Prepared for:

MDOT State Study No. 277
Best Practices for Lighting and Marking Construction and Maintenance Vehicles and Equipment for Safety

Prepared by:

Dr. Tulio Sulbaran
Mrs. Amani Qasrawi

Dec 2022

MDOT State Study No. 277
Best Practices for Lighting and Marking Construction and Maintenance Vehicles and Equipment for Safety

1.Report No. FHWA/MDOT-SS-277	2. **Government Accession No.**	**3. Recipient's Catalog No.**	
4. Title and Subtitle Best Practices for Lighting and Marking Construction and Maintenance Vehicles and Equipment for Safety		**5. Report Date** Dec 2022 **6. Performing Organization Code**	
7. Author(s) Dr. Tulio Sulbaran – ORCID 0002-2422-5226 Mrs. Amani Qasrawi		**8. Performing Organization Report No.** MDOT State Study No. 277	
9. Performing Organization Name and Address Mississippi Department of Transportation PO Box 1850 Jackson, MS 39215-1850		**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.** Your contract/grant # if applicable	
12. Sponsoring Agency Name and Address The University of Texas at San Antonio 1 UTSA Circle San Antonio, TX, 78249		**13. Type Report and Period Covered** Final **14. Sponsoring Agency Code**	
15. Supplementary Notes			
16. Abstract The purpose of this document is to provide recommendations and guidelines that will help MDOT implement improved lighting and marking standards for both its own fleet of vehicles and equipment as well as the equipment and vehicles used by contractors on DOT projects in order to make roadways safer. The recommendation was based on (1) a qualitative systematic literature review; (2) data obtained from the DOT standards and/or provisions; (3) an analysis of the data and the literature findings.			
17. Key Words Lighting, Marking, Equipment, Work Zone Safety		**18. Distribution Statement** Unclassified	
19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages** 159	**22. Price**

Disclaimer

The University of Texas at San Antonio and the Mississippi Department of Transportation do not endorse service providers, products, or manufacturers. Trade names or manufacturers' names appear herein solely because they are considered essential to the purpose of this report.
The contents of this report do not necessarily reflect the views and policies of the sponsoring agency.

MDOT Statement of Nondiscrimination

The Mississippi Department of Transportation (MDOT) operates its programs and services without regard to race, color, national origin, sex, age, or disability in accordance with Title VI of the Civil Rights Act of 1964, as amended, and related statutes and implementing authorities.

Mission Statements

The Mississippi Department of Transportation (MDOT)

MDOT is responsible for providing a safe intermodal transportation network that is planned, designed, constructed, and maintained in an effective, cost-efficient, and environmentally sensitive manner.

The Research Division

MDOT Research Division supports MDOT's mission by administering Mississippi's State Planning and Research (SP&R) Part II funds in an innovative, ethical, accountable, and efficient manner, including selecting and monitoring research projects that solve agency problems, move MDOT forward, and improve the network for the traveling public.

Notice

The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the views or policies of the Mississippi Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government and the State of Mississippi assume no liability for its contents or use.

The United States Government and the State of Mississippi do not endorse products or manufacturers. Trade or manufacturer's names appear herein solely because they are considered essential to the object of this report.

Forward

This report provides a valuable resource regarding recommendations and guidelines that will allow MDOT to implement better standards for lighting and marking its own vehicle and equipment fleet as well as for contractor vehicles and equipment that is used on DOT projects with the goal of making roadway work safer for everyone. This Mississippi Department of Transportation Study No. 277 "Best Practices for Lighting and Marking Construction and Maintenance Vehicles and Equipment for Safety" was conducted by the University of Texas at San Antonio in collaboration with MDOT. This document will be of particular interest to individuals who plan to implement lighting and marking affixed to construction and maintenance vehicles and equipment in work zones. Other audiences for this document include policymakers, transportation professionals, and students in related fields.

Acknowledgment

The PI from the University of Texas at San Antonio would like to thank MDOT Technical Advisory Committee members for their support and thoughtful comments during the meetings and review of the project reports. The PI would like to give special thanks to the MDOT Technical Advisory Committee (TAC): Billy Owen, Jim C. Willis, Hunt Hutson, Cookie Leffler, Cindy Smith, James Sullivan, and Heath Patterson, for their significant contribution to this project. Additionally, the PI would like to express appreciation to the MDOT Research Division and Cindy Smith. Both MDOT TAC and MDOT Research Division provided important guidance, support, and/or contribution to this collaborative effort.

Table of Content

List of Figures

List of Tables

Executive Summary

The purpose of this document is to provide recommendations and guidelines that will help MDOT implement improved lighting and marking standards for both its own fleet of vehicles and equipment as well as the equipment and vehicles used by contractors on DOT projects in order to make roadways safer. The recommendation was based on (1) a qualitative systematic literature review; (2) data obtained from the DOT standards and/or provisions; and (3) an analysis of the data and the literature findings.

The following is a summary of the results of the literature review, DOT standards, and/or provisions in two areas:

1- Warning Lights Construction and Maintenance Vehicles and Equipment: Based on the literature, the warning light on construction and maintenance vehicles and equipment shall be amber high-intensity LED during the day-work and night-work. The reason for selecting amber is that it produces less glare and less brake activations (according to the literature). The reason for selecting high-intensity is that it provides higher attention-getting than a light source with a lower effective intensity (according to the literature). All warning lights on construction and maintenance vehicles and equipment shall be rotating or flashing, placing at least one warning light bar on top of the cab. The system shall be in full operation condition during all the duration of the required lighting period.

2- Retroreflective Marking of Construction and Maintenance Vehicles and Equipment: It was found in the literature in most state DOT standards that the retroreflective marking on the construction and maintenance vehicles and equipment shall be Red and White. Also, the recommendation from the National Fire Protection Association (NFPA) guidelines for operating vehicles is to use a chevron pattern. The retroreflective surface of the sheeting shall be weather resistant and show no appreciable cracking, blistering, crazing, or dimensional change after two years of unprotected outdoor exposure. The retroreflective marking should be placed on the sides, as well as on the back of the bumper of construction and maintenance vehicles and equipment.

To conclude, it is important to recognize that the findings in the two areas presented above are closely related. Therefore, positive actions and policies in any of the areas are very likely to impact both areas.

Chapter 1- Overview of this Best Practice Research

1.1- Introduction

The mission of the Mississippi Department of Transportation (MDOT) is to provide a safe intermodal transportation network that is planned, designed, constructed, and maintained in an effective, cost-efficient, and environmentally sensitive manner (MDOT, 2020a). MDOT personnel is continuously working towards improving their operations. In 2019, MDOT completed an update to its Strategic Highway Safety Plan (SHSP). Furthermore, beginning in 2016, MDOT adopted its Workplace Safety Manual (WSM) and created permanent, full-time staff positions of statewide and districtwide Safety Officers in an effort to achieve workplace safety for all its workers, including maintenance and construction workers who work along the highways in temporary traffic work zones.

The maintenance and construction of roads and bridges are mostly the responsibility of state and local governments. Almost 97 percent of the 4.1 million miles of road in the United States are under the jurisdiction of state and local governments (ARTBA 2020). MDOT's responsibility to maintain and construct roads and bridges is extremely important as it is the catalyst to efficiently move food, raw materials, manufactured products, and people to provide a competitive advantage in the world marketplace to its citizens. Even during the COVID-19 pandemic, MDOT construction and maintenance crews remained on duty to perform core job requirements such as construction inspections, roadway repairs, and severe weather responses (MDOT, 2020).

1.2- Research Problem and Research Objective

The maintenance and construction of roads and bridges are inherently dangerous. Work zones tend to cause hazardous conditions for drivers and construction workers because they create conflict between construction and maintenance activities and traffic, thus exacerbating the existing traffic conditions (Garber, N., Zhao, M. 2002). Highway workers are at risk of being injured by construction vehicles and equipment movement and by the passing of vehicles. Highway workers working in low-lighting conditions, low visibility, and congested areas have a higher risk of being injured.

Road danger is evident particularly in Mississippi, as in 2016, its road safety was ranked as the 50th worst in the nation. This rank was calculated using 2015 data considering: 1- The number of fatalities per 100 million vehicle miles of travel; 2- The number of DUIs per Capita; and 3- The pedestrian fatality rate per capita (Bernado, 2016). Regrettably, in 2015, 604 crashes resulted in fatalities on public roadways in Mississippi, involving 874 vehicles and 1427 people (NHTSA, 2016a). These 604 fatal crashes are substantially lower than the Mississippi traffic fatalities peak of 949 in 2000 (MDOT, 2014), but it is an increase from the 543 fatal crashes in 2014 (NHTSA, 2016a). The situation has not gotten significantly better as in 2018, in Mississippi, there were 597 Fatal Crashes, and 664 deaths accounting for 22.2 deaths per 100,000 population and 1.62 deaths per 100 million vehicle miles traveled. These deaths per 100,000 population and 100 million vehicles represent the worst and second worst in the nation (IIHS 2020). Also, in 2021, Mississippi had the highest death rate per 100,000 population among all states. This means that, in Mississippi, there were more motor vehicle deaths relative to its population compared to other states. According to the data, people living in Mississippi have a greater chance of being involved in fatal car accidents (NSC, 2023).

In the past six years, MDOT lost five employees due to work zone-related crashes (Leffler, 2023). Unfortunately, MDOT continues to experience numerous injuries to its employees and accidents to equipment. Fatal and life-changing injury (severe) crashes are not limited to Mississippi and are considered a major public health issue in the United States (MDOT 2014). In 2019, an estimated 38,800 people lost their lives to car crashes - a 2% decline from 2018 (39,404 deaths). About 4.4 million people were injured seriously enough to require medical attention in crashes last year, as well as a 2% decrease over 2018 figures (NSC, 2020). This safety situation is a critically important issue for workers in job sites on roadways across the country, whether employed by a DOT or a contractor.

Most work zone crashes occur in the daytime. Passenger vehicles are more likely to be involved in fatal crashes during the day than during the night. Furthermore, fatalities are more likely during the day whenever pedestrians and workers are involved. (Zhang, K., and Hassan, M., 2019). However, work zone crashes during nighttime were more severe than both daytime work zone crashes and non-work zone crashes. (Bai, Y., and Li, Y. 2006). A number of studies support that collisions usually are more severe at nighttime than during the day (Abdel-Aty, M., 2003; Arditi, D., et al. 2007, Gray, R. C., et al., 2008, Pigman, J. G., et al., 1990). Night incident injury severity is also found to increase with speeding, particularly for male drivers. A study showed that light condition was interrelated with the number of vehicles. Compared to 18% (13% out of 70%) of multi-vehicle crashes in poor light conditions, 43% (13% out of 30%) of the single-vehicle crashes occurred in poor light conditions. As opposed to good light conditions (daylight), poor light conditions refer to the conditions such as “dawn”, “dusk”, “dark with streetlights”, and “dark without streetlights” (Bai, Y., and Li, Y. 2006).

The positive safety effects of lighting during regular road operations have also been documented in various reports and publications (FHWA 2012). The Federal Highway Administration (FHWA) / American Association of State Highway and Transportation Officials (AASHTO) international technology scanning program documented (FHWA, 2001) that many countries showed a 20 to 30 percent reduction in the number of crashes when the road lighting was installed. The FHWA Signalized Intersection Informational Guide (FHWA, 2004) reported that adding lighting can reduce nighttime crashes by 50 percent and reduce fatal crashes by 43 percent. Thus, it is expected that improved lighting and marking on work vehicles and equipment in work zones should increase awareness of their presence to the traveling public and hence improve safety for MDOT employees, contractors, and the traveling public.

Generally, the comparison showed that poor light conditions contributed to a larger proportion of fatal crashes than injury crashes. From the study, 32% of the fatal crashes occurred in darkness without streetlights, while this unfavorable light condition only contributed to 13% of the injury crashes. Correspondingly, 22% more injury crashes than fatal crashes (75% vs. 53%) occurred in daylight conditions. The considerable differences indicate that poor light conditions could result in high-severity work zone crashes (Bai, Y., and Li, Y. 2006).

The methods used by DOTs and contractors to light and mark vehicles across the country vary significantly. Thus, the objective of this study is to research the multiple methods used and develop an MDOT document that provides lighting and marking recommendations and guidelines to improve safety practices. These recommendations and guidelines will allow MDOT to implement better standards for lighting and marking on its vehicle fleet as well as for

contractor vehicles and equipment that is used on DOT projects with the goal of making roadways work safer for everyone.

1.3- Lighting and Illumination

Previous research has shown lighting to be one of the most important factors in nighttime construction. Safety in the work zone, quality of work, and workers' mortality are all directly related to work zone lighting (Anani, S., 2015). Road lighting is typically provided to improve the safety of motorists and pedestrians, as several previous studies have found that the risk of accidents generally increases in darkness (Johansson, O., et al., 2009; Jackett, M., Frith, W. 2013).

Lighting and marking affixed to construction maintenance vehicles and equipment need to be carefully specified by state DOTs, as low levels of illuminance on nighttime construction sites can negatively affect the quality and safety of construction work, and excessive levels can lead to unnecessary waste in lighting cost, glare to road users, and light trespass to adjacent property (Finley, M. D., et al., 2013) Illumination, lighting, and glare are significant terms in this research project and therefore are essential to understand:

- **Illumination:** the amount of light reaching a unit area of surface at a given time. Usually measured in lux in the International System of Units or Foot-Candle (FC) in the English Units. One lux is the illuminance cast by one lumen one meter away in one square meter (lm/m2), and one foot-candle is the illuminance cast on a surface by one candela source one foot away in one square foot (See Figure 1). The one-foot candle equals approximately 10.764 lux (DOT, 2018). In short, illumination is the act of illuminating or supplying light with a surface. Illuminance in which the light falling on that surface (measured in lux or foot-candle) may be increased by increasing the intensity of a light source, increasing the number of light sources, or decreasing the distance of the light sources from the surface area (Anani, S. 2015).

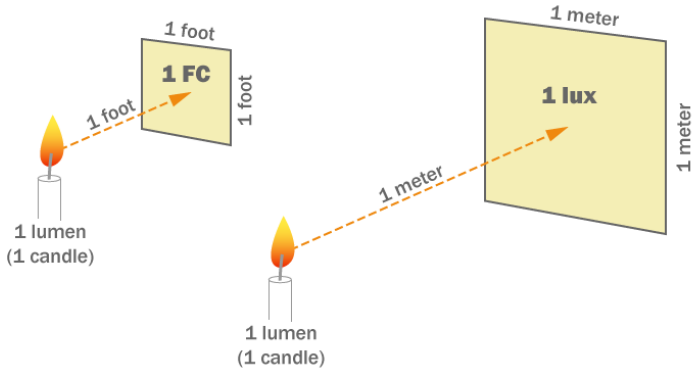


Figure 1. Lux and Foot-Candle (Liberal D., 2020)

- **Lighting:** is the equipment used to provide illumination. The amount of luminance (or luminous flux) emitted by the lighting equipment is measured in candelas per square meter (cd/m2 (DOT, 2018). The two main aims of good lighting are 1. To reveal the task effectively, and 2- To reveal appropriately the general surroundings (Pritchard, D. 2015). Lighting requirements for nighttime highway construction need to be carefully specified by each state DOT, as low levels of illuminance on nighttime construction sites can negatively

affect the quality and safety of construction work, and excessive levels can lead to unnecessary waste in lighting cost, glare to road users, and light trespass to adjacent property (Hyari, K., & El-Rayes, K. 2006). Work zone lighting can be achieved with different types of systems, such as temporary lighting systems and portable lighting systems, which include portable light towers, balloon lights, other trailer-mounted lights, and light stands (see Figure 2).

(a) (b)

Figure 2. (a) Portable Trailer-Mounted Light Tower (Goree, 2019) and (b) Balloon Lights (ASAA, 2020).

The difference between illumination and lighting (luminance) is that illumination is the amount of light that hits a surface (i.e., Road) while luminance is the amount of light leaving an object (i.e., Portable Light Tower) (see Figure 3).

Figure 3. Luminance Vs. Illuminance (Konica Minolta, 2020)

- **Glare:** a condition of vision in which there is discomfort or a reduction in the ability to see details or objects, caused by an unsuitable distribution or range of luminance, or by extreme contrasts. (1) The luminance source could be natural (i.e., Sunlight) or artificial sources (i.e., Light Stands) (see Figure 4).

Figure 4. Blinding Glare Caused by Lighting in A Work Zone (Anani, S., 2015)

1.4- Temporary Retroreflective Equipment Marking

Nighttime construction is a necessity in the transportation industry for multiple reasons, such as a- Lower impact on traffic and delaying motorists (than during the day), b- Workers not exposed to as much automotive emission, c- More lanes can be closed at night to allow for work activities, among others (WarrenCat, 2018). However, during the night there is lower visibility (than during daylight). This lower visibility is mitigated with site lighting and construction vehicles and equipment lights. Additionally, retroreflective materials are commonly used on workers' garments, channelizing devices, signage, and pavement marking (temporary and permanent). To a lesser extent, retroreflective materials are used in construction equipment.

Retroreflective materials return a large portion of the directed light beam to its source as shown in Figure 5. A retroreflective material directs most of the reflected light back along the line of incidence, that is, back toward the light source. Thus, the reflector is seen as brightest when the observer's eye is close to the light source.

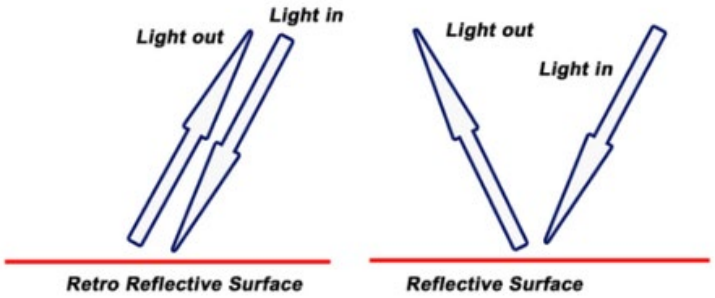


Figure 5. Retroreflective Vs. Reflective Surfaces

Retroreflectivity is necessary to delineate the correct path for road users, especially at night and during inclement weather see Figure 6. Recent innovations in temporary pavement marking in work zones include wet reflective pavement marking elements and sequential lighting devices (FHWA, 2014).

Figure 6. Wet-Reflective Markings Under Wet Conditions. (FHWA, 2014).

1.5- Overall Research Methodology

The proposed research plan to conduct this project was divided into tasks. Each task had a pre-defined set of goals and deliverables to be accomplished. Table 1 summarizes each task's goals and tangible deliverables for each of the project tasks. Unless noted otherwise, these tangible deliverables are the responsibility of the research team. Table 1 also includes the MDOT responsibilities for each task.

Table 1. Project Proposed Tasks with Corresponding Deliverables.

