehicle lighting systems such as headlights or brake lights. Consequently, AASHTO recommends that steady lights only be used to supplement warning lights. They should not be used as the primary warning lights. On the other hand, flashing lights intermittently emit a pulse of light that alternates from on to off. Flashing may be categorized as either asynchronous (flashing from side to side) or synchronous, where both sides flash simultaneously. In addition, the frequency of the flashing pattern influences motorists' response. AASHTO recommends using an asynchronous flashing pattern that employs slow flash frequencies to achieve optimal motorist response. To this extent, a flash rate of 1 Hz produces better reaction times than the faster 4 Hz.

Light intensity measures the amount of light that enters the motorist's visual spectrum (i.e., brightness). Adopting an optimal light intensity range helps ensure that sufficient light is available to illuminate an operations vehicle for passing motorists. At the same time, the light intensity should minimize excessive and potentially disruptive glare, which can negatively impact motorists' response times. Daytime and nighttime conditions require different light intensity ranges. During the day, higher minimum thresholds are necessary to stand out against the ambient light of the sky. Conversely, nighttime conditions necessitate lower maximum thresholds to prevent the approaching driver from encountering intrusive glare conditions. Light source types such as halogen, LED, and strobe lights will also affect the intensity required. To this end, AASHTO recommends maximum and minimum light intensity ranges based upon the light source type and its corresponding intensity. Table 1 summarizes AASHTO's recommendations for daytime and nighttime intensities, arranged by light source. The units are in candelas, an SI unit that is equivalent to lumens.

Table 1: Light Source Intensity Ranges

Light Source	Intensity (by Form Factor Method)		
	Daytime	Nighttime	
	Minimum	Minimum	Maximum
Halogen	3500	900	2200
LED	4000	1650	[a]
Strobe	3500	1200	2200

[a] Note that a maximum value for the LED sources was not found

A warning light's placement on a highway vehicle has the potential to improve safety performance by increasing the vehicle's visibility to approaching motorists. AASHTO recommends that warning light configurations ensure a view of warning lights from any motorists' angle of approach. This requires either using lighting visible from 360 degrees (e.g., rotating beacon on top) or installing separate lighting across each side of the vehicle. In addition, lights should be placed on higher portions of a vehicle to optimize visibility. Lights mounted at a height near a driver's line of sight tends to increase glare, especially at close distances. As such, lights should be placed as high as possible on the vehicle to reduce the potential for visual impairment.

The layout of warning lights should be positioned against the vehicle or against a solid-colored background to maximize visibility. Lights placed at high elevations on the vehicle (e.g., roof) without a contrasting solid-colored background may partially blend in against the ambient sky. Warning lights should provide suitable contrast with surroundings to allow the motorists to readily identify them. Therefore, rotating beacon lights may meet desired placement preferences regarding 360-degree visibility but will not achieve sufficient color contrast. Great care should be exercised when selecting and placing warning lights on highway vehicles. DOTs should attempt to balance the numerous AASHTO recommendations when deciding upon an installation scheme.

2.1.2 State Research Studies

Several state DOTs and related agencies have conducted investigations focused on the characteristics of vehicle warning lights and their potential impacts on highway worker safety. Many studies examined warning light colors and how motorists perceived different color schemes. Some studies also looked at the

effectiveness of different forms of lighting (e.g., strobe, rotating beacon). This section presents key findings from several of the identified studies.

2.1.2.1 Illinois State Police

The Illinois State Police investigated the use of different colored lights on emergency responder vehicles to increase the safety of first responders. This study was conducted in response to the high occurrence of emergency responders being struck by passing vehicles at incident sites. The study sought to identify lighting strategies that would maximize the distance from which approaching motorists could see the emergency response vehicle while reducing motorists' exposure to excessive glare. The study found that motorists could perceive the color white at the greatest distance, followed by amber, red, then blue. White also produced the highest amount of glare, which resulted in drivers near the scene having to cope with an additional distraction. Therefore, the study's authors concluded that the color amber was optimal. The color amber allowed emergency vehicles to be seen at the great distances while reducing passing motorists' exposure to glare.[2]

2.1.2.2 Indiana DOT

The Indiana DOT examined warning light colors for its maintenance vehicles--particularly snow plow trucks--in an effort to improve the safety of its fleet operations. Researchers mounted various lighting configurations on vehicles across a range of weather and lighting conditions. Field technicians observed warning light performance under visually challenging scenarios including snow, cloudy, bright sun, and nighttime conditions. The study found that amber achieved the best results under all tested conditions, while blue came in second.[3]

2.1.2.3 Iowa DOT

In an effort to improve its use of warning lights, the Iowa DOT studied common practices related to warning lights. Primarily, Iowa sought to enhance visibility of its highway maintenance vehicles for the traveling public. Researchers conducted a survey of state DOTs and found that most agencies preferred the use of amber for their vehicle warning lights. Some DOTs also used additional colors to complement amber such as white, blue, or red. The overwhelming majority of states placed reflective material on maintenance vehicles to further increase their visibility. Finally, states prioritized certain maintenance vehicles in their fleet, such as snow plow trucks, by equipping them with additional warning lights.[4]

2.1.2.4 Minnesota DOT

To enhance visibility and safety of maintenance vehicles, a Minnesota DOT study recommended the transition to LED lights The study was prompted by concerns that an excessive number of crashes in work zone areas posed an unacceptable threat to their maintenance workers. Researchers found that LED lights measurably improved performance over incandescent lights. Subsequently, they recommended the Minnesota DOT transition to LED lights. In addition, the study suggested using blue lights in conjunction with amber lights on supervisory maintenance vehicles. These vehicles are often deployed in response to unscheduled incidents.