Tasks #	Task Goals	Tangible Deliverables
Task 1	**Paperwork, Kick-off, and Scope Fine-Tune** ▪ Upon receiving notice to proceed from MDOT, the contract paperwork at the University will be processed and all appropriate signatures to open accounts and initiate the project will be obtained. ▪ Kick-off meeting with project MDOT Technical Advisory Committee (TAC) to discuss possible fine-tune/improvements to the proposed project and identify initial potential project stakeholders. ▪ Disseminate Updated proposal to project TAC and initial project stakeholders	▪ Executed Contract ▪ Fine-tuned/improved proposal ▪ List of initial project stakeholders ▪ Send fine-tuned/improved proposal to project TAC and initial project stakeholders
	MDOT responsibilities: Provide notice to proceed (NTP) and sign appropriate documents. *MDOT responsibilities*: Identify MDOT stakeholders and outside stakeholders such as other State Agencies, Federal Agencies in Mississippi, Associations, Contractors, Vendors, among others.	
Task 2	**Literature Review** ▪ Perform a literature review to gather information from prior studies on the topic of lighting and marking vehicles and equipment for DOT and Contractor use.	▪ Eight-to-twelve-page document summarizing literature review on lighting and marking vehicles and equipment for DOT and contractor use.
	MDOT responsibilities: Share any leads to relevant literature.	
Task 3	**DOTs Laws, Standards and/or Provisions** ▪ Conduct a web-based search of laws, standards, color effect (i.e., green), and/or Provisions that some of the other state DOTs have implemented for various light and marks on vehicles and equipment. ▪ Develop and conduct a survey to elicitation information about DOTs Laws and Standards (and if necessary, conduct follow-up phone calls)	▪ Four-to-eight-page document summarizing laws and standards used by other states DOT to lighten and mark vehicles and equipment in work zones
	MDOT responsibilities: Share leads about states DOTs that have implemented lighting and/or marking laws and/or standards. Provide the names of possible people to reach by phone at DOTs.	

Table continues next page

Table Continuation from previous page

Tasks #	Task Goals	Tangible Deliverables
Task 4	**Progress Meeting and Presentation** ▪ Present findings from the literature review and research that may/will include industry research and other state DOTs and contractor's practices/standards.	▪ Fifteen-to-thirty slide presentations focusing on the main factual highlights of vehicles and equipment lighting and marking. ▪ Stakeholders Invitation
	MDOT responsibilities: Provide space for meetings at the MDOT building and encourage stakeholders to participate.	
Task 5	**Compare Literature, Laws, and Standards** ▪ Determine the similarities and differences between the lighting and marking methods found in the literature, laws, and standards ▪ Provide strengths, weaknesses, limitations, and/or usage of each lighting and marking method	▪ Four-to-eight-page document summarizing strengths, weaknesses, limitations, and/or usage of each lighting and marking method
	MDOT responsibilities: Identify any of the strengths, weaknesses, limitations, and/or usage that while applicable in other places are not applicable in Mississippi (perhaps due to regulatory restrictions).	
Task 6	**Final Presentation, Report, and Close-out** ▪ Prepare a two-page technical brief ▪ Prepare final research presentation and report, including recommendations and guidelines for lighting and marking of construction and maintenance vehicles and equipment for both DOT and Contractors. ▪ Ensure that final deliverables and invoices are submitted by the University	▪ Twenty-to thirty-page final report with recommendations and guidelines for lighting and marking for the state of Mississippi ▪ Research Project close-out documents
	MDOT responsibilities: Provide space for meeting at the MDOT building and encourage stakeholders to participate. Approve final report and presentation. *MDOT responsibilities*: Approve close-out documents	

1.6- Summary

The Mississippi Department of Transportation (MDOT) faces the significant challenge that based on the number of fatalities per 100 million vehicle miles of travel, number of DUIs per capita, and pedestrian fatality rate per capita; Mississippi's road safety was ranked in 2016 as the 50th worst in the nation (Bernado, 2016) and in 2018 among the worst. This safety situation is a critically important issue for Mississippi traveling public and workers on the roadways.

The traveling public and workers in Mississippi deserve safer roadways. Therefore, MDOT partnered with the National Strategy on Highway Safety and launched a campaign entitled "Toward Zero Deaths" (MDOT, 2014). One of the methods to achieve this important goal is to improve the practices of lighting and/or marking vehicles and equipment in MDOT work zones. Improved lighting and marking on work vehicles and equipment should increase awareness of their presence to the traveling public and hence improve safety for MDOT employees, contractors, and the traveling public.

Lighting and marking methods used by DOTs and contractors across the country vary significantly. Thus, the objective of this study is to research the multiple methods used and

develop an MDOT-improved safety practice document that provides lighting and marking recommendations and guidelines.

These recommendations and guidelines will be of great benefit to MDOT. They will allow MDOT to implement better standards for lighting and marking its vehicle fleet as well as for contractor vehicles and equipment that is used on DOT projects with the goal of making roadways work safer for everyone.

Chapter 2 – Literature Review on Lighting and Retroreflective Marking of Construction and Maintenance Vehicles and Equipment

2.1- Introduction

This chapter shows the findings of previous research projects, considering the different methods of equipment lighting and marking, and how they have been implemented. As mentioned in the previous chapter, there is an increase in highway construction and maintenance projects. There has been also an increase in the number of accidents via passing cars and operating vehicles, putting both workers' and road drivers' lives at risk. Some of the factors that cause this increase can be identified as the equipment lighting and marking.

Equipment color, lighting, and marking can sometimes be confusing for both pedestrians and drivers. Based on different research, the color of the equipment (vehicle) and the color of the lighting can show what provides more visibility. Also, there are different types of lighting, such as flashing, rotating, etc., that should be taken into consideration to provide clear visibility. In addition, the intensity of a retroreflective marking can reduce the number of accidents.

2.2- Research Methodology for Literature Review

As mentioned in the previous chapter, the building block of this best practice research project was the current state-of-the-art knowledge. The specific approach used in this research was a qualitative systematic literature review, which is a method of comparing findings from qualitative studies (Grant & Booth, 2009). The qualitative systematic literature review was conducted using the following four phases:

Phase 1 - Design the literature review,
Phase 2 - Conduct the literature review search,
Phase 3 - Analysis of the literature obtained from the search, and
Phase 4 - Structuring and writing up the review.

Phase 1 - Design the Literature Review.

During this phase, three research databases were selected: 1- The University of Texas-San Antonio (UTSA), 2- Google Scholars, and 3- Google, (see Table 2). These three databases were selected as they provided the researcher access to the full papers. In addition to selecting the databases, specific search terms were used. Several iterations of multiple search terms were used, shown in Table 3. These terms were used because they provided their results and showed relevant previously conducted research papers relevant to this research project. Finally, inclusion and exclusions were added to the search term in Table 4.

Table 2. Database Used to Find Research Articles/Papers

Database:
Database UTSA – ProQuest
Database – Google scholar
Database – Google

Table 3. Search Term Keywords Used in the Databases to Find Articles/Papers

Keywords:
Warning lights in highways
Flashing warning lights
Work zone warning lights
Visibility and maintenance in highway work zone
Dump truck reflective tape requirements
Construction equipment marking
Striping recommendations for the dot
Truck lighting requirements

Table 4. Inclusions/Exclusions Used in the Databases.

Restriction:
Only in Titles
Only in Articles

Phase 2 - Conduct the Literature Review Search

When screening the article for the first time the title could be related, but in some cases when looking deeper, it's not, and vice versa. Therefore, the abstract of the paper and the conclusion/summary were read and if the content was considered relevant the full paper was collected (downloaded) for analysis.

Phase 3 - Analysis of the Literature Obtained from the Search

After the papers were collected, each paper was reviewed, and the appropriate content was abstracted to be included in this report. Since most of the literature found was descriptive in nature, a qualitative approach was used to determine the content to be abstracted. The abstraction consisted of the statement of fact found on the papers with the proper referencing (i.e.: authors, years published, title, publication avenue). Also, during this phase, the references in the literature found were reviewed if relevant to this research project. These additional references were analyzed using the same approach described in this paragraph.

Phase 4 - Structuring and Writing Up the Review

The findings from the research review were organized into two main areas: 1- Lighting of Construction and Maintenance Vehicles and Equipment, and 2- Retroreflective Marking of Construction and Maintenance Vehicles and Equipment. In each one of those two areas, the statement of facts obtained was grouped based on their relevance to inform the best practices for safety as shown in the result section of this chapter.

2.3- Results/Findings on Lighting and Retroreflective Marking of Construction and Maintenance Vehicles and Equipment

2.3.1 – Lighting of Construction and Maintenance Vehicles and Equipment

The Manual on Uniform Traffic Control Devices (MUTCD) recommends that lighting devices be present in temporary traffic control (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 (See Figure 7, Figure 8) (Howell, B., et al.. 2015).

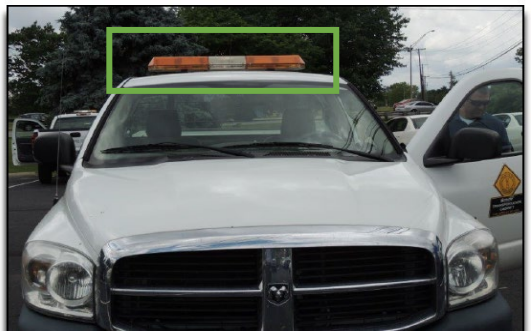


Figure 7. White/Amber Rotating (Howell, B., et al., 2015).

Figure 8. White/Red Flashing (Howell, B., et al., 2015).

2.3.1.a- Construction and Maintenance Vehicles and Equipment Warning Lights Color

The table below shows the results of using different vehicle warning light configurations and their effect on average speed in five different locations. Vehicle speeds when the yellow and blue light combination was displayed were significantly lower than when only a yellow light was displayed in tow locations. At the other three sites, speeds were not significantly different between these two warning light configurations. It is noteworthy that there were no noticeable variations in the average speeds recorded at any of the locations when comparing the yellow/blue/red (or blue/red) warning light to the yellow warning light only. Additionally, the presence of yellow and blue strobes with red strobes in the vehicle tail lights did not lead to a considerable reduction in speed at site 1 in comparison to the yellow-only configuration, regardless of whether it was during the day or night study period (See Table 5) (Ullman, G., et al., 1998).

Table 5. Effect of Warning Light Colors on Average Speeds (Ullman, G., et al., 1998).

Site	Average Speed, mph				
	Yellow Only	Yellow/Blue	Yellow/Blue/Red	Yellow/Blue (Strobe)	Yellow/Blue/Red (DPS)
1: Day	68	71	71	66	N/A
Night	60	58	58	60	61
2: Day	61	56*	63	58	N/A
3: Night	59	56	56**	N/A	58
4: Night	N/A	N/A	N/A	N/A	N/A
5: Night	60	54*	61**	N/A	59

* Significantly Lower (α=0.05) than the yellow only light condition
** The motorist assistance patrol in Houston utilizes a red and blue warning light configuration
N/A data not available
Note: 1mph=1.6kmph

Although significant differences in warning light color configuration were not always present at each site, the presence of warning lights, in general, did affect braking application relative to a normal (no warning light) condition. This is evident in the fact that brake application rates at three of the four sites were significantly greater than zero for all warning light color configurations, including yellow only. At Site 3, the braking percentage associated with the yellow light only was not significantly higher than zero but were for the yellow/blue and yellow/blue/red configurations (See Table 6) (Ullman, G., et al., 1998).

Table 6. Effect of Warning Light Colors on Brake Light Activations. (Ullman, G., et al., 1998).

Site	Percent of Traffic Activating Brake Lights				
	Yellow Only	Yellow/Blue	Yellow/Blue/Red	Yellow/Blue (Strobe)	Yellow/Blue/Red (DPS)
1: Day	N/A	N/A	N/A	N/A	N/A
Night	3.9	9.3*	9.5*	9.1*	4.5
2: Day	N/A	N/A	N/A	N/A	N/A
3: Night	1.6	5.4	7.9*	N/A	15.8*
4: Night	14.9	14	20.4**	N/A	N/A
5: Night	2.2	3	4.2*	N/A	11.3*

* Significantly Lower (α=0.05) than the yellow-only light condition
** The motorist assistance patrol in Houston utilizes a red and blue warning light configuration.
N/A data not available

The combination of yellow and blue lights may have some incremental benefit above and beyond that of a yellow light only. However, this combination does not generate quite as many brake light activations as the yellow/blue/red warning light configuration (Ullman, G., et al., 1998).
A study was conducted to evaluate different lighting configurations for work zone warning lights and their impact on driver behavior in a work zone. The summary in Table 7 simplifies the comparison of different lighting setups, making it easier to identify their impact on driver

behavior and lane choices. Drivers using the lane furthest from the work zone will naturally reduce danger to workers (MnDOT, 2013).

Each of the lighting options reduced driver speeds but by relatively small amounts. Lower are lights located below the strobe lights (See Figure 9 and Figure 10). The Amber Blue without Lower reduced speeds the most, by 5.8 miles per hour (9.1%) at the location where this particular warning light configuration was used relative to the average speed in the test zone. The All-Amber Bar reduced speeds the least, by 3.1 miles per hour (4.7%) (MnDOT, 2013). The light options had a significantly greater impact on driver lane choices. Lane choices refers to the lane that the drive select drive on the road. In the test of the full-width Amber Blue with Additional Amber Blue Lowers, 99% of drivers used the left lane while passing the patrol vehicle. This was a significant improvement over the Double Rotator which are light that are designed to rotate two patterns in opposite direction (see Figure 11), which caused only half of drivers to use the left lane to pass the patrol vehicle. The Amber Blue with Additional Amber Blue Lowers also attracted attention at a distance. At the start of the test area 400 meters from the patrol vehicle, almost nine out of ten drivers had already moved to the left lane. This is much greater than the 23% of drivers who selected the left lane in the control test (MnDOT, 2013). While the Amber Blue with Additional Amber Blue Lowers was most effective at causing drivers to choose the left lane, several other options were nearly as effective. The All-Amber Bar, Amber Bar with Amber Lowers, and Amber Blue without Lowers each caused approximately 90% of drivers to use the left lane when passing the patrol vehicle, although drivers were somewhat slower to move to the left lane. In tests of each of these options, at least 25% of drivers were still in the right lane 200 meters from the patrol vehicle (MnDOT, 2013).

Table 7. Summary of Lighting Impacts on Speed and Lane Choice (MnDOT, 2013)

Type of light	Impact on Speed		Impact on Lane Choice	
	Overall average speed	Average speed at patrol vehicle	Percentage of vehicles in right lane 400 m from patrol vehicle	Percentage of vehicles in right lane at patrol vehicle
Control	66.6 mph	63.5 mph	78%	77%
Double Rotator	67.0 mph	62.7 mph	69%	48%
LED Beacon	67.6 mph	62.3 mph	75%	54%
Mini Bar	66.2 mph	62.3 mph	54%	27%
All Amber Bar	65.0 mph	61.9 mph	47%	11%
Amber Bar with Amber Lowers	64.1 mph	59.6 mph	45%	13%
Amber Blue without Lowers	63.6 mph	57.8 mph	11%	8%
Amber Blue with additional Amber Blue Lowers	64.2 mph	60.1 mph	11%	1%

Figure 9. Amber Bar with Amber Lowers (MnDOT, 2013)

Figure 10. Amber Blue with Additional Amber Blue Lowers (MnDOT, 2013)

Figure 11. Double Rotator (MnDOT, 2013)

Another study was conducted at freeway locations in San Antonio and Houston where they investigated the effect of selected alternative vehicle warning light color configurations on vehicle speeds, lane choice, and braking activity (Ullman, G. L., 2000). Researchers found a few significant reductions in speeds at a few sites (but not all) for the amber-and-blue warning light color combination as compared with speeds observed when only an amber warning light configuration was used. Interestingly, the presence of a Department of Public Safety (DPS) law enforcement vehicle positioned on the shoulder with its lights flashing did not yield any greater reductions in average speed than did the Texas Department of Transportation (TxDOT) courtesy patrol vehicle positioned at the same location with only amber warning lights activated (Ullman, G. L., 2000).

Lane distribution percentages and lane-changing frequencies were inconclusive as to whether warning light color configuration affected these performance measures. However, analysis of brake-light applications did indicate a trend toward increased brake usage for the red, amber, and blue light combination as compared with the amber-light-only configuration. There was also evidence that the amber-and-blue light combination may also result in slightly more frequent brake applications, although not as many as for the red, amber, and blue combination. Also, the presence of a law enforcement vehicle at two out of three sites resulted in significantly more frequent brake-light activations than a TxDOT courtesy patrol vehicle outfitted with the same warning light color combination (See Table 8) (Ullman, G. L., 2000).

Table 8. Effect of Warning Light Colors on Brake-Light Activations. (Ullman, G. L., 2000).

Site	Percent of Traffic Activating Brake Lights					
	Control (no lights)	**Amber-only**	**Amber/Blue**	**Amber/Blue/Red**	**Amber/Blue (strobe)**	**Amber/Blue/Red (DPS)**
1: Day	N/A	N/A	N/A	N/A	N/A	N/A
Night	3.4	3.9	9.3*	9.5*	9.1*	4.5
2: Day	N/A	N/A	N/A	N/A	N/A	N/A
3: Night	1.8	1.6	5.4	7.9**	N/A	15.8*

4: Night	N/A	14.9	14	20.4**	N/A	N/A
5: Night	3.1	2.2	3	4.2*	N/A	11.3*

* Significantly Lower (α=0.05) than the Amber-only light condition
** The motorist assistance patrol in Houston utilizes a red and blue warning light configuration
N/A data not available

The fact that speeds were lower at two sites when the amber and blue light combination was tested suggests that this combination can have the desired speed-reducing effect in some instances. This would indicate a need to maintain the current TxDOT policy to allow blue and amber lights to be used together on those vehicles used for activities that are more hazardous. However, similar speed reductions were not evident when the amber, blue, and red light combination or even when a law enforcement vehicle was used. Consequently, it is not certain if the reductions were truly influenced by the presence of the warning lights or by some other factor that could not be controlled. Researchers believe that the brake-light activations may be a purer measure of the potential impact of warning light color configurations on driving behavior. Specifically, a definite trend toward increased frequency of brake activations was evident as colors were added to the basic amber light used on most service (construction, maintenance, utility, and so on) vehicles. Furthermore, the presence of other enforcement cues (i.e., the law enforcement vehicle) further increased this type of response by motorists. According to these data, the combination of amber and blue lights may have some incremental benefit above and beyond that of an amber light only. At the same time, this combination did not generate quite as many brake-light activations as the amber, blue, and red warning light combination (Ullman, G. L., 2000).

According to the Texas Transportation Code for lighting standards for highway maintenance or construction vehicles and service vehicles. Highway maintenance or construction vehicles shall use flashing amber lights and may use simultaneous amber and blue warning lights in the following situations (TxDOT, 2019):

- Snow and ice removal.
- In a mobile operation where the work moves continuously or intermittently (stopping approximately up to 15 minutes).
- When responding to or parked at an incident.
- When employees must be out of the equipment and in a lane of traffic, channeling devices are not positioned to close the lane to adjacent traffic.
- When working on or near the edge of the shoulder (e.g., edge repair, sign installation/repair, guardrail inspection, debris removal, shoulder maintenance, etc.) outside the protection of a standard work zone.

Kentucky Transportation Center (KTC) researchers conducted a study on Kentucky Transportation Cabinet (KYTC) highway vehicle warning light systems to determine the best characteristics for enhancing the 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.

(Howell, B., et al., 2015). The Kentucky Transportation Center recommends using amber and white colors for all KYTC work vehicle warning lights in their highway work vehicle warning light program (Howell, B., et al., 2015).