2.1.2.5 Ohio DOT

Breaking from conventional practice, the Ohio DOT recently became the first state in the U.S. to use green-colored strobe lights on snow plow trucks. The green lights are combined with existing white and amber warning lights to illuminate a unique color combination visible to traveling motorists. The Ohio DOT grew concerned with their warning light color scheme after learning that snow plow trucks were

involved in four times the number of rear-end crashes as other states. Therefore, the Ohio DOT authorized the study of warning lights and found that green lights were highly visible to the human eye. Because motorists can detect green lights better, the Ohio DOT anticipates this color combination will reduce the number of rear-end maintenance vehicle accidents.[5]

2.1.2.6 Texas DOT

The Texas Transportation Institute (TTI) carried out a study on behalf of the Texas DOT to examine warning light colors and how motorists respond to different colors. In this research, TTI conducted a national survey of vehicle warning light policies by state DOTs, reviewed human factors and driver behavior research that have shaped warning light policies, and studied motorist responses to different warning light configurations.[6] The survey indicated that every (responding) state used yellow as the primary warning light color within their highway vehicle fleets. In addition, 12 states used an additional color to supplement the warning light system, such as blue, red, or white. The survey demonstrated that motorists commonly associated yellow warning lights with highway construction and maintenance vehicles. Red warning lights were associated with various categories of emergency responder vehicles.

The survey also yielded insights into the motorists' perception of hazard severity. Frequently, motorists perceived yellow-only warning lights as indicating less hazardous conditions than other colors (e.g., blue or red). To illustrate this point, TTI conducted field studies at two sites and found that a combined yellow-blue light configuration resulted in a 5 to 6 mph decrease in speed compared to yellow lights only. The study's authors concluded that the use of yellow-only warning lights may not convey the true severity and magnitude of a hazard.

Chapter 3: KYTC Warning Lights

KYTC strategically places warning lights on their internal work vehicles to enhance visibility during roadway operations and to protect workers involved in those activities. The Cabinet relies on external and internal rules and guidelines to govern their vehicle warning light program. First and foremost, KYTC must follow all relevant laws contained in the Kentucky Revised Statutes (KRS). These statutes define the different types of state government vehicles according to their purpose and function and describe characteristics required across each type. The Manual on Uniform Traffic Control Devices (MUTCD) is a national standard on traffic control devices that KYTC has adopted. The MUTCD primarily focuses on commonly used traffic control devices, such as roadside signs and signalized lights at intersections, but its guidance related to vehicle warning lights is limited. Finally, KYTC has internal policies and guidelines that describe authorized warning light packages for its vehicles. The impacts of KRS, MUTCD, and KYTC's policies on the Cabinet's vehicle warning light practices are described below.

3.1 Kentucky Revised Statutes

KYTC relies extensively on Kentucky laws in the form of KRS for guidance related to their vehicle warning lights. Statutory language defines the different types of organizations that may require use of vehicle warning lights. Much of this guidance is restrictive in nature and designates which classes of vehicles are authorized to use certain types of warning lights. Three of the most relevant statutes related to vehicle warning lights for Kentucky agencies include KRS 189.910, KRS 189.920, and KRS 189.950.

3.1.1 KRS 189.910

KRS 189.910 defines the different classes of vehicles employed by governmental agencies. In particular, it distinguishes between emergency vehicles – typically used by police and other first responders – and public safety vehicles. Emergency vehicles are used by police, rescue squads, emergency management services, ambulance services, and coroners. The vehicles KYTC uses during roadway operations are classified as public safety vehicles. Per KRS 189.910 (2), "public safety vehicles means public utility repair vehicles; wreckers; state, county, or municipal service vehicles and equipment; highway equipment which performs work that requires stopping and standing or moving at slow speeds with the traveled portions of the highway; and vehicles which are escorting wide-load or slow-moving trailers or trucks."[7]

3.1.2 KRS 189.920

KRS 189.920 describes warning light colors and types authorized for use in state emergency and public safety vehicles. Fire departments, rescue squads, and other emergency management vehicles are authorized to use "flashing, rotating, or oscillating red lights". Police agencies, including state, county, and municipal organizations, can install flashing, rotating, or oscillating lights that are blue. Incident command post vehicles may use a "green rotating, oscillating, or flashing light". Incident command post vehicles are not specified as belonging to a certain agency or organization within this statute. KYTC's public safety vehicles must be equipped with "one or more flashing, rotating, or oscillating yellow lights, visible under normal atmospheric conditions from a distance of five hundred (500) feet to the front of the vehicle." Public safety vehicles are not authorized to use any other light colors designated for use by other categories as outlined in KRS 189.910 to KRS 195.950.[8]

3.1.3 KRS 189.950

KRS 189.950 prohibits the use of emergency vehicle lights on any other class of motor vehicle, including public safety vehicles. Specifically, motor vehicles not classified as emergency vehicle are prohibited from using "any red or blue flashing, revolving, or oscillating light or [placing] a red light on the front thereof." Conversely, any class of motor vehicle not considered a public safety vehicle cannot use the "yellow flashing, revolving, or oscillating light".[9]

3.2 MUTCD Guidance

The Federal Highway Administration's Manual on Uniform Traffic Control Devices, or MUTCD, represents a national standard on traffic control devices and in many cases, provides specific guidance regarding traffic and safety. However, the MUTCD's role in providing detailed guidance on warning lights installed on transportation work vehicles is limited. The MUTCD briefly addresses the areas of worker safety, lighting devices, and conventional sign colors in areas that directly or indirectly relate to vehicle warning lights.

Transportation workers located in temporary traffic control (TTC) areas draw from guidance on safety measures contained in *Section 6D.03, Worker Safety Considerations*. Much of this section addresses measures related to worker training, traffic barriers, and safety apparel. It also briefly discusses vehicle warning lights within the context of a shadow vehicle, or roadway operations vehicle. Specifically, MUTCD states that "in the case of mobile and constantly moving operations, such as pothole patching and striping operations, a shadow vehicle, equipped with appropriate lights and warning signs, may be used to protect workers from impacts by errant vehicles."[10]

The characteristics of lighting devices installed on transportation work vehicles are detailed in *Section 6F.81, Lighting Devices*. The MUTCD recommends lighting devices be present in TTC locations contingent upon the agency's engineering judgment. TTC locations include areas undergoing highway construction, utility work, maintenance operations, or traffic incident management. Transportation work vehicles may use a warning light device such as high-intensity rotating, flashing, oscillating, or strobe lights to assist with TTC operations. Furthermore, standard vehicle hazard lights cannot be used as a substitute for separately installed warning light systems. The MUTCD does not specify lighting colors for transportation work vehicles.