An evaluation plan was prepared in 2012- 2014 for the Ohio Department of Transportation (ODOT), to reduce accidents involving snowplow trucks, using a multi-color warning system that would decrease accidents. Some of ODOT's recommendations: incorporate all Class 1A intensity LED lights and create a multi-color system using Green/White and Amber. Evaluating accident reporting and cross-referencing light installation to determine if accident reduction has occurred (ODOT, 2021).

The State of Connecticut Department of Transportation (CDOT), requested to add green flashing lights in combination with amber to snow and ice fleet to increase safety and visibility. The Ohio Department of Transportation initiated the use of green flashing lights in combination with amber and white in 2012 and retrofitted approximately 1600 trucks across its fleet with the new system. The change resulted in a dramatic reduction in rear-end collisions and accidents over the past years. (CDOT, 2019). Also, the Michigan Department of Transportation reports after adding green flashing lights to the fleet, they haven't had any rear-end collisions for the past 2 years (CDOT, 2019). However, most recently, the equipment lighting policy for Ohio Department of Transportation changed to mandate distinct amber flashing lights on ODOT vehicles, ensuring easy identification during highway maintenance, snow removal, and construction. Lighting can be photo strobes or LEDs, with amber color differentiating ODOT vehicles from emergency services. Dump truck and ancillary equipment safety lighting will be the responsibility of, and issued from, the Office of Equipment Management which will determine the lighting styles and arrangements (ODOT, 2023)

Smith et al., researched the visual performance of Traffic Management Assistants (TMAs) in clear weather driving conditions in New Zealand. The study showed that using 340 mm diameter flashing strobe lights was more effective than rotating beacons in improving TMA visibility and eliciting faster responses from drivers. It also recommended mounting lights above the arrow board and warning system, operating warning lights asynchronously when arrow board lights were not in use, and using wide retroreflective tape around the arrow board edges to improve driver recognition by at least 125 feet. In summary, the study showed that an all-amber light bar system with rotating elements was effective for mobile operations, a combination of rotating beacons and flashing strobe lights worked well for both mobile and stationary operations, and using blue and amber rotating beacons, as opposed to amber lights only, led to a significant reduction in vehicle speed (Smith et al., 2006)

The single flash pattern for amber warning lights does not provide sufficient conspicuity during the daytime. As such, the single flash amber lights should not be used as part of the warning light configuration during daytime operations. White is the most used color after amber among state DOTs. However, it is not recommended for use due to glare concerns during nighttime operations. The other commonly used colors by state DOTs, blue and red are prohibited in Michigan by legislation (Zockaie et al., 2020).

A study was conducted by Michigan Department of Transportation to enhance the visibility and safety of winter maintenance trucks (WMTs) during operations in adverse weather conditions. It

mainly focused on the use of green warning lights as an alternative to traditional amber lights on WMTs. The results as shown in Table 9 suggest that the addition of green warning lights to WMTs improves visibility. These improvements are anticipated to result in safer interactions between the traveling public and WMTs, particularly during winter maintenance operations (Zockaie et al., 2020).

The study measured 1-conspicuity during daytime and 2-glare at nighttime of different light configurations. The six light configurations for the study are shown in Table 9. The resulting relationship between the two measurements for the six light configurations is shown in Figure 11. For example, the LC32 configuration has very high conspicuity during the daytime, but it has a high glare during the night. Therefore, a better option could be LC35, LC23a, LC19, or LC27 because although they have lesser conspicuity during daytime they also have a much lower glare during the night. The findings of the dynamic experiment suggested that adding green light increased the conspicuity significantly, while the all-amber case had the lowest conspicuity and glare (Zockaie et al., 2020).

Table 9. Dynamic Experiment Under Clear Weather Conditions – Comparing Average Conspicuity (Daytime) and Average Glare (Nighttime) For Six Light Configurations (Zockaie et al., 2020)

Light Configuration	Beacon Color (Flash Pattern)	LED Color (Flash Pattern)
LC03	Amber (Quad)	Amber (Single)
LC19	Amber (Quad) + Green (Single)	Amber (Quad)
LC23a	Amber (Quad) + Green (Single)	Green (Single)
LC27	Amber (Quad)	Amber (Quad) + Green (Single)
LC32	Green (Quad)	Amber (Quad) + Green (Quad)
LC35	Amber (Quad) + Green (Single)	Amber (Quad) + Green (Single)

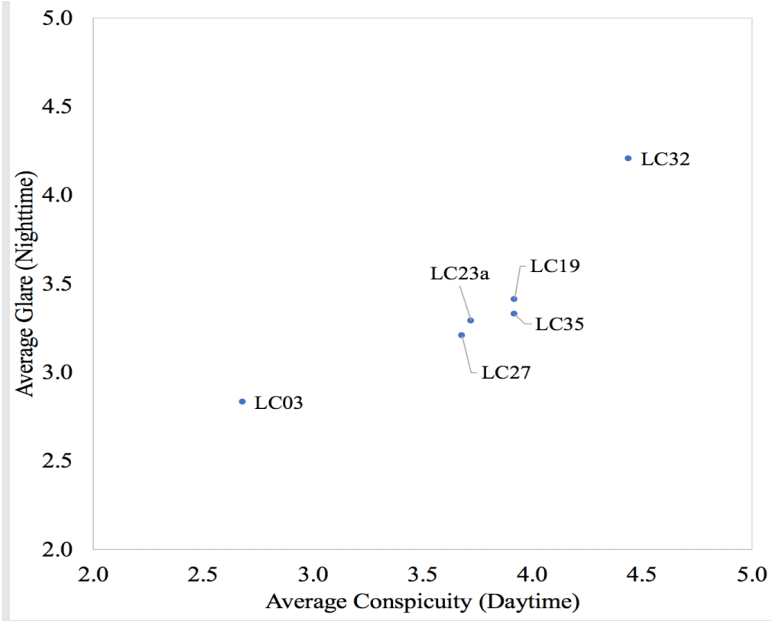


Figure 12. Dynamic Experiment Under Clear Weather Conditions – Comparing Average Conspicuity (Daytime) and Average Glare (Nighttime) For Six Light Configurations (Zockaie et al., 2020)

According to the results, the light configurations were classified into three different clusters: low conspicuity or glare, moderate conspicuity or glare, and high conspicuity or glare. If a statistically significant difference is not observed between a light configuration of a cluster and the light configurations of the other two clusters, it is included in both clusters. Figure 13, shows that the light configuration LC32 provides a disturbing glare and is not a proper configuration. On the other hand, LC03 does not provide sufficient conspicuity. Four light configurations of LC19, LC23a (modified Michigan Department of Transportation current configuration), LC27, and LC35, were the most capable in terms of improving visibility while producing a bearable glare discomfort to travelers (Zockaie et al., 2020).

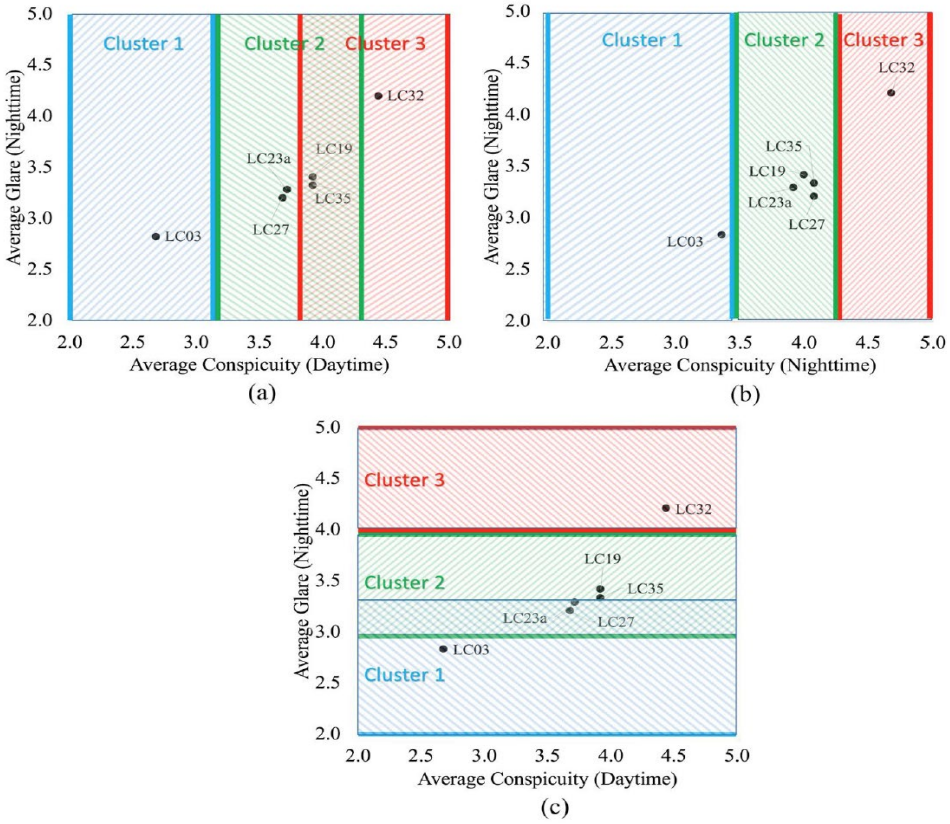


Figure 13. Dynamic Experiment Under Clear Weather Conditions. Warning Light Configuration Clusters Based on Tukey Test for Conspicuity and Glare Measures: (A) Daytime Conspicuity Clusters, (B) Nighttime Conspicuity Clusters, And (C) Nighttime Glare Clusters. (Zockaie et al., 2020).

"The Michigan Department of Transportation conducted a study that specifically examined the use of green lights in winter maintenance, particularly in snowy and nighttime conditions. According to the study, shades of green were found to be more discernible by human eyes compared to other colors. Dr. Bernie Tekiele of the Michigan Eye Institute explained, 'Our visual system would be more attracted to a bright green light versus a bright white flashing light in a heavy snowstorm.' The study emphasized the sensitivity of the human visual system to the green/yellow spectrum (Hill, 2016). The Kent County Road Commission (KCRC) has already piloted the use of green lights for the past two years. Jerry Byrne, KCRC deputy managing director, noted that during this period, there were no reported rear-end accidents involving the trucks equipped with green lights. He emphasized their goal of reducing accidents and injuries

by using green lights in winter maintenance operations (Hill, 2016). It is important to note that the Michigan study focuses on winter maintenance, specifically in snowy and nighttime conditions, which differ significantly from those in Mississippi.

In a research project aimed to improve safety in mobile work zones by evaluating the effectiveness of green lights on Truck-mounted Attenuators (TMAs). Two phases were conducted: a simulator test with four configurations and a field test with two configurations. The results of the simulator test are shown below. The participants were asked to score different attributes of the various TMA configurations during the daytime on a scale of 1-10, with 1 representing the "lowest" and 10 representing the "highest". These attributes included visibility of work zone vehicles, awareness of work zones, clear recognition of arrow direction, and easiness on the eyes (Brown et al., 2018).

Table 10. shows the results of the ratings. Notably, the amber/white TMA had a significantly lower score only in the "easy on the eyes" category, while the green-only and green/amber TMAs scored significantly better in Awareness of Work Zone" and "Visibility of Work Zone Vehicles" (Brown et al., 2018).

Table 10. Rating for Daytime TMA Configuration (Brown et al., 2018)

	Visibility of Work Zone Vehicles			
	Mean	**Median**	**Diff.**	**Confidence Level**
Amber/White	8.3	9.0	Baseline	
Green-only	7.2	8.0	-1.1	92.8%***
Green/Amber	8.0	8.0	-0.3	50.6%
Green/White	7.7	8.0	-0.6	78.2%
	Awareness of Work Zones			
	Mean	**Median**	**Diff.**	**Confidence Level**
Amber/White	8.9	10.0	Baseline	
Green-only	7.8	8.0	-1.1	95.0%**
Green/Amber	8.5	9.0	-0.4	67.4%
Green/White	8.1	8.0	-0.6	86.8%
	Clear Recognition of Arrow Direction			
	Mean	**Median**	**Diff.**	**Confidence Level**
Amber/White	7.1	7.0	Baseline	
Green-only	8.0	8.0	0.9	85.8%
Green/Amber	8.0	8.0	0.9	82.6%
Green/White	7.1	7.0	0.0	5.0%
	Easy on Eyes			
	Mean	**Median**	**Diff.**	**Confidence Level**
Amber/White	5.6	6.0	Baseline	
Green-only	8.6	9.0	2.6	99.9%*
Green/Amber	8.1	8.0	2.5	99.9%*
Green/White	6.1	6.0	0.6	51.6%

* Indicates significance at 99% confidence level
** Indicates significance at 95% confidence level
*** Indicates significance at 90% confidence level

In part 2 of the survey participants were asked to rank the light bar color options on the TMA for nighttime using the same scale as Part 1. The results from this part are summarized in Table 11. The amber/white TMA excelled in visibility but lagged in other attributes, while the green-only

TMA performed well in clear arrow recognition and being easy on the eyes. It seems that the green/amber configuration has found a way to balance these attributes (Brown et al., 2018).

Table 11. Ratings for Nighttime TMA Configurations (Brown et al., 2018)

	Visibility of Work Zone Vehicles			
	Mean	**Median**	**Diff.**	**Confidence level**
Amber/White	8.7	10.0	Baseline	
Green-only	8.1	9.0	-0.5	76.5%
Green/Amber	8.6	9.5	0.0	44.6%
Green/White	8.0	9.0	-0.7	87.7%
	Awareness of work zones			
	Mean	**Median**	**Diff.**	**Confidence level**
Amber/White	9.1	10.0	Baseline	
Green-only	8.2	8.5	-0.9	93.8%***
Green/Amber	8.7	9.5	-0.4	82.4%
Green/White	8.4	9.0	-0.7	88.2%
	Clear recognition of arrow direction			
	Mean	**Median**	**Diff.**	**Confidence level**
Amber/White	6.5	6.5	Baseline	
Green-only	8.0	8.5	1.5	98.3%**
Green/Amber	7.6	8.0	1.1	93.7%***
Green/White	7.0	8.0	0.5	56.2%
	Easy on eyes			
	Mean	**Median**	**Diff.**	**Confidence level**
Amber/White	4.8	5.0	Baseline	
Green-only	8.1	9.0	3.3	99.9%*
Green/Amber	7.5	8.0	2.7	99.9%*
Green/White	6.2	6.0	1.4	97.2%**

* Indicates significance at 99% confidence level
** Indicates significance at 95% confidence level
*** Indicates significance at 90% confidence level

Based on the post-simulator survey results, it was found that the amber/white TMA was too bright and caused discomfort to the eyes. Additionally, the visibility of the green-only TMA was too low. However, the survey showed that the green-only TMA allowed for clear recognition of the arrow direction and was comfortable for the eyes. The green/amber TMA scored in between the amber/white and green-only versions and was preferred for both daytime and nighttime use (Brown et al., 2018).

During the two-day field study, the travel speeds of the TMAs varied due to different drivers and other factors. The green-only TMA maintained consistent speeds during daytime hours, While the amber/white TMA showed noticeable variations in speed between the morning and afternoon. Since TMA speeds can impact the speed of passing vehicles, a statistical test was conducted on the speed data using amber/white as the reference point. Table 12 shows that the afternoon travel speed of the amber/white TMA was notably lower than in the morning, and the speed of leading vehicles in the afternoon also showed a significant decrease compared to the morning (Brown et al., 2018).

Table 12. Daytime Speeds for Amber/White (Mph) (Brown et al., 2018)

	Daytime Speed: Amber/White (mph)			
	TMA Speed (mph)		Leader Speed (mph)	
	Morning	Afternoon	Morning	Afternoon
Count	13	35	186	566
Mean	20.3	9.8	64.5	61.9
Std Dev	1.1	2.9	6.0	6.9
Confidence level	100.0%*		100.0%*	
Cohen's	4.76		0.40	
Effect size	Large		Small	

* Indicates significance at 99% confidence level

The results of the statistical analysis indicate that the TMA speeds may impact vehicle passing speeds. Therefore, the field data results are presented along with different TMA speeds. The overall mean daytime speeds are shown in Table 13, The amber/white TMA speed was significantly lower than the green-only TMA speed, and the leading vehicle passing speed for amber/white TMA was slightly higher than for the green-only TMA. It could be implied that if TMAs were traveling at the same speed, the leading vehicle passing speed for green-only TMA would be much lower. In terms of impacts on vehicle speeds, the daytime performance of green-only TMA was more desirable (Brown et al., 2018).

Table 13. Mean Speed: Green-Only Daytime Vs Amber/White Daytime (Mph) (Brown et al., 2018)

	Mean Daytime Speed (mph)			
	TMA Speed (mph)		Leader Speed (mph)	
	Green-only daytime	Amber/White daytime	Green-only daytime	Amber/White daytime
Count	45	48	702	752
Mean	19.0	12.6	62.6	62.6
Std Dev	1.6	5.4	6.1	6.7
Confidence level	100.0%*		52.0%	
Cohen's	1.67		n/a	
Effect size	Large		n/a	

* Indicates significance at 99% confidence level

In order to test if drivers behave similarly under comparable TMA speeds, another statistical test was performed to compare the green-only daytime data and amber/white morning data. The average morning amber/white TMA speed was 20.2 mph which was close to the green-only TMA speed of 19 mph. The results are shown in Table 14 Although the speed of leading vehicles for green-only TMA was slower, the speed of green-only TMA was slightly slower than amber/white as well (Brown et al., 2018).

Table 14. Mean Speed: Green-Only Daytime Vs Amber-Only/White Morning (Mph) (Brown et al., 2018)

	Mean Speed for Speed: Green-Only Daytime vs Amber-Only/White Morning			
	TMA Speed (mph)		Leader Speed (mph)	
	Green-Only Daytime	Amber/White Morning	Green-Only Daytime	Amber/White Morning
Count	45	13	702	186
Mean	19.0	20.2	62.6	64.5
Std Dev	1.6	1.1	6.1	6.0
Confidence level	99.8%*		100.0%*	
Cohen's	0.90		0.32	
Effect size	Large		Small	

* Indicates significance at 99% confidence level

During the nighttime, even though the green-only TMA traveled at a significantly higher speed than amber/white TMA, the vehicle passing speed for green-only TMA was slightly lower, as shown in Table 15. The results show that green-only TMA performed better than amber/white TMA during nighttime (Brown et al., 2018).

Table 15. Mean Speed: Green-Only Daytime Vs Amber-Only/White Nighttime (Mph) (Brown et al., 2018)

	Mean Nighttime Speed (mph)			
	TMA Speed (mph)		Leader Speed (mph)	
	Green-Only Daytime	Amber/White Daytime	Green-Only Daytime	Amber/White Daytime
Count	45	48	504	631
Mean	22.2	12.6	52.1	52.9
Std Dev	2.7	1.2	8.4	7.9
Confidence level	100.0%*		94.6%***	
Cohen's	4.60		0.10	
Effect size	Large		Small	

* Indicates significance at 99% confidence level
** Indicates significance at 95% confidence level
*** Indicates significance at 90% confidence level

For the same TMA configuration, driver behavior in daytime and nighttime was different. As shown in Table 16. even though the green-only TMA traveled faster during nighttime, the vehicle passing speed was significantly slower during nighttime (Brown et al., 2018).

Table 16. Green-Only Speed: Daytime Vs. Nighttime (mph) (Brown et al., 2018)

	Mean Speed for Green-Only (mph)			
	TMA Speed		Leader Speed	
	Daytime	Nighttime	Daytime	Nighttime
Count	45	45	752	504
Mean	19.0	22.2	62.6	52.1
Std Dev	1.6	2.7	6.7	8.4
Confidence level	100.0%*		100.0%*	
Cohen's	1.43		1.36	
Effect size	Large		Large	

*Indicates significance at 99%

The mean speeds of amber/white were similar for daytime and nighttime. As shown in Table 17 under the same TMA speeds, drivers tended to slow down during nighttime, and the passing speed at nighttime was significantly slower than daytime by almost 10 mph.

Table 17. Amber/White Speed: Daytime Vs. Nighttime (mph) (Brown et al., 2018)

	Mean Speed for Amber/White (mph)			
	TMA Speed		Leader Speed	
	Daytime	Nighttime	Daytime	Nighttime
Count	48	48	752	631
Mean	12.6	12.6	62.6	52.9
Std Dev	5.4	1.2	6.7	7.9
Confidence level	50.4%		100.0%*	
Cohen's	n/a		1.32	
Effect size	n/a		Large	

*Indicates significance at 99%

The green-only TMA performed better than the amber/white TMA, in both daytime and nighttime. This result could be due to various reasons. It could be that the green color caught people's eyes better, or it could be the novelty effect of the green-only TMA (Brown et al., 2018).

The findings from the field study should be considered in light of certain factors. The green lights were deployed on work vehicles in Missouri for the first time, and this novelty factor may have influenced the observed outcomes of green lights. It is important to acknowledge that drivers may perform differently with green light TMAs once they become familiar with them. Results may differ if the study is conducted in different states. A more extensive study is needed to examine the impact of green light novelty. Additionally, the field test in winter showed a green contrast with the road background. Notably, the green light TMA outperformed the amber/white TMA, as indicated by the considerably lower overall passing speed for the green-only TMA. Furthermore, during nighttime conditions, it was noticed that drivers significantly reduced their speed. In summary, the results obtained from both the simulator study and field tests complemented each other, suggesting that all four configurations appear to be viable options, with none emerging as superior (Brown et al., 2018).

In a study, they compared the performance of green-only with amber/white morning and nighttime TMAs in various driving conditions. Here are the key findings from the study (Brown et al., 2018):

- Green-only daytime TMAs had an average speed of 19.0 mph, while amber/white morning TMAs had an average speed of 20.2 mph.
- Green-only nighttime TMAs had a significantly higher speed (22.2 mph) compared to amber/white TMAs (12.6 mph).
- Comparing green-only TMA performance between daytime and nighttime, it was observed that even though they traveled faster at night, the passing speed was significantly slower during nighttime.
- Amber/white TMAs showed similar mean speeds for daytime and nighttime. However, drivers tended to slow down significantly during nighttime, with passing speeds nearly 10 mph slower at night compared to daytime.

- Overall, green-only TMAs performed better than amber/white TMAs, both in daytime and nighttime. This may be because the green color catches drivers' attention or due to the novelty effect of the green-only TMAs.

Field test in winter showed a green contrast with road background. Notably, the green light TMA outperformed the amber/white TMA, as indicated by the considerably lower overall passing speed for the green-only TMA. Furthermore, during nighttime conditions, it was noticed that drivers significantly reduced their speed. In summary, the results obtained from both the simulator study and field tests complemented each other, suggesting that all four configurations appear to be viable options, with none clearly emerging as superior. (Brown et al., 2018).

2.3.1.b- Construction and Maintenance Vehicles and Equipment Warning Lights Pattern, Intensity, and Direction

When choosing the best light for your application, you may come across the identifiers SAE J595 and SAE J845 followed by Class 1, Class 2, or Class 3. It is important to note that these titles refer to the functionality of light and that the SAE Class ratings are equivalent in both instances (Safety Lights and Signals., 2023).

SAE Class 1 Warning Lights are most often used for emergency response vehicles such as police, fire, and ambulance. Lights in this class have a candela value greater than 8100, with some reaching close to 18,000 cd-s/m when used to clear traffic in emergencies. SAE Class 1 lights are 4 times more intense than SAE Class 2 lights and 10 times more intense than SAE Class 3 lights (Safety Lights and Signals., 2023).

SAE Class 2 Warning Lights are commonly used on utility and service vehicles moving at or below the speed of traffic. Candela values in this class range from 1981 cd to 8099 cd-s/m. Vehicles that are slow-moving or blocking traffic typically have warning lights with a candela value close to 4,500. SAE Class 2 lights are approximately 2.5 times as bright as SAE Class 3 lights (Safety Lights and Signals., 2023).

Because SAE Class 3 Warning Lights have the lowest light intensity of the three SAE classes, they are typically used inside buildings where there is little or no ambient sunlight. Class 3 warning lamps may be used on forklifts, specialized machinery, or for an attention-grabbing effect at trade shows and indoor events (Safety Lights and Signals., 2023).

Flashing lights were found to be more conspicuous than continuous lights and provide a sense of urgency. An asynchronous flashing pattern (flashing side to side) provided a higher attention-getting rating than a synchronous flash pattern (both sides flashing at once). Amber light sources and white light sources provided higher responses than blue or red. With regard to the relationship of the light color to the vehicle type, amber and white are more related to maintenance vehicles than the other possible colors that are closely tied to police and fire services (Gibbons, R. B., et al., 2008).

The research also showed that light sources with a higher effective intensity will provide higher attention-getting than a light source with a lower effective intensity, although this effect is offset by the flash characteristics. A warning-light system that provides a different flash pattern than the other lighting systems in the road environment improves the ability of the driver to identify the vehicle sooner. Using a double flash or varying the effective intensity (such as with a rotating beacon) allows the maintenance vehicle to be identified at a longer distance than other flash

patterns. Also, when approaching a vehicle from the rear, drivers primarily use the vehicle's tail lights for vehicle identification, locating the warning light system high on the vehicle away from the taillights improves vehicle identification distance (Gibbons, R. B., et al., 2008).

The research showed that a warning-light system must have a higher effective intensity during the daytime to provide adequate daytime conspicuity. This intensity may vary by the type of light source used. The research further showed that a warning-light system with halogen lamps may provide higher conspicuity at a lower effective intensity than warning lights using LEDs. Because there is no evident glare in the daytime environment, no maximum effective-intensity limit is suggested. Another issue relevant to daytime conspicuity is the location of the light source (Gibbons, R. B., et al., 2008).

The recommendations for changes to NFPA 1901 and NFPA 1906 emergency lighting requirements are based on research findings and aim to enhance emergency vehicle lighting. The proposed changes include (Stalnaker, T.,2019):

- adjusting lighting displays during right-of-way blocking,
- allowing slower flash rates as low as 60 flashes per minute,
- promoting synchronized and less intense lighting,
- specifying nighttime intensity ranges (Each upper zone should be in a range of 400,000 Cd-Sec/Min to 1,600,000 Cd-Sec/Min. At night the lighting intensity in each lower zone should be in a range of 150,000 to 600,000 Cd-Sec/Min), and
- encouraging a dim flash pattern during "off" time.

The study titled "Investigation of flashing and intensity characteristics for vehicle-mounted warning beacons "aimed to assess the impacts of the intensity and flash frequency of truck-mounted warning beacons on the detection distance of front-line service workers outside of vehicles, with the goal of increasing safety and reducing crashes involving these workers. The study found that the optimal combination of intensity and flash frequency for nighttime conditions was determined based on the distance at which workers were seen by participants: (Kersavage, K., et al., 2018)

- Intensities up to 150/15 cd did not significantly improve worker visibility at night compared to no warning beacons, even when workers wore reflective vests. However, it's important to note that the lack of reflective apparel or its poor performance was a factor in some work zone crashes.
- The optimal combination of intensity and flash frequency for nighttime conditions was identified. Reflective vests, intensities of 25/2.5 or 150/15 cd, and flash frequencies of 1 Hz or 4 Hz allowed for the farthest worker detection distances.
- Daytime conditions were not addressed in this study, as higher ambient light levels make beacon effectiveness less critical during the day.
- The presence of vehicle headlights and reflective clothing played a significant role in worker visibility. In cluttered or well-lit environments, detection distances might vary, warranting further investigation.

A study titled "Impacts of fog characteristics, forward illumination, and warning beacon intensity distribution on roadway hazard visibility "used the PROF simulation software to model various road scenarios, including warning beacons and atmospheric conditions. The study aimed to assess the impact of flashing warning beacons under different fog scenarios using a physically

accurate model of scattered light characteristics in perturbed atmospheres. The primary findings of the present study were as follows: (Bullough & Rea, 2016)

- A directional beam with a 10° beam angle is preferable over an omnidirectional beacon. It reduces scattered light but also optimizes electrical energy usage, benefiting battery life.
- During fog and other perturbed atmospheric conditions like falling snow, the luminous intensity of warning beacons should be reduced. Lower warning beacon intensity (150 cd) consistently provided better visibility (RVP) in fog compared to higher intensity (750 cd).
- High-beam operation (100,000 cd) headlights were more effective in detecting hazards near the warning beacon than low-beam operation (30,000 cd), except in the densest fog conditions. In extremely dense fog, neither low-beam nor high-beam operation allowed drivers to see hazards at 100 m.
- In atmospheres with greater backscatter (e.g., smoke), using high beams may have visibility penalties, even with low overall atmospheric density.
- The reduced driving distances attributed to warning beacon intensity distribution can have significant safety implications, especially in foggy conditions with reduced headway.
- As technology advances, "intelligent" warning beacons that control intensity and direction in response to fog and other factors could be developed.

A field study titled “Toward the development of standards for yellow flashing lights used in work zones” was conducted to assess driver responses to warning lights. The luminous intensities and flash patterns of warning lights along a simulated work zone were varied during daytime and nighttime. The study highlights the importance of tailored warning light patterns and intensities for different lighting conditions: (Rea, M., et al., 2016)

- Daytime: During the daytime, work zone warning lights can be operated at various intensities and flash patterns without significantly affecting driver behavior. The flash pattern of warning lights and the necessity of lane changes were found to significantly impact driving speed. A synchronized flash pattern initially slowed down drivers, likely due to perceived barriers, but this effect diminished with familiarity.
- Nighttime: Nighttime operations require more precision, with subjective judgments being significantly affected by various factors associated with warning lights. Discomfort glare ratings were influenced by the intensity of the initial warning light, with the sequential pattern reducing glare perceptions. The sequential flash pattern, especially when paired with energizing the initial warning light, is associated with less discomfort glare and improved driver perceptions of ease and speed of navigation through work zones. However, it may also lead to potentially faster driving speeds, which could pose risks to front-line workers.

A study titled “Toward performance specifications for flashing warning beacons“ aimed to establish performance specifications for flashing yellow warning beacons based on empirical psychophysical data. Two key considerations guided the development of these specifications: worst-case scenario conditions and an objective performance criterion. The study found that the worst-case scenario for reaction times (RTs) occurred for older female subjects viewing the beacon off-axis during the daytime in an urban context, with a peak intensity of 739 cd. For disability glare, the worst-case scenario occurred for older female subjects viewing the beacon on-axis at night in an urban context, with a peak intensity of 2108 cd. Based on these findings, the proposed preliminary performance for yellow warning beacons was: (Rea, M. S., et al., 2016)

- Peak intensity (day/night), minimum 750cd, and maximum 2000cd (as values aim to ensure quick response times while avoiding excessive disability glare and reducing the visibility of low-contrast hazards at night).
- Flashing Minimum Intensity (day/night), 10% of peak intensity (Provides conspicuity of flashing light while supporting closure detection)
- Number of Warning Beacons, two (Using two warning beacons enhances closure detection compared to a single beacon)

The study titled “Improving the Effectiveness of Nighttime Temporary Traffic Control Warning Devices” conducted by Applied Research Associates, Inc. (ARA) analyzed the impact of warning lights on nighttime highway operations such as mobile lane closures, incident responses, and police activities. It involved reviewing relevant literature, conducting observational and experimental field studies, and administering driver surveys and focus groups to understand driver perceptions and behavior in response to nighttime mobile operations. Some of the conclusions are as follows, the highly visible lights, which have very high intensities or flash rates, can cause uncomfortable glare and undesirable driver emotions. This is especially of concern at close driving distances, for older drivers, inexperienced drivers, or persons who are not comfortable driving at night. Lights that are too intense or attention-getting can be distracting, annoying, and anxiety-inducing, all of which are undesirable driver characteristics from a safety point of view. For example, field testing revealed that in the presence of high-intensity police lights, five of six drivers did not detect pedestrians standing near the vehicle (Steele D., et al., 2013).

Drivers of various ages and experience levels in rural and urban areas were surveyed in focus groups to understand their perceptions and actions when passing mobile nighttime highway operations. Their responses to specific nighttime mobile operation video were as follows, when using a traffic Control Truck with Strobes On and Off, the participants stated that the flashing arrow provided guidance to change lanes and that the flashing rate and intensity of warning lights influenced their perception of the seriousness of the situation (Steele D., et al., 2013). The study included six groups based on age: 16 to 24 years old, 25 to 34 years old, 35 to 44 years old, 55 to 64 years old, and 65 years or older. While the strobe lights increased the attention-getting aspect of the trucks, most groups were either neutral on the use of the strobe lights or preferred no strobes. The reasons for preferring the truck with strobes off were related to making it a less visually cluttered scene that allowed them to see the arrows better and caused less distraction and discomfort. Suggestions for improvement included synchronizing the flashing of the strobe lights with the arrow or turning the strobe lights off (See Figure 14 and Figure 15) (Steele D., et al., 2013).

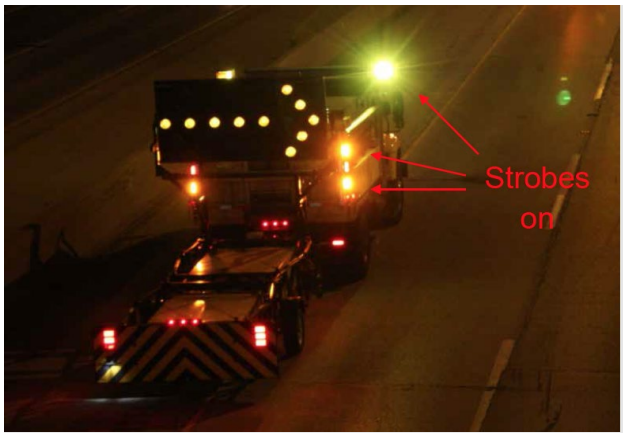


Figure 14. Traffic Control Vehicle with Strobe Lights Turned On (Steele D., et al., 2013).

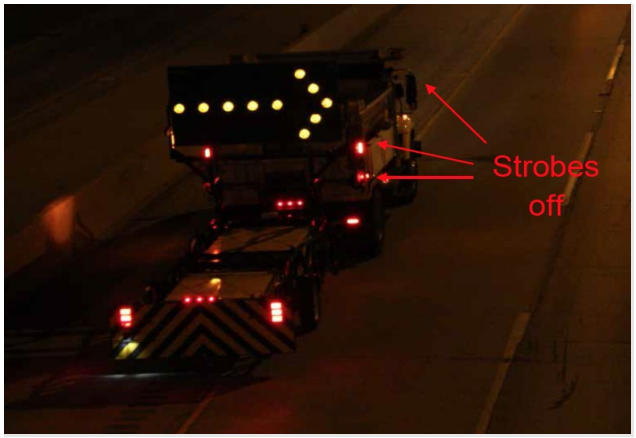


Figure 15. Traffic Control Vehicle with Strobe Lights Turned Off (Steele D., et al., 2013).

KTC researchers conducted a comprehensive study to optimize the safety of Kentucky Transportation Cabinet (KYTC) highway workers and motorists by evaluating warning light systems on KYTC vehicles. Primarily, this study focused on warning light colors but other characteristics, such as light placement and light source, were also examined. This study recommends the use of amber and white lights amber and white lights as the primary warning colors due to their heightened visibility and strong association with maintenance and construction activities. Furthermore, the study proposes additional warning light characteristics to improve driver detection and response times, ensuring safer roadways for all (Howell, B., et al., 2015):

- Use an asynchronous flashing pattern (flashing from side to side) consisting of slow flash frequencies (≈ 1 Hz) for vehicle warning lights.
- Use LED lights with a minimum intensity of 4,000 and 1,650 lumens for daytime and nighttime conditions, respectively.
- Place warning lights on highway work vehicles, preferably at higher elevations on the vehicle, so they can be seen at any angle of approach.
- Place warning lights on highway work vehicles against solid-colored backgrounds to provide contrast (to increase visibility, warning lights should be positioned against the vehicle or a solid-colored background. Placing lights at high elevations on the vehicle, such as the roof, without a contrasting solid color may cause them to blend in with the sky).

The Michigan Department of Transportation in addition to multiple county road commissions and municipalities, has added green lights to roughly 70 percent of winter maintenance vehicles (such as snowplow trucks) to improve visibility to motorists. The lights will either be flashing, rotating, or oscillating and aim to reduce crashes (Hill, 2016).

According to the Ohio Department of Transportation, to reduce accidents involving snowplow trucks, using a multi-color warning system would decrease it. Some of ODOT's recommendations: incorporate all Class 1A intensity LED Lights and Create a multi-color system using Green/White and Amber. Also, create a unique, consistent flash pattern, of 6 6-position light configurations, all light positions have both amber and white or green, and all light positions have one of the lights on (no light positions are dark at any time) (ODOT, 2021).

This study titled "Effectiveness Of Green Strobes On Winter Maintenance Vehicles and Equipment " investigates the degree to which visibility can be affected by including green lights, and the results suggest that the addition of green warning lights to winter maintenance trucks WMTs improves visibility. It is anticipated these improvements will result in safer interactions between the traveling public and WMTs, particularly during winter maintenance operations. To this end, the following recommendations are presented based on the results of this study (See Figure 15 and Figure 16) (Zockaie et al., 2020):

- The single flash pattern for amber warning lights does not provide sufficient conspicuity during the daytime. As such, single flash amber lights should not be used as part of the warning light configuration during daytime operations (Zockaie et al., 2020).
- Based upon the human factors experiments, the use of a combination of quad flashing amber lights and single flashing green lights on the rear side and/or top of the maintenance trucks is recommended as the most effective warning light configuration. This color/flash pattern combination is consistent with current Michigan Department of Transportation practice (Zockaie et al., 2020).
- The current Michigan Department of Transportation configuration incorporates quad flashing amber lights and single flashing green lights for the top beacons and single flashing green lights for the rear LEDs. The beacons and LEDs flash independently of each other. Slight improvements in terms of conspicuity and glare were observed once the amber beacons and green LED lights were synchronized. Although the improvements were not statistically significant, synchronizing green LED lights with beacon amber lights can be recommended (Zockaie et al., 2020).
- Incorporating a quad flash pattern for the green auxiliary lights during nighttime is not recommended. This specific combination produces a high level of glare that introduces potential discomfort among motorists (Zockaie et al., 2020).
- The use of higher intensity warning lights (e.g., quad flashing green lights) is recommended during daytime maintenance operations under severe weather conditions. Given concerns related to glare under nighttime conditions, this would require a programmable configuration as noted in the preceding point. However, there is an extra cost associated with the application of programmable warning light configurations that need to be considered (Zockaie et al., 2020).