Conventional sign colors include those colors that are most commonly used. In some cases, these are mandated by the MUTCD (see Table 2A-5). The manual assigns specific colors to specific sign types. Multiple colors are represented across the roadway sign spectrum including: black, blue, brown, green, orange, red, white, yellow, purple, fluorescent yellow-green, and fluorescent pink. Although similar guidance for vehicle warning lights is absent, the same reasoning could be applied to sign colors, in order to convey a similar message to the motorist. The sign types most closely aligned in meaning with transportation work vehicles found in TTCs – along with the workers occupying those same areas – are pedestrian warning signs and temporary traffic control signs. Pedestrian warning signs use yellow and fluorescent yellow-green, whereas temporary traffic control signs adopt yellow or orange. These color schemes should provide a useful context and familiar meaning to the traveling public when assigning warning light colors.

3.3 State of Practice

KYTC primarily relies upon the KRS as the legally-binding guidance for its work vehicle warning lights program. As such, work vehicles should be outfitted with amber lights. These lights will notify motorists that a particular vehicle is a public safety vehicle. In addition, white lights are typically combined with amber lights to improve their visibility to motorists. As specified in KRS 189.910, 189.920, and 189.950, red and blue lights are not authorized for use on the front of public safety vehicles. The Secretary of KYTC reiterated this policy with a memorandum specifying the requirements for KYTC vehicle warning lights on February 17, 2015 (see Appendix A).

KYTC has also developed internal policies and guidance to further develop and set the requirements for its vehicle warning light program. To this extent, KYTC released a list in 2005 that described authorized warning light packages and their applicability across its vehicle fleet. This policy sought to standardize warning light packages across KYTC. Yet, a District 7 site survey revealed challenges with consistently implementing KYTC's standard packages. Other challenges involve the limitation in colors available for LED lights (particularly yellow-green) by LED original equipment manufacturers.

3.3.1 KYTC Policy

In April 2005, KYTC issued a directive on the lighting packages used in warning light installations on Cabinet work vehicles. This directive is known as "SHS #05-P1.3a2, Division of Safety and Health Services, Lighting Packages".[11] Its purpose is to ensure compliance with mandatory requirements, such as the KRS, while simultaneously providing guidelines and recommendations to further enhance vehicle visibility and to promote highway worker safety. The directive should be used in conjunction with standard KYTC master agreements. It should be applied to high-risk work activities which may include, but are not limited to, the following:

- Emergency storm damage tasks
- Incident response
- Snow removal escorts
- Shadow vehicles for mobile operations
- Traffic control installers
- Road sign repair and installation
- Highway patching
- Skid-resistant testing
- Emergency responders

The directive applies to all KYTC one-half, three-quarter, and one-ton trucks; sport utility vehicles (SUVs); vans; and sedans used in highway operation, maintenance, and construction activities. In addition, it requires adherence to other regulatory documents, such as KRS 338.030; 29 Code of Federal Regulations (CFR) 1296.203, Subpart G-Signs, Signals, and Barricades; MUTCD, Section 6D.03F; and Employee Safety and Health Manual, Chapter 16. Appendix B includes descriptions of each tiered lighting package.

3.3.2 District Seven Site Survey

On May 26, 2015, KTC researchers conducted a site survey on KYTC work vehicles in District 7. The intent was to identify trends or patterns related to installed warning lights. This site visit was admittedly a small sample and not statistically representative of practices throughout KYTC. Nonetheless, the survey provided an interesting case study that could identify and evaluate any potential issues and challenges with the program.

KTC researchers examined six KYTC work vehicles: three SUVs and three trucks. Each vehicle contained a different assortment and arrangement of warning lights. Some of the warning lights were set as rotating beacons on top of the roof while others included light bars mounted in the front or rear windshields. Warning light colors consisted of assorted colors including yellow, white, red, and green — all being used across the different locations and in various combinations. Photographs of the survived work vehicles are shown in Appendix C.

3.3.3 LED Vendor Survey

In accordance with an approved vendor list, KYTC uses several manufacturers for lighting products. These manufacturers produce LED lights in an array of colors and product specifications. KYTC relies upon LED lights as the primary light source component within their highway vehicle warning light systems. Three vendors residing on KYTC's approved list for LED lights include Whelen Engineering[12], Inc.; Leotek Electronics USA LLC[13]; and the Dialight Corporation[14]. KTC researchers conducted an online survey of all three companies to determine what color variations existed in their product catalog. This survey revealed that LED lights used in vehicle warning light systems predominantly exist as conventional colors. Specifically, LED lights were found in the colors of amber, blue, green, red, and white.

KTC researchers also examined the potential of using the color fluorescent yellow-green as a LED light source. The MUTCD specifies the use of this color in pedestrian warning signs and the color might be useful to identify KYTC workers operating outside of a vehicle during maintenance operations. Furthermore, this color has strong visual acuity and is not expressly prohibited from use by the Kentucky Revised Statutes. However, the survey revealed that none of the three vendors offered the fluorescent yellow-green color as an option within their LED product lineup. It was also determined that one of the vendors (Leotek) did not offer LED lights for use in vehicle warning light systems. Next, KTC contacted Whelen Engineering and the Dialight Corporation to directly inquire if this color might be available for vehicle warning lights. In the first discussion, the Whelen Engineering sales representative stated this color did not exist within their product lineup. He was not able to elaborate whether this product could be produced for the given color specification. In the second discussion, the Dialight representative also stated that this color was not offered within their LED products. He further elaborated that he was unaware of this LED product color existing anywhere in the high-powered LED light marketplace. In his judgment, the absence of a yellow-green LED color in the market stemmed from three primary reasons including: (a) lack of demand among the transportation community, (b) the initial cost barriers to developing the technology, and (c) its exclusion as a specific color mentioned with the Federal Motor Vehicle Safety Standards and Regulations.[15] Consequently, KTC researchers concluded that the color of fluorescent yellow-green does not appear to exist within the currently available LED vehicle warning light market.

Chapter 4: State DOT Survey

4.1 Vehicle Warning Lights Survey

4.1.1 Purpose

State DOT vehicle warning light programs rely on an uneven and non-standardized set of national guidelines. Lacking clearly defined FHWA criteria, each state has been tasked with developing its own set of policies and procedures for DOT vehicle warning lights. Further complicating the situation, each state legislature has independent authority to develop laws and statutes defining safety standards. State legislatures frequently issue legal requirements pertaining to the use of warning lights and their characteristics for state government vehicles. Therefore, it is no surprise that state DOT vehicle warning lights vary among the different states. Vehicle warning lights come in many colors, types, and can be mounted on multiple spots on a vehicle. KYTC seeks to better understand vehicle warning light programs implemented by other state DOTs across the U.S. and seeks to identify the most promising and feasible solutions for updating its own vehicle warning light program.

4.1.2 Survey Methodology

KTC researchers developed a survey to better understand the types of vehicle warning lights being used at state DOTs across the nation. This brief survey attempted to identify trends and potential best practices for vehicle warning lights concerning color, form of light, light intensity, and placement. The survey was distributed to state DOT and other highway agency officials through the web-based State Highway Safety Engineers LISTSERV database.[16] This database allows transportation safety practitioners at DOTs, universities, and other highway agencies to communicate with peers from other states. The survey asked questions related to the following topics:

- Colors available
- Color combinations
- State DOT policies on warning lights
- Types of light sources
- Intensity of light sources
- Location of warning lights
- Research studies on warning lights

The survey was developed electronically and administered using the Qualtrics online survey platform.[17] All of the questions were posted in an online format, which could be accessed by the intended recipient using a hyperlink. Once completed, responses were automatically aggregated, and a summary of results was displayed in a number of formats. The survey was circulated among state DOTs on June 1, 2015, via the LISTSERV database. Instructions requested that respondents reply no later than June 12, 2015. The original survey template is shown in Appendix D.

4.2 Summary of Results

The survey generated 16 responses. The fact that participants responded quickly and through an electronic format suggested a strong interest in the topic across the transportation community. Fifteen survey participants self-identified as representatives from state departments of transportation while one survey did not answer to this question. State DOTs responding to this survey included: Alaska, Iowa, Maine,

Massachusetts, Michigan, Minnesota, Missouri, New Hampshire, Oklahoma, South Dakota, Texas, and Washington (two responses). Two completed surveys did not specify their DOT association, while one survey did not identify its name or type of agency.

The survey consisted of 16 questions that solicited information on various facets of warning lights used on highway agency vehicles. In addition to issues relevant to lighting system attributes (see list above), the survey collected data on the responding agency's name, warning light policies and regulations, and identified previous studies involving highway vehicle warning lights. The survey responses gave researchers additional context about the current state of practice for vehicle warning light programs at state DOTs. They also highlighted potential solutions KYTC may consider. The following paragraphs summarize the key survey findings.

- *Warning Light Colors on Highway Vehicles*: All 16 agencies use the amber/yellow light for their warning light systems. White, red, and blue colors were employed by seven (44%), six (38%), and four (25%) of the survey participants, respectively. No other colors were identified as being used in warning lights.

- *Organizational Policies and Regulations*: Fifteen agencies have formal policies and regulations for installing warning lights on highway work vehicles. The sixteenth response was left blank. In addition, the majority of agencies stated that warning light color selections matched guidance found within their respective state policies and regulations. Amber was the predominant color authorized for use at 14 (88%) agencies. It was followed by white, red, and blue at 5 (31%), 5 (31%), and 4 (25%), respectively.

- *Colors Vary by Work Vehicle*: The agencies were split evenly on the use of assigning the color of warning light by vehicle type. Eight agencies (50%) stated that colors varied according to vehicle type while the other eight (50%) stated the warning light colors remained consistent across their highway vehicle fleets. Agencies favoring light color variation across their fleets frequently assigned different colors to incident emergency response vehicles, maintenance vehicles, and snow removal trucks.

- *Light Source*: In the survey, light source referred to the type of bulb used in the warning light system. Common bulb types included halogen, LED, and incandescent. All 16 agencies use LED lights in their warning light systems. Five agencies (31%) also reported using halogen lights and incandescent lights in other vehicle lighting configurations.

- *Light Intensity*: Two agencies (13%) specified that warning lights must be visible to traveling motorists within 500 feet of the highway work vehicle. No survey respondent indicated use of a minimum or maximum brightness threshold measured in lumens. Several agencies did, however, require different light intensities for daytime and nighttime conditions. Seven agencies (47%) reported varying the warning light intensity between daytime and nighttime conditions while eight agencies (53%) did not.

- *Warning Light Placement on Vehicle*: Warning lights may be placed at many locations on a highway work vehicle. However, there is no established guidance or best practices designating where those locations should be. This is demonstrated by the wide range of responses KTC received on a survey question asking about the placement of warning lights. Agencies reported placing warning lights at many different locations on their work vehicles. The locations, ranked from highest to lowest, include: roof of vehicle (toward rear) – 13 (81%); roof of vehicle (toward

front) – 12 (75%); rear taillight assembly – 6 (38%); inside rear windshield – 5 (31%); side of vehicle – 5 (31%); front headlight assembly – 4 (25%); and inside front windshield – 3 (19%).

- *Research Studies for Vehicle Warning Lights*: Five agencies (31%) indicated they had conducted recent studies on the types of color combinations appropriate for use on highway work vehicles. Four studies have been completed, while one is ongoing. None of the studies are publicly available.

In summary, the survey provided several overarching themes regarding warning light systems found on state DOT highway work vehicles. First, several survey topics demonstrated 100 percent consensus among the state DOT survey participants. All participating agencies indicated the use of:

- Policies and regulations guiding their warning light program efforts
- Amber colored lights in their warning light systems
- LED lights as a light source

Second, a majority of reporting agencies indicated a strong preference for roof-top placement of warning lights. The survey provided state DOTs with seven vehicle locations for warning light placement. Roof-top warning light installations represented the most commonly selected location, with 81 percent of agencies choosing this location. However, no other vehicle location response surpassed 50 percent (i.e., front headlight, rear taillight, front windshield, rear windshield, or the side of the vehicle).

Finally, several survey topics demonstrated little to no consensus among the responses. In this category, half of reporting agencies used different warning light colors in accordance with a specific work vehicle type versus the other half reporting consistent color usage across the entire fleet. Similarly, just under half of agencies varied warning light intensity on their highway work vehicles during daytime versus nighttime operations. The remainder did not.

Chapter 5: Conclusion

5.1 Findings

KTC researchers conducted a study on KYTC highway vehicle warning light systems to determine the best characteristics for enhancing safety of state DOT highway workers and traveling motorists. Primarily, this study focused on warning light colors but other characteristics, such as light placement and light source, were also examined. The team reviewed existing guidance and best practices (including FHWA and AASHTO publications) and statutes and policies authorizing or restricting warning light configurations on KYTC vehicles. A state DOT survey was conducted to identify existing practices on highway vehicle warning light systems across the nation.