Figure 16. Glare Rating Test Configuration (Zockaie et al., 2020)

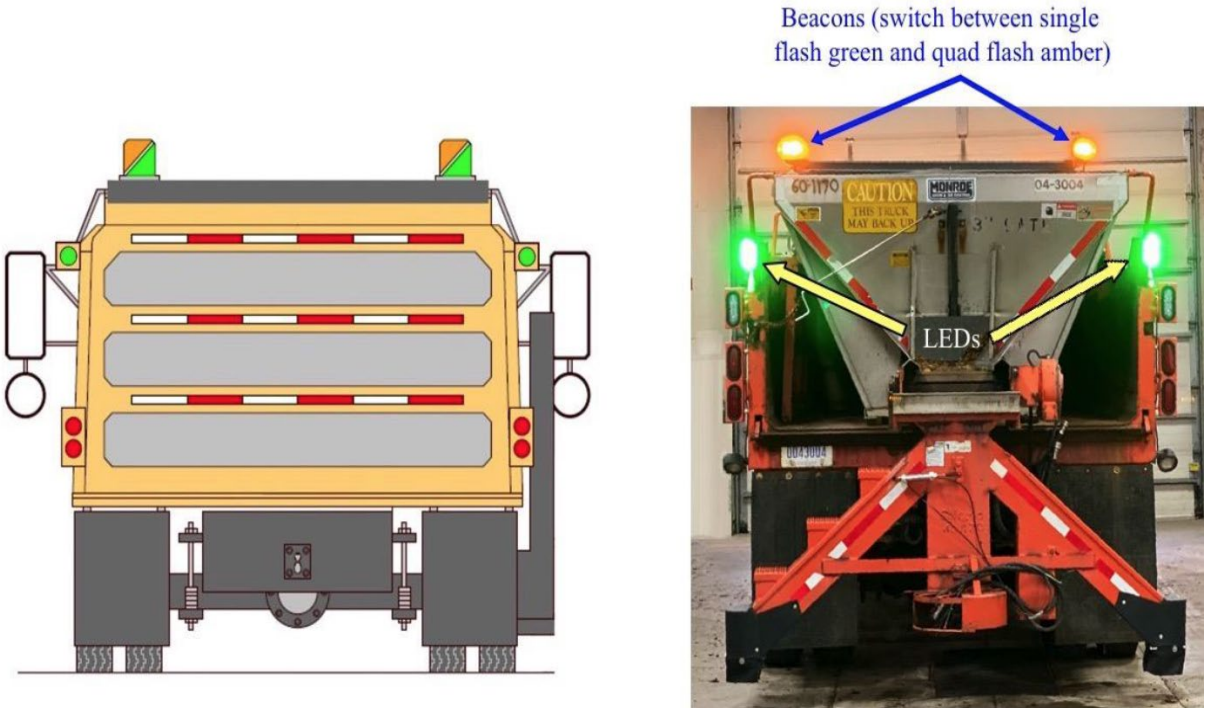


Figure 17. Michigan Department of Transportation Current Configuration for Warning Lights (Zockaie et al., 2020)

2.3.1.c- Construction and Maintenance Vehicles and Equipment Warning Lights Location

Another issue relevant to daytime conspicuity is the location of the light source. A warning light seen against the sky will have reduced contrast and conspicuity compared to a warning light seen against a dark background. Therefore, the light must appear against a controlled background for the conspicuity to remain constant (Gibbons, R. B., et al., 2008). Vehicle warning lights at night are effective in capturing drivers' attention. Flashing lights indicate alert or caution, while faster rates and intensities mean greater urgency (Steele D., et al., 2013). The quantity and placement of warning lights vary from state to state. It is common among the states to have at least one warning light on top of their maintenance vehicles (See Table 18) (Kamyab, A., et al., 2002, Howell, B., et al., 2015)

Table 18. State Survey Responses: Warning Lights

State	Warning Light Usage Source (1) from Kamyab, A., et al., 2002, (2) from Howell, B., et al., 2015
Alabama	(1) Use white, amber, and some red warning lights. Believe the white and amber strobe combinations are effective. Place warning lights above the cab and integrate some into the headlights (Kamyab, A., et al., 2002).
Alaska	(1) Use Whelen strobes that have flash tubes rather than rotating elements. The flash tube gives a 360-degree visibility. Each vehicle normally has two lights mounted on the roof of the cab, 1 blue light on the right, and one amber light on the left (Kamyab, A., et al., 2002). (2) The usage of amber/yellow, blue color for vehicles used in highway work-related activities (Howell, B., et al., 2015).
Arizona	(1) Use rotating amber lights on maintenance vehicles. Pickup lights are placed on the toolbox with a light stand. Also use some light bars (Kamyab, A., et al., 2002).
Arkansas	(1) Use rotating yellow lights (Kamyab, A., et al., 2002).
California	(1) Use amber rotating or strobe lights. Amount and type of light depends on level of severity vehicle is subject to. All vehicles have at least one amber single rotator. They may also have an amber mini light bar, and amber light stick, one way flashing light with one or more at corners with flasher, and/or flashing arrow sign (Kamyab, A., et al., 2002).
Colorado	(1) Use Whelen strobe lights on maintenance vehicles, and Whelen snow and fog lights on snow removal vehicles. Snow removal vehicles run a combination of amber and blue lights, while normal maintenance vehicles run only amber lights. Snowplows have strobes on the left- and right-hand side of the cab. Also place strobes on the corner posts of the bed on the rear, so snowplow has a total of 4 strobes. Place a LED warning light on the end of the wing plow. Use LED service lights with signal alert (Kamyab, A., et al., 2002).
Connecticut	(1)Have two Whelen 360-degree amber strobes on front cab guard, and two 360-degree amber strobes on the back placed on the side. In 1999 put LED taillights in, the dump body and cab lights are soon to be all LED lights (Kamyab, A., et al., 2002).
Florida	(1) Use yellow flashing lights placed on a light bar (Kamyab, A., et al., 2002).
Georgia	(1) Use an amber and clear strobe combination. Pickups have two light bars; dump trucks have two warning lights on the cab protector. Bucket trucks have at least four lights, some maybe in the front grill. Cars have dash mounted amber lights and sometimes amber and clear in the rear window deck. Mowers have one amber on the cab. Vans have either one amber or have a roof bar with amber and clear. Fixing to get into LEDs (Kamyab, A., et al., 2002).
Idaho	(1) ID vehicles are equipped with a mixture of lights in effort to accommodate various conditions. Pickups and other maintenance equipment that is utilized during summer maintenance have a single dual halogen rotating light. This same light configuration is used on pretty much all equipment other than snowplows. Snowplows have a Whelen Super strobe Comet Flashlight mounted on the truck cab. At the top /center rear of the sander is a dual rotating halogen light. Each truck is equipped with four amber halogen lights on the sides of the sander, two per side. These lights are equipped with a flasher unit to give the appearance of a bouncing ball, i.e., the lights flash side to side, top to bottom. All snowplow trucks are equipped with LED taillights. Dump bodies have a total of four lights and sanders have a total of four lights. If a truck has a slide-in sander, the vehicles could (Kamyab, A., et al., 2002).
Illinois	(1) Use 96-inch strobe light bar on cab that extends past the rock guard. Have strobes on dump body posts that face the rear. Also, on top of the dump body post have LED stop and turn taillights. Have experimented with white and amber combination but think it seems more difficult for drivers to comprehend. Believe that the LED lights are best to use (Kamyab, A., et al., 2002). (2) The usage of amber color for emergency vehicles. Prevent glare (Howell, B., et al. 2015).
Iowa	(1) Use a 360-degree amber rotating beacon. Snowplow trucks use a dual amber rotating beacon and two amber rear directional alternate flashing strobes. Amber warning lights are required per Iowa code. (2) The usage of amber/yellow color for vehicles used in highway work-related activities (Howell, B., et al. 2015).

Kansas	(1) Put yellow strobe lights on maintenance vehicles. Some state workers want to put white strobes on vehicles, but it is currently against state legislation (Kamyab, A., et al., 2002).
Kentucky	(1) Use yellow strobe lights placed on the cab (Kamyab, A., et al., 2002).
Louisiana	(1) Use a combination of red and amber warning lights (Kamyab, A., et al., 2002).
Maine	(1) Use amber strobe halogens. Normally one is placed on the roof, and one is placed on the back (Kamyab, A., et al., 2002). (2) The usage of amber/yellow color for vehicles used in highway work-related activities (Howell, B., et al. 2015).
Massachusetts	(1) Use amber strobes, placed on highest point of vehicle. Extra strobes may be placed on the dump body. Do not use LED lights yet but are looking into them (Kamyab, A., et al., 2002). (2) The usage of amber/yellow, red, white color for vehicles used in highway work-related activities (Howell, B., et al. 2015).
Michigan	(2) The usage of amber/yellow color for vehicles used in highway work-related activities (Howell, B., et al., 2015).
Minnesota	(1) Snowplows are equipped with six amber strobes. Four of these are mounted in two housings on top of the stationery cab shield. The other two are mounted on the top rear of the dump box. In addition to this put two white strobes on the rear of the box on all left-hand wing trucks. Districts have the option of adding the white strobes to the other plow trucks. White strobes are used only during daylight hours. Other vehicles are using either a, double rotating, or strobe light, most of these lights are amber, some are blue. Trying a few L.E.D. lights on vehicles, but only with other lights, not by themselves (Kamyab, A., et al., 2002). (2) The usage of amber/yellow, blue color for vehicles used in highway work-related activities (Howell, B., et al., 2015).
Mississippi	(1) Use amber and blue strobe light bars (Kamyab, A., et al., 2002).
Missouri	(1) Use two amber rotating strobes lights on top of the bed on each side. Have LED operating lights that are side mounted on the box. Signal trucks use either red or yellow (Kamyab, A., et al., 2002). (2) The usage of amber/yellow, white color for vehicles used in highway work-related activities (Howell, B., et al., 2015).
Nebraska	(1) For stripping and slow-moving operations have rotating white, blue, and amber lights. White is mainly used during snow removal. Lights are placed on top of the box. Do not have LED lights (Kamyab, A., et al., 2002).
Nevada	(1) Use yellow strobe lights placed on top of the cab (Kamyab, A., et al., 2002).
New Hampshire	(1) Use mainly roof mounted flashing ambers on dump trucks. Some snowplows have small strobes mounted on the extension arms of the mirrors. Also mount some lights on the backside near the tailgate. Pickups use roof mounted amber strobes. Starting to phase in LED lights with new vehicles (Kamyab, A., et al., 2002). (2) The usage of amber/yellow, red, white color for vehicles used in highway work-related activities (Howell, B., et al., 2015).
New York	(1) Use two amber rotating strobes placed on the cab, and two alternating amber warning lights on the rear of the vehicle (Kamyab, A., et al., 2002).
North Carolina	(1) Lighting of maintenance vehicles varies by vehicle type and function. Use a combination of strobes and rotating beacons with a preference for strobes. The primary color of warning lights is yellow; however, use clear lights to a large degree as well. Pickups use a 22" or a 44" low-profile light bar mounted on the cab. A sign truck has a 44" light bar with an arrow stick or a 44" light bar with six high-intensity lights, 2 mounted on the rear, and 4 mounted on the side. Single-axle and tandem dump trucks have two high-intensity strobe lights mounted on each side of the cab protector. Incident Management Assistance Patrol vehicles are also equipped with additional warning strobe lights (Kamyab, A., et al., 2002).
North Dakota	(1) Have two yellow strobes and two white strobes (mainly for daytime) elevated on the box for rear viewing. Also put two yellow 360-degree rotary strobes on the cab (Kamyab, A., et al., 2002).
Oklahoma	(1) Use amber strobe lights (Kamyab, A., et al., 2002). (2) The usage of amber/yellow, blue, red, white color for vehicles used in highway work-related activities (Howell, B., et al. 2015).

Ohio	(1) ODOT safety lighting consists of amber halogen strobe lighting. The change to strobes occurred in 1986. The array is two strobes mounted on a light bar on top of the cab and two rear facing lights on each side of the front of the bed (Kamyab, A., et al., 2002).
Pennsylvania	(1) Use yellow flashing lights, normally two placed on the cab. New trucks are starting to use LED lights (Kamyab, A., et al., 2002).
Rhode Island	(1) Use red and white Whelen strobe lights (Kamyab, A., et al., 2002).
South Carolina	(1) Use amber rotating, strobe, and ball lights. Place lights in the center of cab (Kamyab, A., et al., 2002).
South Dakota	(2) The usage of amber/yellow color for vehicles used in highway work-related activities (Howell, B., et al., 2015).
Tennessee	(1) Older vehicles use amber flashlights, some of the new lights are amber LED strobes. Typically, the lights are placed on the cab, and some may be placed on the rear (Kamyab, A., et al., 2002).
Texas	(2) The usage of amber/yellow, blue color for vehicles used in highway work-related activities (Howell, B., et al. 2015).
Vermont	(1) Use amber warning lights. Most warning lights are strobes but are experimenting with LEDs. Snowplow trucks have a 360-degree light mounted either on a bar on top of the cab or on the upper mirror brackets so that there is a light on each side. There are rear facing lights in the rear body corner posts. Also, two large strobes mounted on swinging plates on the tailgate so that they aim directly back whether the body is up or down. Presently experimenting with LEDs mounted on the discharge end of the wing plow. Pickups, vans, and service vehicles have different configurations depending how the vehicle is set up. If there is no obstruction, a single mounted roof top 360-degree strobe light is used. If there are obstructions, then on or more lights are added to the rear of the vehicle (Kamyab, A., et al., 2002).
Virginia	(1) For a single axle dump truck 30,000 GVW the strobe light is to be mounted on a self-leveling bracket. Location of mounting to be center on top or front leading edge of cab shield. Virginia rotating amber lights have a minimum of two halogen sealed beams enclosed within an amber colored dome. Sealed beams are at least 60,000 candlepower and have a flash rate of 80 to 100 flashes per minute. Rotating lights shall be approximately 8 ½ inches or greater in diameter and height, 6 inches in height for multi-light bars. High intensity amber strobe lights consist of a double flash unit, with a flash rate 80 ± 10 flashes per minute. The strobe lights shall be approximately 6 5/8 inches in diameter and 7 ½ inches in height or greater. During snow removal an auxiliary snow removal headlight with park/turn lamps is used. Use clear halogen head lamps and amber park/turn lamps that are mounted in the grill or fender area providing a minimum height to center of sealed beam of 66" above road surface. If fender mounted, the lights must be mounted far enough forward to allow aiming with mechanical headlight aimer. Final location subject to VDOT approval. Headlight to be controlled from switch located in cab control console. Use a spreader light to provide light for checking sand spreader operation. This light is to be mounted under the left rear corner of the dump body, facing down. This lamp is a shock mounted Truck-lite 40204 clear lens or equal. To be controlled from a control console mounted switch with On/Off maintained action and include light to indicate function (Kamyab, A., et al., 2002).
Washington	(2) The usage of amber/yellow, red, white color for vehicles used in highway work-related activities (Howell, B., et al. 2015).
Wisconsin, Eau Claire County	(1) Use a pair of twin amber rotating beacons. Also mount a flashing strobe or beacon on each side of the dump box. Started going to flashing LED lights on the dump box. Also have started using LED service lights (Kamyab, A., et al., 2002).
Wisconsin, Dane County	(1) Use alternating lights on the tailgate, and a revolving amber light on cab. Use extends lights above the plow in the front. Also have stop lights on top of the tailgate. Supervisors can have red and yellow lights on their vehicles (have to flash at same time) (Kamyab, A., et al., 2002).
Wisconsin, Fond Du Lac County	(1) Use yellow strobes and 4-way flashers on tailgate (Kamyab, A., et al., 2002).

2.3.1.d- Construction and Maintenance Vehicles and Equipment SMART Technologies

Warning beacons are crucial for worker safety, but existing standards don't consider reduced visibility situations like fog. In the study done by Bullough & Rea simulations were conducted to assess how factors like fog density and beacon intensity impact driver visibility. Three warning beacon intensity distributions were simulated under different fog densities and visibility distances to assess their impact on driver visibility and safety. As noted in the study, it is important to reduce beacon intensity in fog so that hazards near the beacon can be seen more clearly. “Intelligent” systems that control beacon intensity overall as well as directional intensities in the presence of fog can be readily envisioned and, thus, engineered. These systems may be informed by manual control by people in a work zone or driving a utility vehicle, or automatically from weather reports or local feedback using a photosensor designed to detect backscatter from the beacon. The cost of these “intelligent” beacons would be higher than those presently available, but a simple cost-benefit analysis suggests that a reduction of worker fatalities by 5% (i.e., avoiding 5 worker fatalities annually) over current annual levels could justify an incremental cost of $100 per beacon in work zones where workers are particularly exposed or where fog conditions are most common (Bullough & Rea, 2016).

Incorporating programmable warning light configurations is recommended (Zockaie et al., 2020). Because these systems allow for the use of different configurations based on prevailing conditions to reduce glare. For example, alternate patterns could be used during daytime versus nighttime or when the WMT is stopped at signalized intersections with vehicles queued behind in proximity. In these situations, the WMT warning lights can be dimmed to decrease glare discomfort (Zockaie et al., 2020).

2.3.2- Retroreflective and Marking Color and Location on Construction and Maintenance Vehicles and Equipment

Retroreflective marking and vehicle color are important in providing guidance and information for road users. The guideline document introduces utility work zone operations and safety guidelines with recommendations. A driver’s ability to detect and appropriately respond to a utility work zone vehicle is based on multiple factors. The passing motorists must visually detect the work vehicle far enough in advance so that, if necessary, appropriate action can be taken. To ensure an appropriate response, the driver must also recognize that the vehicle is a part of the work zone traffic control treatment, especially for short duration work (Datta, T., et al. 2008).

The retroreflectivity is provided by affixing a highly durable retroreflective tape approximately four to six inches in width on the sides and rear of the vehicle. A majority of state agencies use red and white striped tape, with some agencies using additional colors including orange, yellow, blue, and green (Datta, T., et al. 2008).

2.3.2.a- Construction and Maintenance Vehicles and Equipment Color

Vehicle color has been found to influence the frequency of motor vehicle traffic crash involvement during daylight hours. White vehicles have a lower crash risk due to high contrast with the surroundings, while darker colors have a higher risk due to lower contrast.(Datta, T., et al. 2008).

For daytime utility work zones, visibility is crucial against various background colors. Orange vehicles, though not as attention-grabbing as white or fluorescent yellow-green, are recognized as work zone-related. Using orange as the standard color enhances driver recognition and work zone awareness (See Figure 15) (Datta, T., et al., 2008).

Figure 18. Vehicle Color Orange (Datta, T., et al. 2008).

Most participating states indicated that the color of their vehicles is orange; white is the second most common color used (See Table 20) (Kamyab, A., et al., 2002).