The AASHTO *Guidelines for the Selection and Application of Warning Lights on Roadway Operations Equipment* manual remains the best single-source document for warning light system guidance — as determined from the research findings found in NCHRP Report 624. This study recommends the use of amber and white lights as the primary warning light colors due to increased detection by motorists and a high degree of association with maintenance or construction activities (compared to other colors). In addition, the study recommends other warning light characteristics to enhance driver detectability and reaction time such as:

- Use of an asynchronous flashing pattern (flashing from side to side), consisting of slow flash frequencies (≈ 1 Hz) for optimal motorist response
- Use of an LED light with a minimum intensity of 4,000 and 1,650 lumens for daytime and nighttime conditions, respectively (no maximum intensity)
- Placement of warning lights to be seen at any angle of approach, preferably at higher elevations on the vehicle
- Placement of warning lights against solid-colored backgrounds which contrast with the sky

The FHWA's Manual on Uniform Traffic Control Devices (MUTCD) provides authoritative guidance for traffic control measures but remains limited when discussing warning light configurations. It indicates transportation work vehicles may use a warning light device such as high-intensity rotating, flashing, oscillating, or strobe lights to assist with temporary traffic control operations. The lighting colors for transportation work vehicles are not specified. However, conventional sign colors most closely aligned with highway work vehicles include pedestrian warning signs (yellow and fluorescent yellow-green) and temporary traffic control signs (yellow or orange).

Several state agencies, including DOTs, have conducted or sponsored their own internal studies and identified optimal colors to use in highway vehicle warning lights within their own agencies. Those studies include the following:

- Illinois State Police reported that the colors of white, amber, red, and blue could be seen from the greatest distances (in order of greatest to least visibility)
- Indiana DOT reported the color of amber to be the strongest color for visual acuity
- Iowa DOT reported that amber was the primary state DOT color of choice for vehicle warning lights
- Minnesota DOT reported use of amber and blue lights for their supervisory maintenance vehicles
- Ohio DOT reported the use of green warning lights for select highway vehicles
- Texas DOT reported amber to be the most commonly used color for highway vehicle warning lights through a survey conducted by the Texas Transportation Institute

Kentucky law in the form of the Kentucky Revised Statutes (KRS) defines and in some cases, restricts the types of colors that can be employed across different state governmental agencies. KRS considers KYTC vehicles to be classified as public safety vehicles. In this context, KRS states that public safety vehicles must come equipped with "one or more flashing, rotating, or oscillating yellow lights". Furthermore, KRS prohibits the use of other colors such as blue (police) and red (emergency services) on public safety vehicles. The color green is utilized by command post vehicles for incident response. However, KRS does not grant the use of green to any specific state agency.

KTC researchers conducted two external surveys to identify trends and options for vehicle warning light systems. In the first survey, KTC conducted an online survey to identify common LED light colors found in vehicle warning light systems. This survey revealed that LED lights are primarily available in the colors of amber, blue, green, red, and white. KTC followed up the online survey with phone calls to approved KYTC LED vendors and learned that the fluorescent yellow-green color does not exist as a product option. In the second survey, KTC distributed a warning lights survey on the LISTSERV server, a portal for highway officials and representatives. Sixteen state DOT officials responded to this survey. The survey respondents demonstrated 100 percent usage of the color amber and of LED light sources for warning lights installed on their internal state highway vehicles (although other colors and light sources were also used). To increase visibility from different angles of approach, more than 75 percent of the agencies placed warning lights on the vehicle's roof. The agencies showed less consistency, however, in differentiating warning light colors by vehicle type, by light intensities, or by daytime versus nighttime operations.

5.2 Recommendations

The Kentucky Transportation Center recommends the following measures for use in the Kentucky Transportation Cabinet's highway work vehicle warning light program:

1. Use amber and white colors for all KYTC work vehicle warning lights.
2. Use asynchronous flashing pattern (flashing from side to side) consisting of slow flash frequencies (≈ 1 Hz) for vehicle warning lights.
3. Use LED lights with a minimum intensity of 4,000 and 1,650 lumens for daytime and nighttime conditions, respectively
4. Place warning lights on highway work vehicles, preferably at higher elevations on the vehicle, so they can be seen at any angle of approach.
5. Place warning lights on highway work vehicles against solid-colored backgrounds to provide contrast
6. Consult with approved LED vendors to investigate the feasibility of the yellow-green color in warning lights

Appendix A – KYTC Memo on Flashing Red Lights

TRANSPORTATION CABINET
Frankfort, Kentucky 40622
www.transportation.ky.gov/

Steven L. Beshear
Governor

Michael W. Hancock, P.E.
Secretary

MEMORANDUM

TO: Chief District Engineers
Department of Highways Division Directors
Office of Highway Safety Division Directors

FROM: Michael W. Hancock, P.E.
Secretary

SUBJECT: Flashing Red Lights on KYTC Vehicles

DATE: February 17, 2015

Please be reminded that as per KRS Sections 189.20 - 189.50, there should be no flashing, rotating, or oscillating **red** lights on KYTC vehicles. Please make sure all appropriate personnel are aware of these regulations.

c: Steve Waddle
Nancy Albright
Bob Lewis
Bill Bell

Kentucky UNBRIDLED SPIRIT

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Appendix B – KYTC Lighting Packages

PACKAGE 1 (LOWER RISK)
Package 1 is to be utilized for lower risk/exposure activities. All Transportation Cabinet one-half, three-quarter, and one-ton trucks; SUVs; vans; and work sedans shall be equipped with headlight/rear strobe packs. The strobe packs shall be installed to meet the requirements of KRS 189.043 for installation to headlights and the rear yellow lens, utilizing existing lighting lens. Should the rear yellow lens be physically too small to accept the strobe (for example, on the Taurus), then the rear red lens may be used. Additional magnetic top strobe for 360-degree visibility coverage is to be installed. Law enforcement "wig-wag" lighting installation is prohibited.

PACKAGE 2, HIGH-RISK
Package 2 is to be used in addition to Package 1 headlight/rear strobe packs. All Transportation Cabinet one-half-, three-quarter, and one-ton trucks; SUVs; vans; and work sedans engaged in high-risk activities shall be equipped, at a minimum, with a third-generation mini light emitting diode (LED) lightbar (18 to 24 inches with up to 6 heads, all amber front and rear, with 1 red in center facing the rear), which provides 360-degree visibility protection. (High-intensity lighting such as LED lights is far superior to strobe lights in darkness, rain, fog, and snow conditions.)

PACKAGE 3, HIGH-RISK OPTIONAL
Package 3 is to be used in addition to Package 1 or 2. All Transportation Cabinet one-half, three-quarter, and one-ton trucks; SUVs; vans; and work sedans engaged in high-risk activities may be equipped, in addition to Package 1 or Package 2, with an LED lightbar (44 to 49 inches). All light heads are to be amber front and rear, with one or two red in the center facing the rear, providing 360-degree visibility protection. (High-intensity lighting such as LED lights is far superior to strobe lights in darkness, rain, fog, and snow conditions.)

Note: Mounting approval by the Division of Fleet Management shall be required for all vehicles weighing less than one ton. Mounting approval by the Division of Equipment shall be required for all one-ton vehicles.

Additional options include:

- LED NarrowStik, 39-inch: Supplemental LED lightstick to enhance visibility to the rear
- LED ArrowStik, 47-inch: Lightstick with capability of LED directional right, left, or caution-mode arrow to direct and enhance traffic flow
- Spotlight: Portable magnetic, mountable searchlight, or Lightbar Takedowns

Appendix C – District Seven Work Vehicles Survey

Figure A: Vehicle #1 (Front), White Flashing

Figure B: Vehicle #1 (Rear), Red Flashing

Figure C: Vehicle #2 (Front), White/Amber Flashing

Figure D: Vehicle #2 (Rear), Green/Amber/Red Flashing

Figure E: Vehicle #3 (Front), White/Amber Flashing

Figure F: Vehicle #3 (Rear), White/Red Flashing

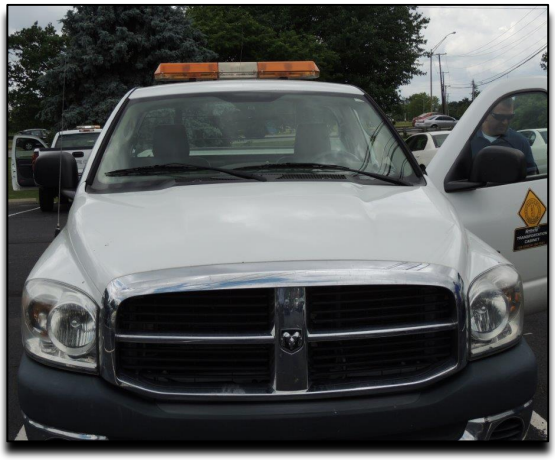

Figure G: Vehicle #4 (Front), White/Amber Rotating

Figure J: Vehicle #5 (Rear), White/Amber Flashing

Figure H: Vehicle #4 (Rear), White/Amber Rotating

Figure K: Vehicle #6 (Front), White/Amber Flashing

Figure I: Vehicle #5 (Front), White/Amber Flashing

Figure L: Vehicle #6 (Rear), White/Amber Flashing

Appendix D – State DOT Survey on Vehicle Warning Lights

KENTUCKY TRANSPORTATION CENTER

Survey of Warning Lights Installed on Vehicles used in Highway Work-Related Activities
LISTSERV State Departments of Transportation
May 29, 2015

In your organization, what colors are presently used as warning lights installed on vehicles used in highway work-related activities? [Please select all that apply]

- ❑ Amber/Yellow (1)
- ❑ Blue (2)
- ❑ Green (3)
- ❑ Red (4)
- ❑ White (5)
- ❑ Other (6)

If other, please list the color/s below.

Does your organization have formal policies and regulations specifying the use of warning lights installed on vehicles used in highway work-related activities?

- ❍ Yes (1)
- ❍ No (2)

If yes, please select those colors authorized for use by policies and/or regulations as warning lights for these vehicles. [Please select all that apply]

- ❑ Amber/Yellow (1)
- ❑ Blue (2)
- ❑ Green (3)
- ❑ Red (4)
- ❑ White (5)
- ❑ Other (6)

If other, please list the color/s below.

Does color of warning lights vary by type of work-related vehicle?

- ❍ Yes (1)
- ❍ No (2)

If yes, please provide the color combinations used by vehicle type.

What type of light source is used as warning lights? [Please select all that apply]

- ❑ Halogen bulb (1)
- ❑ LED (2)
- ❑ Incandescent bulb (3)

If available, please indicate the intensity in terms of lumens per light source.

Does light intensity vary by daytime and nighttime usage?
- ❍ Yes (1)
- ❍ No (2)

Where are warning lights located on work-related vehicles? [Please select all that apply]
- ❑ Roof of vehicle (toward front) (1)
- ❑ Roof of vehicle (toward rear) (2)
- ❑ Inside front windshield (3)
- ❑ Inside rear windshield (4)
- ❑ Front headlight assembly (5)
- ❑ Rear taillight assembly (6)
- ❑ Side of vehicle (7)

If located on the side of vehicle, please specify the location.

What organization do you currently represent?
- ❍ State department of transportation (1)
- ❍ Local highway agency (2)

Please list the name of the selected organization you represent.

Has your organization conducted any recent studies on the types of color combinations appropriate for use on highway work-related vehicles?
- ❍ Yes (1)
- ❍ No (2)

If yes, please indicate whether this study and its results are publicly available and how to obtain

Appendix E –State DOT Survey Responses on Vehicle Warning Lights

Question #1: In your organization, what colors are presently used as warning lights installed on vehicles used in highway work-related activities? [Please select all that apply]

Answer	No. of Responses	Percentage of Total Responses	Survey Responders
Amber/Yellow	16	100%	Alaska DOT, Iowa DOT, Maine DOT, Massachusetts DOT, Michigan DOT, Minnesota DOT, Missouri DOT, New Hampshire DOT, Oklahoma DOT, South Dakota DOT, Texas DOT, Unknown State DOT (2x), Unknown Agency, Washington State DOT (2x)
Blue	4	25%	Alaska DOT, Minnesota DOT, Oklahoma DOT, Texas DOT
Green	0	0%	N/A
Red	6	38%	Massachusetts DOT, New Hampshire DOT, Oklahoma DOT, Unknown State DOT, Washington State DOT (2x)
White	7	44%	Massachusetts DOT, Missouri DOT, New Hampshire DOT, Oklahoma DOT, Unknown State DOT, Unknown Agency, Washington State DOT
Other	0	0%	N/A

Question #2: If other, please list the color/s below.
Answer:

- *Iowa DOT* Response: Begin testing "rear facing white and blue" warning light colors next winter (2015/16)

Question #3: Does your organization have formal policies and regulations specifying the use of warning lights installed on vehicles used in highway work-related activities?