Table 19. State Survey Responses: Vehicle Color (Kamyab, A., et al., 2002)

State	Vehicle Color Practices
Alabama	Vehicles are white.
Alaska	Vehicles are either orange (older vehicles) or white (newer). The graders and heavy equipment are manufacturers standard color.
Arizona	Vehicles above 1 ton are highway yellow. Vehicles a ton and less are white
Arkansas	Maintenance vehicles are white.
California	Vehicles cabs are white, for large trucks, bodies, and accessories above the frame and behind the cab are orange
Colorado	Smaller trucks are fleet white; larger vehicles are orange. Off road equipment is standard factory colors.
Connecticut	Vehicles are Omaha orange
Florida	Vehicles are DOT yellow
Georgia	Vehicles are school bus yellow
Idaho	As of May 1, 2002, all work vehicles, (everything except sedans and passenger vans) with a factory installed bed, will be painted white. All other vehicles such as 1-ton truck and larger that are equipped with an aftermarket utility, flatbed or bump body have white cabs and the bodies are painted DuPont No. 7893 yellow. Construction equipment is painted the manufacturer's standard safety yellow or DuPont No. 7893 yellow.
Illinois	No information
Iowa	Vehicles are orange.
Kansas	No information
Kentucky	Vehicles are mostly white.
Louisiana	Vehicles are white. Found that it was costing quit a lot extra to require all orange on maintenance vehicles.
Maine	Vehicle bodies are Omaha orange, and cabs are brown.
Massachusetts	Vehicles are highway yellow.
Minnesota	Plow trucks are orange; all others are variety of colors.

Mississippi	Vehicles are either white, orange, or blue.
Missouri	DOT trucks are "Highway Yellow."
Nebraska	Large vehicles are highway orange. Pickups are various colors
Nevada	Heavy equipment and large trucks are yellow; Sedans and pickups are white.
New Hampshire	Maintenance vehicles are orange.
New York	Vehicles are yellow; the hood is flat blue to be easier on the driver's eyes.
North Carolina	All vehicles and equipment are painted yellow, commonly called "NCDOT Safety Yellow, " DuPont paint number 54701AK.
North Dakota	No information
Oklahoma	Vehicles are yellow or white.
Ohio	In 1994, ODOT started phasing in white as standard color for all licensed, motorized vehicles. This replaces the previous special yellow. The reasons are decreased cost, better delivery, better visibility, and higher resale value. Off-road and construction equipment is purchased with manufacturer's standard colors. Snowplows are ordered in gloss black.
Pennsylvania	Vehicles are yellow.
Rhode Island	Vehicles are orange.
South Carolina	Vehicles are school bus yellow
Tennessee	Old trucks are orange; new trucks are going to be white because of cost.
Vermont	Trucks over 12,000 lbs. GVWR are orange, the smaller vehicles are either blue, green, black, or white.
Virginia	The maintenance vehicles are to be factory painted orange in accordance with the color now used by the Virginia Department of Transportation, lead free, Du Pont color #LF74279AT or equivalent.
Wisconsin, Eau Claire County	Vehicles are a yellowish green (slime green), considered most visible during all types of lighting.

2.3.2.b- Construction and Maintenance Vehicles and Equipment Retroreflective/Marking Color and Location

Almost all the responding state DOTs indicated using some form of reflective material on their vehicles to make them more visible. The most common colors are red and white; amber is also used (See Table 21.) (Kamyab, A., et al., 2002).

Table 20. State Survey Responses: Reflective Tape (Kamyab, A., et al., 2002)

State	Reflective Tape Usage
Alabama	Do not use reflective tape on smaller vehicles anymore due to lower resale value. Use red and white reflective tape on larger vehicles.
Alaska	Have striping installed on all maintenance vehicles. Stripes are either orange or white, depending on the vehicle color.
Arizona	Do not commonly use reflective tape on maintenance vehicles.
Arkansas	Use red and white bands of reflective tape along the sides and across the back of the bumper of vehicles.
California	Passenger vehicles have a rear 3" to 4" orange horizontal stripe using 4" 3M Scotch lite orange reflective tape. Light duty vehicles have a 5" to 6" horizontal orange stripe applied to both sides and rear of all light duty utility vehicles using 3M Scotch lite orange reflective tape. Orange and white diagonal reflective striping is applied to the rear of vehicles having a width greater than or equal to 80 inches. Large trucks have a 6" horizontal orange stripe of 3M Scotch lite orange reflective tape on both sides of the cab. Orange & white diagonal reflective striping is applied across the rear of the vehicle. Vehicles also have a white reflective "Caltrans" sticker on the rear, and a reflective "CT."
Colorado	Use red and white reflective tape on service vehicles. Have a stripe down both sides, and across the tailgate. The Colorado DOT logo is also reflective.
Connecticut	Put contiguity tape on tailgates of dump trucks. Supervisor vehicles have red and white reflective tape on the tailgates. Normal pickups have a 1" orange reflective tape down the sides of the vehicle.
Florida	Continuity markings are red and white and are normally two inches wide around the whole truck.
Georgia	Use reflective tape on most vehicles. For small vehicles, the tape is same color as the vehicle. On large dump trucks use red and white reflective tape.
Idaho	As of May 1, 2002, all work vehicles, (everything except sedans and passenger vans) with a factory installed bed, will be equipped with reflective yellow striping tape on the sides and back. The striping tape used is 3M Diamond grade sheeting. Pickups are equipped with a 4" wide stripe. All other vehicles such as 1-ton truck and larger that are equipped with an aftermarket utility, flatbed or bump body have white cabs with the reflective striping and bodies are painted DuPont No. 7893 yellow. The bodies also feature a reflective yellow stripe. Construction equipment is painted the manufacturer's standard safety yellow or DuPont No. 7893 yellow.
Illinois	Put a four-inch band of amber reflective tape under the rock shield on both sides below the top rub rail.
Iowa	Iowa uses red and white (silver) DOT C-2 reflective tape on tailgate and sides of snowplow (dump) trucks and side and rear of 10,000 GWR and larger trailers.
Kansas	Apply high intensity reflective tape on dump trucks, but have a problem of snow covering it during snow removal operations.
Kentucky	Do not use much reflective tape.
Louisiana	Do not use reflective tape on any vehicles except lowboy trailers. Do use a reflective emblem on the doors to identify DOT vehicles with state logo.
Maine	Put red and white reflective tape on the sides of vehicles.
Massachusetts	Have a blue and green reflective stripe down both sides of the vehicle.
Minnesota	Red and white reflective tape is used on all plow trucks. Some other vehicles use the tape, but there are no standards. The tape is made by 3M. See attached pictures.
Mississippi	Use red and white reflective tape on larger vehicles.
Missouri	Put contiguity tape on all new trucks and salt spreaders.
Nebraska	Apply reflective tape to vehicles.
Nevada	Use silver and red reflective tape on tailgates of vehicles.

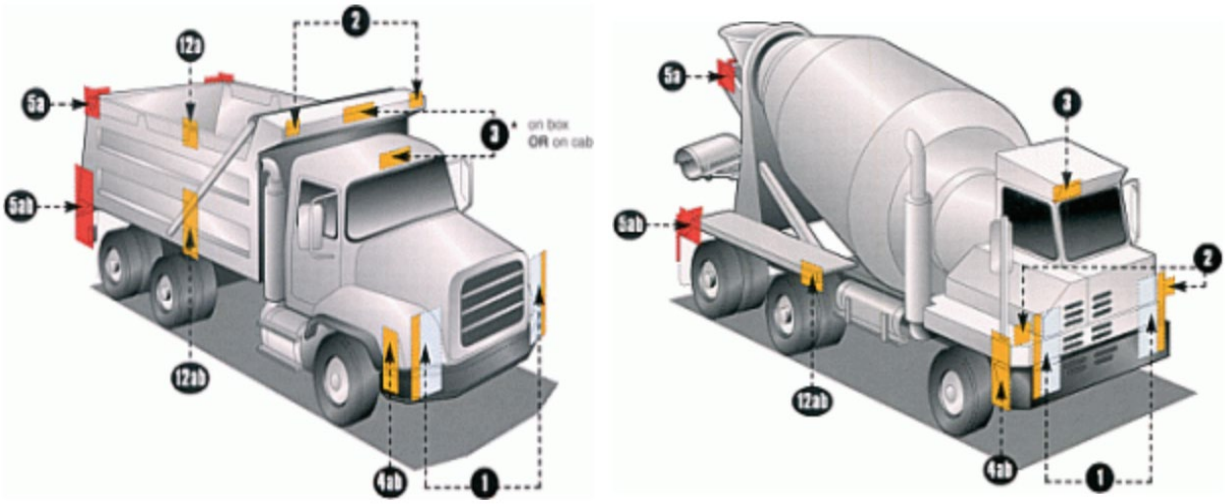
New Hampshire	Use red and white reflective tape. On patrol trucks tape is placed on bumpers, some also have some on the side. The decals are also reflective
New York	Are experimenting with 3M reflective tapes on the back of vehicles, and on the back of wing plows.
North Carolina	Trailers have reflective tape around the perimeter of the trailer. Flat-bed trucks have reflective tape around the perimeter of the bed. Some field units will add reflective tape to equipment at various locations to supplement visibility when they expect to perform any night work. Incident management assistance patrol vehicles are marked with reflective decals (like those used on many law enforcement vehicles) along the sides, as well as reflective markings on the front and rear.
North Dakota	Use reflective tape on snowplow trucks.
Oklahoma	Use red and white reflective tape.
Ohio	Trailers are taped according to FMVSS 108. Dump trucks are taped on the sides and rear of the dump body with 2 inch red and silver tape.
Pennsylvania	Use red and white reflective tape.
Rhode Island	Use silver reflective tape.
South Carolina	Use red and white reflective tape on larger vehicles.
Tennessee	Use red and white reflective tape, especially on snowplows.
Vermont	Vehicles 12,000 lbs. GVWR and under have a 3" reflective orange stripe down the sides and across the back. All larger vehicles have the DOT red/white reflectorized markings down the sides and across the back.
Virginia	Use red and white reflective tape along the sides of the dump box and on the hood of the cab
Wisconsin, Eau Claire County	Place red and white reflective tape on the back side of the tailgate. There is a L-shape pattern of reflective tape along the sides of the box.
Wisconsin, Dane County	Use 6-8 inch red and white reflective tape across the back and down the sides.
Wisconsin, Fond Du Lac County	Have reflective tape on 5-ton dump trucks.

Vehicle markings and retro reflectorizing vary greatly between utility companies. Standards have been developed in other industries and have proven to be successful at improving conspicuity. To increase the conspicuity of work vehicles, particularly large trucks, the installation of red and white retroreflective tape is recommended along the sides of the truck. The combination of red and white type is recommended as these colors are commonly associated with danger, such as in the context of railroad crossing gates. It is further recommended that vehicles be oriented such that the rear of the vehicle is perpendicular to approaching traffic where possible, with allowances for angles of up to a maximum of thirty degrees (Datta, T., et al. 2008).

An evaluation team was formed to assess the performance of conspicuity tape markings on TxDOT dump trucks and light-duty pickup trucks. The evaluation team noted certain specifications needed to ensure quality, warranty, and effectiveness by evaluating the performance of reflective vehicle markings from two manufacturers, 3M and ORAFOL. They all agreed that both products provided excellent long distance advanced warning. Most agree that the conspicuity tape provides better long-distance advanced warning than emergency LED lights during daytime use (TDOT, 2018). The recommended specifications included all reflective sheeting to be fluorescent yellow-green printed with black ink to create a chevron pattern, and some other specifications (See Figure 19) (TDOT, 2018).

Figure 19. Reflective Sheeting (TDOT, 2018).

The Canadian Regulations Amending Safety Regulations (Canadian Centre for Occupational Health and Safety, 2020) specified the location of retroreflective tape as shown in Figure 20. The Canadian Regulations are shown in this study, because like in the United States, in Canada ensuring the safety of workers and the public is of utmost importance when it comes to Construction and Maintenance Vehicles and Equipment. The Canadian Regulations provide a point of reference guideline regarding their color schemes and retroreflective markings. These measures are pivotal in enhancing visibility and reducing the risk of accidents, making the workplace safer for everyone. By adhering to these specifications, Construction and Maintenance Vehicles and Equipment are effectively marked, ensuring overall safety standards are met.



Legend

1: Headlamps - Lower Beam.
2: Front Clearance Lamps- Attention: Required for vehicles 2032mm wide or wider
3: Front Identification Lamps (ID)
4ab: Front Side Marker Lamps and Front Side Reflex Reflectors.
5a: Rear Side Marker Lamps
5b: Rear Side Reflex Reflectors
12a: Intermediate Side Marker Lamps
12b: Intermediate Side Reflex Reflectors

Figure 20. Location of Retroreflective Tape as The Following (Canadian Centre for Occupational Health and Safety, 2020)

Other locations of retroreflective tape are shown below in Figure 21, Figure 22, and Figure 23.

Figure 21. Side and Rear View of a Minnesota DOT Snowplow (Kamyab, A., et al., 2002).

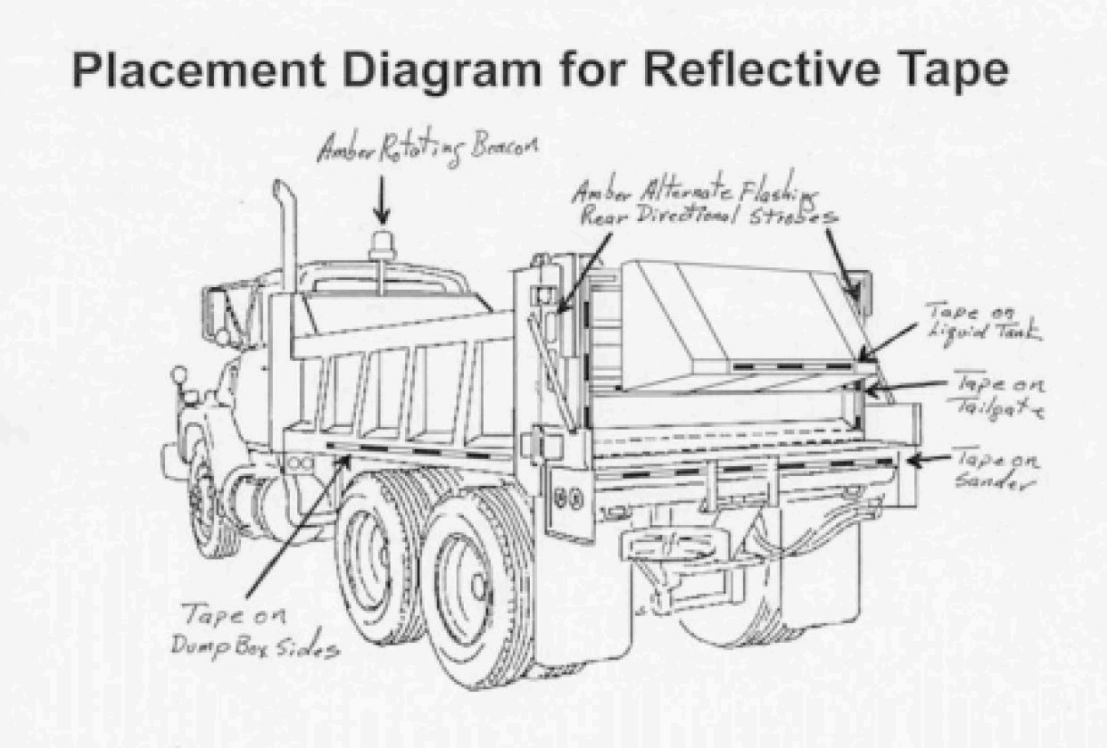
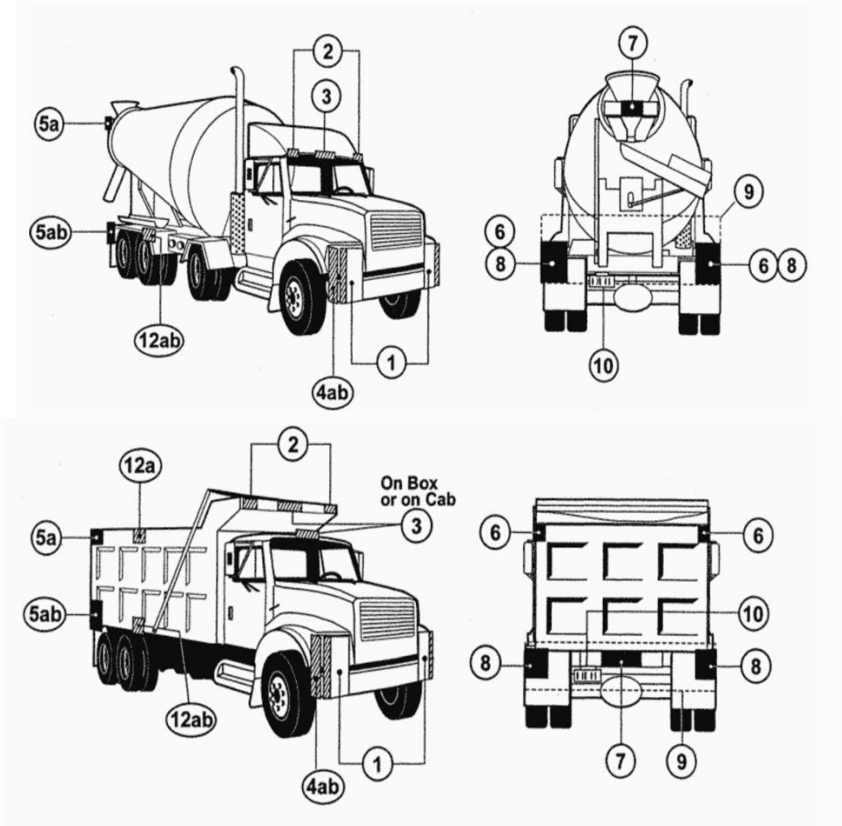


Figure 22. Iowa: Warning Light and Reflective Tape Diagram (Kamyab, A., et al., 2002).



Legend

1 Headlamps - Lower Beam.
Headlamps - Upper Beam.
Parking Lamps - Attentions: Required only on vehicles less than 2032mm wide.
Front turn Signal/Hazard Warning Lamps
2 Front Clearance Lamps – Attentions: Required for vehicles 2032mm wide or wider.
3 Front Identification Lamps (ID)
4a Front Side Marker Lamps
4b Front Side Reflex Reflectors
5a Rear Side Marker Lamps - Not required on Truck Tractors
5b Rear Side Reflex Reflectors - Not required on Truck Tractors
6 Rear Clearance Lamps
Attention: Required for vehicles 2032mm wide or wider, but not required on Truck Tractors
7 Rear Identification Lamps (ID)
Attention: Required for vehicles 2032mm wide or wider, but not required on Truck Tractors
8 Tail Lamps
Stop Lamps
Rear Turn Signal/Hazard Warning Lamps
Rear Reflex Reflectors
9 Backup Lamp
10 License Plate Lamp
11 Center High Mounted Stop Lamp - Attentions: Required for vehicles 2032mm wide or 4536kg.