Answer	Response	Percentage of Total Responses	Survey Responders
Yes	15	100%	Alaska DOT, Iowa DOT, Maine DOT, Massachusetts DOT, Michigan DOT, Minnesota DOT, Missouri DOT, Oklahoma DOT, South Dakota DOT, Texas DOT, Unknown State DOT (2x) , Unknown Agency, Washington State DOT (2x)
No	0	0%	N/A

Question #4: If yes, please select those colors authorized for use by policies and/or regulations as warning lights for these vehicles. [Please select all that apply]

Answer	Response	Percentage of Total Responses	Survey Responders
Amber/Yellow	14	88%	Alaska DOT, Iowa DOT, Maine DOT, Massachusetts DOT, Michigan DOT, Missouri DOT, New Hampshire DOT, South Dakota DOT, Texas DOT, Unknown State DOT (2x), Unknown Agency, Washington State DOT (2x)
Blue	4	25%	Alaska DOT, Minnesota DOT, Oklahoma DOT, Texas DOT
Green	0	0%	N/A
Red	5	31%	Massachusetts DOT, Oklahoma DOT, Unknown State DOT, Washington State DOT (2x)
White	5	31%	Missouri DOT, Oklahoma DOT, Unknown State DOT, Unknown Agency, Washington State DOT
Other	0	0%	N/A

Question #5: If other, please list the color/s below.
Answer:

- *Iowa DOT* Response: Current study starting winter of 2015/16 for three years on rear facing white and blue lights on a limited number of snow removal trucks

Question #6: Does color of warning lights vary by type of work-related vehicle?

Answer	Response	Percentage of Total Responses	Survey Responders
Yes	8	50%	Iowa DOT, Massachusetts DOT, Minnesota DOT, Missouri DOT, Texas DOT, Unknown State DOT, Washington State DOT (2x)
No	8	50%	Alaska DOT, Maine DOT, Michigan DOT, New Hampshire DOT, Oklahoma DOT, South Dakota DOT, Unknown State DOT, Unknown Agency

Question #7: If yes, please provide the color combinations used by vehicle type.
Answers:

1. *Unknown State DOT Response*: Incident Emergency Response Truck: Red/White/Amber Maintenance Truck: Red/Amber Plow Truck: Red/Amber Passenger Car: Amber
2. *Minnesota DOT Response*: Blue lights are prohibited on all vehicles except road maintenance equipment and snow removal equipment operated by or under contract to the state or a political subdivision thereof. Authorized emergency vehicles may display flashing blue lights to the rear of the vehicle as a warning signal in combination with other lights permitted or required by this chapter. In addition, authorized emergency vehicles may display, mounted on the passenger side only, flashing blue lights to the front of the vehicle as a warning signal in combination with other lights permitted or required by this chapter. Blue Lights: The following defines on which maintenance vehicles blue lights may be used in addition to amber lights. Blue lights must be mounted on the passenger side only. Blue lights shall not be used on the following vehicles, they shall use amber lights only: Signing, Bridge, Guardrail, Traffic Control, Surveys, Inspection, Materials, Construction and Roadside Maintenance Vehicles/Equipment such as Mowers, Herbicide applicators, etc. Blue lights may be used on the following vehicles, in addition to amber lights: (1) Maintenance Supervisor or Superintendent's vehicle that is frequently used to respond to unscheduled incidents on the roadway or roadway shoulder (high exposure vehicle), (2) a dedicated vehicle utilized for area wide debris patrol only, (3) FIRST vehicle, or (4) Snow Removal Equipment. At this time, no more than 50% of the light bar may be blue. Contact the Area Maintenance Engineer in your district for guidance on the use of blue lights. Any variances from the above must be reviewed and approved by MBMT. Vehicles that are not listed above and currently have blue lights, shall have them removed immediately.
3. *Iowa DOT Response*: As you will see to answers below, the Iowa DOT is about to start a 3 year study adding white and blue rear facing (LED or Strobe). These can only be used while preforming winter snow and ice functions.
4. *Texas DOT Response*: Blue and Amber while not protected by channeling devices. Amber only when behind channeling devices.
5. *Massachusetts DOT Response*: Pickup and sedans - amber and white (note; white is being phased out at the request of the State Police). Snow and ice material spreaders - amber with red rear facing alternately flashing lights. All other on and off road equipment - amber.
6. *Missouri DOT Response*: Maintenance and construction use amber/white Emergency response use red/blue
7. *Washington State Responses*:
    a. Almost all WSDOT vehicles use amber warning lights. The exception is incident response vehicles which use red warning lights and wig-wag headlights only when responding to and during an incident.
    b. Red lights can only be used when they are flashed simultaneously. - Amber lights can be used when they are alternating or simultaneous. - Blue lights can only be used by law enforcement.

Question #8: What type of light source is used as warning lights? [Please select all that apply]

Answer	Response	Percentage of Total Responses	Survey Responders
Halogen	5	31%	Michigan DOT, Minnesota DOT, Unknown State DOT, Washington State DOT (2x)
LED	16	100%	Alaska DOT, Iowa DOT, Maine DOT, Massachusetts DOT, Michigan DOT, Minnesota DOT, Missouri DOT, New Hampshire DOT, Oklahoma DOT, South Dakota DOT, Texas DOT, Unknown State DOT (2x), Unknown Agency, Washington State DOT (2x)
Incandescent	5	31%	Massachusetts DOT, Michigan DOT, Minnesota DOT, Unknown State DOT, Washington State DOT

Question #9: If available, please indicate the intensity in terms of lumens per light source.
Answers:

1. *Michigan DOT Response*: Converting to LED, but still have older models on some vehicles and equipment. SAE Class 1 is desired. All must be visible from at least 500 feet, 360 degrees.
2. *Iowa DOT Response*: The Iowa DOT uses two types of lighting LED and Strobe. There are two settings high and low (low is used mostly at night and high during the daylight time frame). I do not have a listing on lumen output on these setting.
3. *Alaska DOT Response*: Visible in all directions at 500 ft in normal sunlight, 13 Alaska Administrative Code 04.095
4. *Massachusetts DOT Response*: Various

Question #10: Does light intensity vary by daytime and nighttime usage?

Answer	Response	Percentage of Total Responses	Survey Responders
Yes	7	47%	Iowa DOT, Maine DOT, Massachusetts DOT, Minnesota DOT, South Dakota DOT, Texas DOT, Unknown State DOT
No	8	53%	Alaska DOT, Michigan DOT, New Hampshire DOT, Oklahoma DOT, Unknown State DOT, Unknown Agency, Washington State DOT (2x)

Question #11: Where are warning lights located on work-related vehicles? [Please select all that apply]

Answer	Response	Percentage of Total Responses	Survey Responders
Roof of vehicle (toward front)	12	75%	Massachusetts DOT , Michigan DOT, Minnesota DOT, Missouri DOT, New Hampshire DOT, Oklahoma DOT, South Dakota DOT, Texas DOT, Unknown State DOT (2x), Washington State DOT (2x)
Roof of vehicle (toward rear)	13	81%	Alaska DOT, Iowa DOT, Maine DOT, Massachusetts DOT, Michigan DOT, Minnesota DOT, Missouri DOT, New Hampshire DOT, South Dakota DOT, Texas DOT, Unknown State DOT, Unknown Agency, Washington State DOT
Inside front windshield	3	19%	Massachusetts DOT, South Dakota DOT, Washington State DOT
Inside rear windshield	5	31%	Massachusetts DOT, South Dakota DOT, Unknown Agency, Washington State DOT (2x)
Front headlight assembly	4	25%	Massachusetts DOT , Unknown State DOT, Washington State DOT (2x)
Rear taillight assembly	6	38%	Iowa DOT, Massachusetts DOT , Michigan DOT, New Hampshire DOT, Unknown State DOT, Washington State DOT
Side of vehicle	5	31%	Massachusetts DOT , Michigan DOT, Minnesota DOT, Unknown State DOT, Washington State DOT

Question #12: If located on the side of vehicle, please specify the location.
Answers:

1. *Michigan DOT Response*: Depends on the vehicle and the equipment. 360 degrees visibility is the driver for location.
2. *Unknown State DOT Response*: Attach to up-fitter components such as service bodies, racks and behind side windows
3. *Washington State DOT Response*: We have six warning light levels depending on class and function of equipment. Location of lights varies depending upon which level we are lighting to.
4. *Minnesota DOT Response*: MnDOT has a policy that all vehicles have 360 degree coverage by warning lights. These lights can be placed in housings near the rear of a plow truck or as part of the actual light bar placed on top of the unit.
5. *Iowa DOT Response*: Amber 360 degree lighting is mounted center just above and behind the truck cab, rear facing amber (LED or Strobe) lights are mounted in the rear box corners above the stop/turning lights.
6. *Massachusetts DOT Response*: Below dump body between the cab and rear axle angled toward oncoming traffic.
7. *New Hampshire DOT Response*: Strobes on our plow trucks are mounting on top of the mirrors providing a 360 degree view.
8. *Maine DOT Response*: Technically, they are not mounted on the roof. They are right behind the cab, above the roof, on a custom pedestal that allows 360 degree visibility

Question #13: What organization do you currently represent?

Answer	Response	Percentage of Total Responses	Survey Responders
State DOT	15	94%	Alaska DOT, Iowa DOT, Maine DOT, Massachusetts DOT, Michigan DOT, Minnesota DOT, Missouri DOT, New Hampshire DOT, Oklahoma DOT, South Dakota DOT, Texas DOT, Unknown State DOT (2x), Washington State DOT (2x)
Local Highway Agency	0	0%	N/A
Unknown	1	6%	Unknown Agency (No Response)

Question #14: Please list the name of the selected organization you represent.
Answers:

1. Alaska DOT
2. Iowa DOT
3. Maine DOT
4. Massachusetts DOT
5. Michigan DOT
6. Minnesota DOT
7. Missouri DOT
8. New Hampshire DOT
9. Oklahoma DOT
10. South Dakota DOT
11. Texas DOT
12. Unknown State DOT (2x)
13. Unknown Agency
14. Washington State DOT (2x)

Question #15: Has your organization conducted any recent studies on the types of color combinations appropriate for use on highway work-related vehicles?

Answer	Response	Percentage of Total Responses	Survey Responders
Yes	5	31%	Iowa DOT, Michigan DOT, Minnesota DOT, Oklahoma DOT, Texas DOT
No	11	69%	Alaska DOT, Maine DOT, Massachusetts DOT , Missouri DOT, New Hampshire DOT, South Dakota DOT, Unknown State DOT (2x), Unknown Agency, Washington State DOT (2x)

Question #16: If yes, please indicate whether this study and its results are publicly available and how to obtain.

Answers:

1. *Michigan DOT Response*: Not publicly available but considering the use of green strobes with amber on snow removal equipment (snow plows) only.
2. *Minnesota DOT Response*: Yes. MNDOT did a formal study and had a consultant complete the final report.
3. *Iowa DOT Response*: Iowa code restricts DOT vehicles to amber warning lights. The Iowa legislature and the governor just approved the Iowa DOT to conduct a three year test of white and blue rear facing only warning lights on a limited number of snow plow equipment, These will be mounted in line and just below the bottom of the center mounted 360 amber behind the cab and on top of and to the side of the truck box. (approaching from behind, white to the left and blue to the right) these new lights will be in addition to the current lighting package already in use. Along with this study the Iowa DOT has decided to add in the same location as the white and blue light set, new amber rear facing lights on the rest of the snow removal truck fleet. Giving the truck four rear facing amber located in two locations (high and low). The white and blue lights during the testing time frame can only be used while the equipment is preforming winter snow and ice operations.
4. *Texas DOT Response*: Research programs
5. *Oklahoma DOT Response*: Texas Traffic Institute

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