Figure 23. Lamps and Reflex Reflectors (eCFR, 2023)

A study was done using literature review to gather information from sources across the United States and other countries, and site visits for several manufacturers of retroreflective sheeting products, with emphasis on emergency vehicle installations (versus other applications such as traffic signs or personal protective equipment (PPE) (FEMA, 2009). It seems clear that properly applied/maintained retroreflective sheeting materials can effectively increase the visibility and

conspicuity of treated objects, the current research suggests that leveraging the properties of readily available retroreflective sheeting products, by incorporating them into U.S. emergency vehicle designs, appears promising for enhancing emergency vehicle visibility and conspicuity, especially during dark lighting conditions. Retroreflectivity is of limited benefit with daylight illumination (FEMA, 2009). It is also mentioned to consider (and allow) the use of fluorescent retroreflective materials in applications where a high degree of day or nighttime visibility is desired (FEMA, 2009).

In a study tractor-trailer combination in which trailers are equipped with retroreflective tape ought to experience a reduction of side and rear impacts into the trailer by other vehicles. Two separate analyses were performed: one to estimate the effectiveness of the tape in rear impacts and one to estimate the effectiveness of the tape in side impacts. The fleet study concluded that the tape is effective not only in dark conditions but also during daylight. Other research suggests that the tape might be more effective on the side than the rear of the trailer during daylight. To the limited extent that our data can be used to address this issue, they do not support either premise (Morgan, C., 2001).

The analysis tabulates tractor/trailer vehicle involvements in crashes by trailer treatment (treated; untreated) and damage area (side and rear impacts; single-vehicle and frontal impacts). The analysis compares the involvement rates of treated and untreated tractor/trailer combination trucks at only daylight conditions. Table 21, shows the two-variable contingency table and the effectiveness estimates by state. Neither estimate is significant; therefore, there is no evidence here of a reduction in crashes involving treated trailers during daylight (Morgan, C., 2001).

Table 21. Number of Crash Involvement and Effectiveness During the Daylight (Morgan, C., 2001).

Number of Crash Involvement and Effectiveness During the Daylight				
	Florida		Pennsylvania	
	Side ad Rear	SV and Frontal	Side ad Rear	SV and Frontal
Treated	1,024	1,231	873	1,271
Untreated	648	875	282	459
"Effectiveness"	-12%		-12%	

When you only compare side to single-vehicle and frontal impacts, the tape is -7 and -27 percent effective during daylight in Florida and Pennsylvania, respectively. For rear impacts, the tape is -27 and 1 percent effective in Florida and Pennsylvania, respectively. The tape does not appear to reduce either side or rear impacts during daylight (Morgan, C., 2001).

The use of contrasting colors can positively affect conspicuity by assisting drivers in locating a hazard amid the visual clutter of the roadway. There are basically two types of contrast: luminance contrast, the degree to which an object is brighter than its background, and color contrast, the difference in an object's color(s) and those found in its background (Cook et al., 1999). Contrast is enhanced by using colors not normally found in the environment, including fluorescents (Trench, N., et al., 2014).

The effectiveness of fluorescent colors for enhancing daytime visibility/conspicuity in traffic safety applications is well-established in the literature (Schieber et al., 2003; Buonarosa and Sayer, 2007). Since fluorescence relies on ultraviolet radiation, fluorescent colors offer no additional benefit at night (Trench, N., et al., 2014). Fluorescent Colors Fluorescent retroreflective materials, especially yellow and orange, have superior conspicuity properties and are particularly useful where a high degree of daytime visibility is desired (Zwahlen and Vel, 1994).

The tape shall be a red/white combination and should be installed with the red starting on the driver's side. Conspicuity tape should be installed on all SUVs and pickups. While there is no standard for installation, it is recommended that the tape should be installed approximately 13" from the bottom of the tailgate (See Figure 24) (MoDOT, section 616.27.1, 2021).

Figure 24. Conspicuity Tape (MoDOT, section 616.27.1, 2021).

2.3.2.c- Construction and Maintenance Vehicles and Equipment Retroreflective/Marking Material

According to Tennessee Department of Transportation (TDOT) Occupational Health and Safety Division, a reflective tape was applied to a variety of vehicles, and the location of the tape was determined based on ease of installation while ensuring maximum visibility on the rear of the vehicle. From this trial, they came up with a couple of recommendations including all reflective sheeting to be fluorescent yellow-green printed with black ink and to be constructed using Total Internal Reflectors (TIR) for added durability to fading and corrosion during winter activities. The retroreflective surface of the sheeting shall be weather-resistant and show no appreciable cracking, blistering, crazing, or dimensional change after two years of unprotected outdoor exposure (See Figure 26, Figure 27). Also, install conspicuity tape on the inside of all doors to face traffic when the door is opened (See Figure 25) (TDOT, 2018).

Figure 25. Tape On the Inside Door to Face Traffic When Door is Opened (TDOT, 2018).

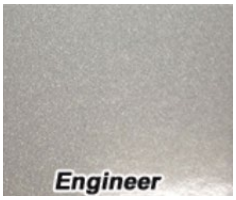
Figure 26. The Location of Chevron Stripes on the Vehicles (TDOT, 2018).

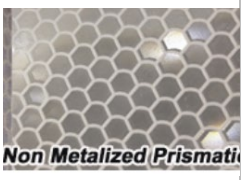
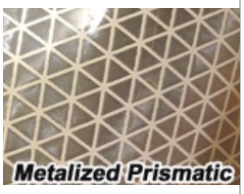
Figure 27. Chevron Stripes (BriargateSupply,2020)

When choosing a retroreflective marking tape, it's not only about the brightness, but there are also many other factors to consider. Such as color, flexibility, price, longevity, adhesion, contrast, competitive lighting, and light dispersion. It is because of these other factors that so

many different types and colors of reflective tape are manufactured. In the following table different types of reflective tape and their basic characteristics (See Table 22) (Cole, 2020):

Table 22. Types of Reflective Tape and Basic Characteristics (Cole, 2020)

Tape Type	Specifications	Example
Flexible Engineer Grade Type 1 	Engineer-grade retroreflective tape is a type 1 material with glass beads providing the retro-reflectivity. It is a thin, flexible material and is molded in a single layer which prevents delamination. It comes in the widest variety of colors and is also the least expensive and most popular of all the tapes. It is used in a variety of applications where viewers will be fairly close to the tape itself. Engineer grade comes in a standard and flexible grade. The flexible grade will stretch and is used in applications where conformability is important. If you have a rough, uneven surface to mark then this is the tape you need. (Example – bicycle wrap) This material can be computer-cut into letters, shapes, and numbers and is widely used on emergency vehicles and signs for this reason. It is often combined with a brighter background so that both colors are reflective, but contrast is still achieved. Because it is a glass bead tape it disperses light at a wide angle. Recommended for applications where the viewer is within 50 yards of the tape. The estimated brightness of this grade in the different colors measured in candelas is as follows: ● White – 108 candelas ● Yellow – 88 candelas ● Gold – 78 candelas ● Orange – 54 candelas ● Green – 28 candelas ● Red – 21 candelas ● Blue – 12 candelas ● Black – 10 candelas	Orange Reflective Tape Type 1 Flexible Engineer Grade 1" 2" 4" Nikkalite ELG DOT: Rated for a 7-year outdoor life.
Flexible High Intensity Grade Type 3 Reflective Tape	Flexible High Intensity Type 3 Tape is a flexible, stretchable version of our standard high intensity tape. It only comes in three colors, white, yellow, and orange. This tape is designed to be used on traffic cones and road barrels; however, it is also great for a variety of other applications where a bright, stretchable tape is needed. For example, hard hats have an uneven convex surface, and most tapes will not conform. But flexible high intensity will. White – 250 candelas Yellow – 170 candelas Orange – 100 candelas	1’’ Flexible (Stretchable) High Intensity Reflective Tape - 30' & 150' Rolls: a 10-year outdoor rated
High Intensity Grade Type 3 Reflective Tape	High intensity type 3 tape is made by laminating layers together. The high index glass beads are contained in little honeycomb chambers with an air space above them. This arrangement makes for a brighter tape. Although still thin, this tape is a little stiffer than engineer grade. It is excellent for smooth surfaces and is about 2.5 times brighter than engineer grade. This tape is used in applications that require a viewer to see the tape from medium distances away. It is more expensive than engineer grade but less expensive than prismatic films. This tape also disperses light in a wide angle. This combined with the tapes increased reflectivity makes it light up quicker to the viewer than other tapes. CAD cutting into letters and shapes is not recommended with high intensity. It is very popular for creating	High Intensity Retroreflective Tape (HXREF): Durability: 7-10 years Application temperature: 18°C - 28°C (64.4°F - 82.4°F)

	sign backgrounds, wrapping bollards, marking loading docks, making gates reflective and other similar applications. Recommended for applications where the viewer is within 100 yards of the tape or in areas where there is competitive lighting. ● White – 250 candelas ● Yellow – 170 candelas ● Orange – 100 candelas ● Green – 45 candelas ● Red – 45 candelas ● Blue – 20 candelas	
Non-Metalized Micro-Prismatic Reflective Tape – Type 4 (also known as high intensity prismatic HIP) Oralite 5900 	Non-Metalized micro-prismatic tape is made by laminating a layer of prismatic film onto a honeycomb grid and white backing. It is similar in construction to high intensity glass bead tape but with the air chamber below the prisms. (Air backed micro-prisms) The white backing makes the tape color more vivid. It is a little more expensive than high intensity but less expensive than metalized micro-prismatic. Best if applied to a smooth surface. This film is visible from much farther away than high intensity or engineer grades and is great for applications where the viewer is far away from the tape. ● White – 360 candelas ● Yellow – 270 candelas ● Orange – 145 candelas ● Green – 50 candelas ● Red – 65 candelas ● Blue – 30 candelas	Oralite (Reflexite) 5900 HIP Prismatic-Grade Reflective Tape: Tape durability is 10 years.
Metalized Micro-Prismatic Reflective Tape – Type 5 – Oralite/Reflexite V82 	Metalized micro-prismatic reflective tape is the top of the line when it comes to durability and reflectivity. It is molded into one layer which means you never need to worry about delamination. This is especially good when using the tape in a dynamic environment where it may be abused. You can beat it up and it still reflects. It is made by coating the back of a micro-prismatic layer with a mirror coating and then applying adhesive and a release liner to the back. It is more expensive to make but well worth the effort. Because it is a single layer film it can be CAD cut into letters and shapes. This material can be used for all applications as well as those where the viewer is more than 100 yards from the tape. In most cases, this reflective tape can be seen from over 1000 feet away. This makes it excellent for highway applications or applications where the tape will be shining through snow or rain. ● White – 750 candelas ● Yellow – 525 candelas ● Green – 130 candelas ● Red – 130 candelas ● Blue – 55 candelas	V82 Reflective Tape Oralite Type 5 (Brightest Colored Tape on Market) Orafol USA
V92 Metalized Prismatic Reflective Tape – (comparable to type 5)	V92 Reflective Tape by Orafol/Reflexite is very similar to V82 only it is a little less expensive and slightly less bright when it reflects.	Oralite (Reflexite) V92-DB-COLORS Microprismatic Conspicuity Tape: Tape is weather-resistant

V98 Conformable Reflective Tape by Orafol/Reflexite – Metalized Prismatic – (comparable to type 5)	V98 is designed for vehicle graphics and is also cuttable on a plotter. I have found it to be the easier to cut than the V82 or V92 films. It is a little thicker and has a slightly rubberier texture. It reflects at 750 candelas for white. It is very popular for striping emergency and utility vehicles.	White Reflective Tape Oralite V98 1" 2" 4" 6" Orafol Reflexite Safety: 5-year outdoor rating.
Reflexite SOLAS Metalized Micro-Prismatic Tape – Oralite/Reflexite SOLAS 	Lastly, Reflexite SOLAS reflects at over 1000 candelas. It is available only in white/silver. It has a greyish silver look in the daytime but is bright white at night. It can be seen from over a thousand feet away in good and bad weather conditions.	SOLAS Reflective Tape M82 1404 Oralite Orafol Reflexite Flexible Safety USCG: The tape has a strong aggressive ad hesive and is designed to withstand the harsh marine environment and extreme cold

According to NFPA Type 1 (engineer grade) is the minimum acceptable type of reflective sheeting that can be used. Other acceptable materials are a Type 3 High Intensity, a V92/V97 Prismatic Tape, a V82 Type 5 tape, and a Crystal Grade Type 8 material (NFPA, 2021).

2.3.2.d- Construction and Maintenance Vehicles and Equipment Retroreflective / Markings Patterns and Contouring

Outlining vehicle boundaries with “contour” or “edge” markings, using retroreflective material, is expected to help enhance emergency vehicle visibility/conspicuity. The potential value of outlining a vehicle on its ultimate visibility/conspicuity is supported by research going back to 1984. (Henderson et al.) A Canadian study of large truck trailers identified continuous contour markings, made with white retroreflective tape, on the sides and rear of trailers to be more visible under varied weather conditions than the standard FMVSS 108 conspicuity treatment required by U.S. regulations (See Figure 28 and Figure 29) (FEMA, 2009).

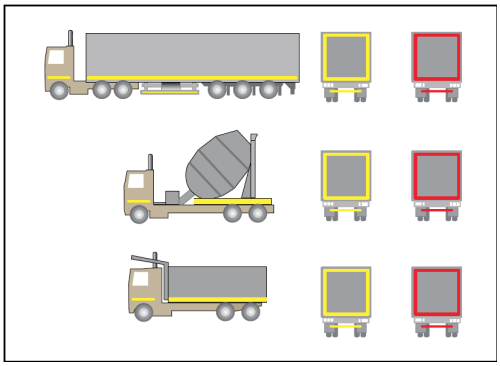


Figure 28. Contour Markings on Large Vehicles (FEMA, 2009).

Figure 29. Edge Markings on a Patrol Car (FEMA, 2009)

In 2013 the NFPA officially added Chevron Striping guidelines to their recommendations for Ambulances operating in the U.S. The guidelines are contained within the NFPA 1917 manual. The recommendations are a cut and paste from their NFPA 1901 manual for Chevron Striping for Fire Apparatus made official in 2009. It is appropriate to point out that although NFPA guidelines are followed by most of all fire and EMS departments, they are guidelines and not laws or federal regulations. However, some states, counties, and cities have made them official requirements (NFPA 1917, 2021).

Any door of the apparatus designed to allow persons to enter or exit the apparatus shall have at least 96 square inches (62,000 sq mm of retroreflective material applied to the inside of the door. (This is to call attention to the door when it is opened) (NFPA 1901, 2021). Retroreflective stripe or stripes shall be applied to at least 50% of the cab and body length on each side of the vehicle, excluding the pump panel areas, and at least 25% of the width of the front of the fire apparatus. The stripe or combination of stripes shall be a minimum of 4 inches (100 mm) in total width. (2 – two-inch stripes, a 3″ and a 1″, etc. would meet the criteria) (NFPA 1901, 2021).

A reflective graphic design shall be allowed to replace all or part of the required striping material if the design or combination thereof covers at least the same perimeter length(s) required by the previous paragraph (NFPA 1901, 2021). At least 50% or half of the rear-facing vertical surfaces, visible from the rear of the fire apparatus, “not including” any pump panel areas not covered by a door, shall be outfitted with retroreflective striping in a chevron pattern sloping downward and away from the centerline of the vehicle at 45-degree angles, See Figure 30 (NFPA 1901, 2021).

Figure 30. Reflective Pre-Made Chevron Panel (NFPA 1901, 2021).

2.4- Summary

The objectives are to reduce highway construction accidents by comparing the different cases of using different lights and retroreflective marking tap colors, patterns, and locations, and how it will increase safety. As mentioned before there are several factors to consider for vehicle lighting. For instance, the vehicle lighting color, location, intensity, and direction, as well as how to minimize the glare effect as much as possible. The majority of state road agencies use amber warning lights; some states are trying to add more colors to increase visibility during nighttime and daytime along with other conditions such as fog. Colors include red, blue, white, and green. However, several states prohibit the use of blue and/or red lights for any non-emergency vehicles.

Lighting patterns are important it was found synchronous flashing patterns (side-to-side) are more attention-grabbing than synchronous patterns (both sides flashing simultaneously). Tailoring flash patterns to be different from other vehicles on the road improves identification. Different flash patterns, like double flash or varying intensity, can enhance identification at longer distances. Warning lights should have a higher effective intensity during daytime to ensure adequate conspicuity.

The vehicle color is also an important factor, as it can create a relatively high contrast with the background colors in the roadway environment, Darker colors (lower contrast with the environment background) were found to have a higher risk of crash involvement. Retroreflective/marking tape colors, and the location to be identified from longer distances, the addition of retroreflective/marking tape on the side and rear of the vehicle reduces crashes. In most cases, the retroreflectivity is provided by affixing a highly durable retroreflective/marking tape.

Chapter 3 - DOTs Standards and/or Provisions (by States) Lighting and Retroreflective Marking of Construction and Maintenance Vehicles and Equipment

3.1- Introduction

The construction standards and provisions by all of the states' Department of Transportation (DOTs) were secured and reviewed regarding the lighting and retroreflective marking of construction and maintenance vehicles and equipment during operations. This chapter synthesizes the review of each state that included the content. It is worth noting that some states did not address or mention the standards for equipment lighting and marking and therefore are not presented in the chapter tables synthesizing the information.

The State Department of Transportation (DOT), the terms construction "standards" and "provisions" refer to the established guidelines, rules, specifications, and requirements that govern various aspects of the construction of roads and/or bridges in the corresponding state. Standards refer to a set of guidelines or specifications that define the technical requirements and best practices. Provisions are requirements or conditions outlined in standards or accompanying documents.

3.2- Research Methodology for Review of States' DOT Construction Standards and/or Provisions

To build upon the current state-of-the-art knowledge literature (previous chapter), the States' DOT Construction Standards and/or Provisions were also reviewed using a qualitative systematic review process. The review process A was conducted using the following four phases:

Phase 1 – Conduct Search of State DOT construction standards and/or provisions
Phase 2 - Find lighting and retroreflective marking of construction and maintenance vehicles and equipment in DOT construction standards
Phase 3 - Analysis of DOT construction standards
Phase 4 - Synthesis and write up of information found

Phase 1 – Conduct Search of State DOT construction standards and/or provisions

Obtained all the State DOT construction standards and/or provisions online. Created a list of states DOT standards and provisions and visited the official websites of each state's DOT on the list. During the search, specifically looked for documents such as "Standard Specifications for Road and Bridge Construction."

Phase 2 - Find lighting and retroreflective marking of construction and maintenance vehicles and equipment in DOT construction standards

Reviewed table of contents of each DOT construction standard and/or provisions to identify lighting and retroreflective marking of construction and maintenance vehicles and equipment during operations. If the standard did not have a section dedicated to this topic, a word search using the keywords in Table 23, was performed to check if the content was distributed in other sections of the standard.

Table 23. Search Term Keywords Used in the Standard and Provisions

Standard Keywords
Rear of
Reflective tape
Chevron
Strobe lights
Traffic control
Beacons
Visibility
Vehicle warning
Conspicuity tape

Phase 3 - Analysis of DOT construction standards

Analyzed the sections regarding lighting and/or marking a section of the state DOT construction standard. After locating the relevant sections or chapters, the information was read and carefully examined to ensure a comprehensive understanding of the subjects.

Phase 4 - Synthesis and write up of information found

The pertinent information was highlighted, extracted, and summarized in Table 24 and Table 25 in this chapter. The states that didn't have anything about equipment lighting and marking were not included in the tables.

3.3- Results of DOTs Standards and/or Provisions (by States) on Lighting, Retroreflective Marking of Construction and Maintenance Vehicles and Equipment

3.3.1- Lighting of Construction and Maintenance Vehicles and Equipment.

The lighting of construction and maintenance vehicles and equipment refers to the lighting devices installed on construction and maintenance vehicles and equipment to ensure visibility and safety during operation. Table 24 synthesizes the review of each state that includes the content regarding the lighting of construction and maintenance vehicles and equipment.

Table 24. Lighting DOT's Standards and/or Provisions (by States)

State	Color of equipment illumination and/or warning lights	Visibility of Equipment Illumination and/or Warning Lights (distance, 360, height etc.)
Alabama (Alabama DOT, 2018)	These lights shall be amber, or orange-colored and mounted to be readily seen by traffic at a safe distance.	When deemed necessary by the Engineer, special warning lights shall be used on equipment working adjacent to traffic lanes to warn traffic. These special warning lights shall be either all purpose, 360°-2 sealed beams, revolving types of at least 8 inches {200 mm} in height, or electronic strobe beacon
Alaska (Alaska DOT, 2017)		Use high intensity flashing strobe lights, oscillating beacons, or rotating beacons on the Work Zone Supervisor's vehicle and on vehicles being used to transport and set-up traffic control devices. Vehicle hazard warning lights may supplement but are not permitted to be used instead of high intensity flashing strobe lights, oscillating beacons, or rotating beacons.

Arizona (Arizona DOT, 2021)	Attenuators shall have a standard trailer lighting system, including brake lights, turn signals, ICC-bar lights, and two yellow rotating beacons	Beacons mounted on opposite rear corners of the truck approximately 4-1/2 feet from ground level.
Delaware (Delaware DOT, 2016)	Provide a large rotating amber beacon or strobe lights on the shadow vehicle in such a manner to be compliant with the DE MUTCD.	
District Of Columbia (District of Columbia DOT, 2013)	Amber strobe light	The TMA shall be equipped with a minimum of 1 high intensity amber strobe light in operation while the TMA is installed in the work zone
Florida (Florida DOT, 2019)	Amber or white rotating, flashing, oscillating or strobe light	The warning lights must be a high intensity. Equip all pickups and automobiles used on the project with a minimum of one Class 2 warning light that meets the Society of Automotive Engineers Recommended Practice SAE J595.
Idaho (Idaho DOT, 2018)		Ensure vehicles used to perform traffic control activities (e.g., traffic control device installation, removal, maintenance, or monitoring) are equipped with a working high-intensity rotating, flashing, oscillating, or strobe light meeting the Manual on Uniform Traffic Control Devices (MUTCD) requirements
Indiana (Indiana DOT, 2020)	Vehicle warning lights shall be amber and shall be a strobe light or a flashing, oscillating, or rotating directed beam light.	They shall be visible to all approaching traffic for a distance of 1,000 ft.
Iowa (Iowa DOT, 2015)	Equip each tractor with an amber revolving light. In lieu of an amber revolving light, an amber strobe light may be used. Monitoring With Incident Response: Equipped with an amber revolving light or amber strobe light visible in all directions and a cellular telephone or similar type of mobile phone	· Visible from the front and rear, · Mounted at least 10 feet high as measured to the lamp axis, and flashes between 60 and 120 times per minute.
Louisiana (Louisiana DOT, 2016)	Use of strobe lights on vehicles and equipment is prohibited. Use of flashing lights shall be kept to a minimum to prevent motorist distraction. Flashing lights shall not be used behind barrier protection systems.	Conventional vehicle headlights shall not be permitted as the sole means of illumination while working. All motorized vehicles shall be equipped with conventional vehicle headlights to permit safe movement in non-illuminated areas.
Maine (Maine DOT, 2014)	All vehicles used on the project, including pickup trucks and personal vehicles, shall be equipped with amber flashing lights, visible from both front and rear, or by means of single, approved type, revolving, flashing or strobe lights	Mounted to be visible 360º. The vehicle flashing system shall be in continuous operation while the vehicle is on any part of the project.

Montana (Montana DOT, 2014)	Equip all vehicles, hauling units, and mobile construction equipment operating within the project limits and operating on roadways used by the traveling public with an amber flashing or strobe light	Visible from all directions for at least 0.4 mile (0.6 km) during daylight and clear weather conditions.
Missouri (Missouri DOT, 2018)		Each T MA shall have a standard trailer lighting system, including brake lights, taillights, turn signal lights and Federal Motor Carrier Safety Administration identification bar lights. The TMA shall have the same standard trailer lighting system noted above when the unit is in the transport position.
New York (New York DOT, 2019)	All vehicles and equipment within the contract limits and on the roadway shall operate a rotating or flashing amber beacon.	All vehicles and equipment within the contract limits and on the roadway shall be equipped with a rotating amber or flashing Light Emitting Diode (LED) beacon visible from all directions for a minimum of 1,000 feet during daylight. Flashing LED beacons shall meet the requirements of SAE J845 Class 2. Strobe lights shall not be used. If visibility of the beacon is blocked by a portion of the vehicle or equipment, additional beacons shall be provided. Beacons shall be mounted in a manner which does not cause glare for the driver or operator. Short-term delivery vehicles not equipped with rotating or flashing amber beacon shall display four-way emergency flashers when in the temporary traffic control zone.
Oregon (Oregon DOT, 2018)	Amber light	Equip each TCS as follows: A vehicle that is equipped with a roof or post-mounted rotating amber light or strobe light that is visible for 360 degrees. Provide pilot cars with the following features: A roof or post-mounted rotating amber light or strobe light that is visible for 360
Rhode Island (Rhode Island DOT, 2004)		Light fixtures shall consist of combination run, turn, brake, and side clearance lights with ICC identification lights on the rear of the TMA. All light fixtures shall have rubber grommet seals. A standard SAE/AT/TTMA interchangeable 7-way trailer light wire connector shall be installed and wired to SAE standards.
Utah (Utah DOT, 2017)	Yellow color. Pilot car: Equip with a minimum of two rotating lights, oscillating, or strobe lights.	Minimum 4-inch diameter/width and minimum 6 ft mounting height.
Virginia (Virginia DOT, 2016)	The support vehicle shall have at least one rotating amber or one high intensity amber flashing vehicle warning light	(Visible for 360-degrees) functioning while in operation in accordance with the VWAPM. When allowed by the VWAPM, an electronic arrow operated in the caution mode may be used with the vehicle warning light. When installing and removing lane closures on a multilane roadway as well as when performing mobile operations, the support vehicle shall be equipped with a vehicle warning light and an arrow board.
Wisconsin (Wisconsin DOT, 2021)	Furnish two vehicles equipped with two-way communications equipment, full width flashing yellow light bars	(1) with 360 -degree visibility, and distance measuring instruments (DMI). Ensure that DMI have an accuracy of at least 10 foot per mile and decrease the measured distance when the vehicle backs up. (2) Provide a target on the lead vehicle 42 inches above the roadway offering a sharp cutoff when it appears and disappears.

3.3.2- Retroreflective Marking of Construction and Maintenance Vehicles and Equipment.

Many states recommend retroreflective marking as it is important in providing guidance for road users. The further the passing vehicle can identify the work vehicle, the more likely an appropriate action is taken. Table 25 synthesizes states of DOT uses of different retroreflective marking colors and locations.

Table 25. Retroreflective Marking DOTs Standards and/or Provisions (by States)

State	Equipment Reflective Marking Colors	Equipment Reflective Marking Location and /or Dimensions
Alaska (Alaska DOT, 2017)	Provide red sheeting on the rear of the equipment and yellow sheeting elsewhere.	Furnish each side of non-street legal equipment with a minimum of 75 square inches high intensity retroreflective sheeting in each corner, so at least 150 square inches of sheeting is visible from each direction.
Arizona (Arizona DOT, 2021)	Attenuators shall have rear-mounted, black and high-intensity yellow chevron stripes	
California (California DOT, 2021)	Non-reflective black stripes and 4-inch-wide, yellow retroreflective stripes sloping at 45 degrees	Inverted V chevron pattern placed across the entire rear of the attenuator composed of alternating 4-inch-wide,
Connecticut (Connecticut DOT, 2016)	The standard chevron pattern shall consist of stripes, alternating non-reflective black and Type IV retroreflective yellow sheeting, slanted at 45 degrees in an inverted “V” pattern, centered on the rear of the unit	The TMA unit shall have a chevron pattern that covers the rear face of the unit. The stripes shall be between 4 in and 8 in wide.
Delaware (Delaware DOT, 2016)	Install ASTM D4956 Type IV retroreflective sheeting consisting of alternating 3 inch wide yellow and black stripes positioned at a 45-degree angle with the stripes pointing down towards the side where traffic is to pass the impact attenuator.	On the nose of the TIA facing traffic, Cover the entire nose of the attenuator with retroreflective sheeting.
Florida (Florida DOT, 2019)	The orange stripes shall be fabricated from fluorescent orange prismatic lens sheeting conforming to 824.02. The chevron shall cover a minimum of 75 percent of the rear panel area and shall be visible to traffic at all times.	The TMA shall also be equipped at the rear panel with a chevron object marker consisting of orange and black stripes 6 inches wide sloped at a 45 degrees’ angle from the top of the panel in both directions. The TMA shall be not less than 72 inches wide and not more than 96 inches wide. The color of the TMA shall be yellow or orange, and conspicuity markings shall be provided.
Idaho (Idaho DOT, 2018)	Black with yellow or white with orange sheeting	Install either alternating black with yellow or white with orange sheeting on the rear of trailer mounted attenuators and truck mounted attenuators in both the operating and raised position. Use Type III (work zone) or Type IV sheeting consisting of 4- or 6-inch-wide stripes installed to form chevrons that point upward. All sheeting except black must be retroreflective.
Maryland (MDOTSHA, 2018)		The rear facing surface of the TMA/TTMA shall have an inverted "V" chevron pattern formed by alternating 4 in. Wide black and yellow stripes as shown in Standard No. MD104.01-19C. The sides of the TMA/TTMA shall have a border of 4 in. Red and white reflective tape as shown on Standard No. MD 104.01-18A.

Michigan (Michigan DOT, 2012)	Red and white	Equip vehicles and equipment in the work zone, and vehicles delivering materials or equipment to the project, with red and white conspicuity tape. Apply one 2-inch-wide horizontal stripe of red and white conspicuity tape along at least 50 percent of each side of, and across the full width of the rear of the vehicle or equipment.
Missouri (Missouri DOT, 2018)	Yellow and black or, Red and white	In the operating position, the rear facing of the TMA shall be marked with alternating 8-inch yellow and 8-inch black retroreflective sheeting forming an inverted "V" at the center and slope downward at an angle of 45 degrees toward each side of the unit or a checkered board pattern consisting of 12-inch square red and 12-inch square white retroreflective sheeting. The TMA may be marked with the same operating pattern or red and white DOT conspicuity tape to simulate the looks of a standard van body trailer when traveling.
Nevada (Nevada DOT, 2014)	Yellow and Black	The TMA unit shall have a chevron pattern. Black and high intensity yellow chevron stripes and a standard trailer lighting system, including brake lights, turn lights, turn signals and 2 yellow rotating beacons mounted on opposite rear corners of the truck at approximately 1.4m from ground level
New Jersey (New Jersey DOT, 2007)	Red and white	Equip moving equipment with 2-inch wide, alternating red and white, conspicuity tape meeting the National Highway Transportation Safety Administration standards. Equip off-road equipment with conspicuity tape along the full length of all 4 sides. Equip on-road vehicles, including trailers and trailer-mounted devices, with conspicuity tape along the full length of both sides, excluding the cab, and across the rear of the vehicle.
New York (New York DOT, 2019)		Work shall consist of equipping construction vehicles and equipment with warning lights and reflective markings, and maintenance of vehicles and equipment in safe operating condition. All trucks with a GVWR greater than 10,000 lbs. Shall display a minimum 2-inch-wide band of reflective sheeting on the front, rear, and each side. The sheeting need not be continuous, but the sum of the length of the segments shall be at least one-half the length of the body or trailer. The centerline of the sheeting shall be between 15 inches and 60 inches above the ground. All other construction equipment shall display a minimum 2-inch-wide band of reflective sheeting on the front and rear (100 square inches per end minimum) as practicable. Reflective markings on construction vehicles and equipment shall conform to §730-05 *Reflective Sheeting* ASTM Type III, Type VII or Type IX.
Ohio (Ohio DOT, 2019)	Red and white	In addition, equip all project motor vehicles and trailers having a gross vehicle weight rating of 10,000 pounds or greater, in single or combination, with conspicuity tape. Also, delineate all NCHRP 350 Category IV equipment (arrow boards, portable changeable message signs, etc.) With conspicuity tape. Conspicuity Tape: Use red and white, Type G, H, or J retroreflective

		sheeting that complies with 730.19, 730.192, and 730.193.
Pennsylvania (Pennsylvania DOT, 2020)		Reflective Markings. Place reflective tape or reflectors at each corner on the front, rear, and sides of the trailer.
Rhode Island (Rhode Island DOT, 2004)	Black and yellow	All standard modules shall have a chevron pattern painted on the rear of the module. The standard chevron pattern shall have 4-inch-wide stripes, alternating black and yellow, slanted at 45 degrees in an inverted "V" form with the "V" located at the center of the module.
Virginia (Virginia DOT, 2016)	Orange or yellow prismatic	The Truck/Trailer-mounted attenuator, the rear panel shall have alternate 6- to 8-inch-wide orange and black or yellow and black chevron (inverted V) stripes. Stripes shall be sloped at a 45-degree angle downward in both directions from the upper center of the rear panel. Stripes shall be fabricated from fluorescent orange or yellow prismatic lens reflective sheeting conforming to Section 247.
Wisconsin (Wisconsin DOT, 2021)	Black and yellow	The transportable attenuator shall have a chevron pattern on the rear of the unit. The standard chevron pattern shall consist of 4-inch yellow stripes, alternating nonreflective black and retroreflective yellow sheeting, slanted at 45 degrees in an inverted "V" with the "V" at the center of the unit.

3.3.3- Wearing Retroreflective Garments.

Although garments were not part of this study, many of the state's DOT construction standards and/or provisions reviewed included that information and the research team considers it appropriate to include it in this report as workers are an essential part of the operations. Many states recommend the use of retroreflective garments. Wearing retroreflective garments with high contrast can help the worker be detected at longer distances than with low contrast. Safety garments are strictly regulated by standards issued by the American National Standards Institute and the International Safety Equipment Association. Some safety vests perform better than others in actual site conditions (See Table 26) (Arditi, D., et al. 2004).

Table 26. Retroreflective Garments DOTs Standards and/or Provisions (by States)

State	Flaggers
Illinois (Illinois DOT, 2022)	All personnel on foot shall wear fluorescent orange, fluorescent yellow/green, or a combination of fluorescent orange and fluorescent yellow/green vest meeting the requirements of ANSI/ISEA 107-2004 or ANSI/ISEA 107-2010 for Conspicuity Class 2 garments. Other types of garments may be substituted for the vest if the garments have a manufacturer's tag identifying them as meeting the ANSI Class 2 requirement.
Iowa (Iowa DOT, 2015)	Ensure flagger operations, equipment, and apparel comply with the current Iowa DOT Flagger's Handbook.
Kentucky (Kentucky DOT, 2019)	Ensure that all workers exposed to construction equipment or highway traffic wear high visibility safety apparel that conforms to and is labeled as meeting Performance Class 2 or 3 of the ANSI/ISEA 107-2004 publication. Additionally, for nighttime work, the Department will require flaggers to wear ANSI Performance Class 3 apparel.
Maine (Maine DOT, 2014)	Flaggers shall wear safety apparel meeting ANSI 107-2004 Class 2 risk exposure that clearly identifies the wearer as a person and is visible at a minimum distance of 1000 ft and shall

	wear a hard hat with 360° retro reflectivity. For nighttime conditions, Class 3 apparel, meeting ANSI 107-2004, shall be worn along with a hardhat with 360° retro reflectivity.
Missouri (Missouri DOT, 2018)	During daytime activities, flaggers shall wear a Performance Class 3 top OR a Performance Class 2 top. Hard hats other than high visibility orange or green shall be covered with a high visibility covering. During nighttime activities, workers shall wear a hard hat, safety glasses, a Performance Class 3 top OR Performance Class 2 top AND Class E bottoms, and safety footwear.
Nevada (Nevada DOT, 2014)	All personnel within the department's right of way shall wear vests meeting vest pattern 3(performance class 2) or coveralls/jumpsuits meeting performance class 3 requirements set forth in ANSI/ISEA 107-2004" American National Standards for high-visibility safety apparel and headwear". Garment stripes shall consist of retroreflected material of a contrasting color of silver, white, or fluorescent yellow green.
New Hampshire (New Hampshire DOT, 2016)	Flaggers shall wear high visibility apparel in accordance with the MUTCD and their attire shall be distinctive from the other workers. Flaggers shall wear ANSI Performance Class 3 safety apparel when flagging during hours of darkness. While encouraged, the Class 3 requirement does not apply to pants.
New Jersey (New Jersey DOT, 2007)	Ensure that workers wear a 360° high-visibility retroreflective orange safety garment meeting ANSI/ISEA Class 3, Level 2 standards.
New Mexico (New Mexico DOT, 2019)	The Contractor shall provide Type VIII or greater retroreflective sheeting for construction signing, flagger paddle, drums, cones, and channelization devices for legends and sign backgrounds, unless otherwise specified in the Contract.
North Carolina (North Carolina DOT, 2018)	Use highly-visibility safety apparel that meets the Performance Class 2 or higher requirements of the ANSI/ISEA 107-2010 or the equivalent revision. For nighttime flagging operations, Performance Class 3 safety apparel is required.
North Dakota (North Dakota, 2014)	When not enclosed in a truck or equipment cab, require that all workers within the right of way wear retroreflector clothing in accordance with ANSI/ISEA 107, Performance Class 2 or Class 3 requirements
Oregon (Oregon DOT, 2018)	Wear safety apparel that at least meets the following minimum requirements: • ANSI Class 2 or Class 3 fluorescent orange-red, fluorescent yellow-green or a combination of the two of these colors for the apparel background material color. • Fluorescent yellow-green, orange, yellow, or bright white hardhat or baseball-style cap. Wear hard hats when there is danger of falling or flying objects or electrical shock or burns. • For daytime and nighttime flagging operations, wear high-visibility safety apparel that meets the Performance Class requirements of the most current version of ANSI/ISEA 107, "American National Standard for High Visibility Safety Apparel and Headwear Devices". Wear safety apparel that at least meets one of the following minimum requirements: • Class 3 upper body garment. • Class 2 upper body garment and Class E trouser or gaiters. • Safety apparel with background material colors according to 00225.25.
Pennsylvania (Pennsylvania DOT, 2020)	Require all persons to wear high-visibility safety apparel (orange or yellow green) that is intended to provide conspicuity during both daytime and nighttime usage, and that meets the Performance Class 2 or 3 requirements of the ANSI/ISEA 107-2004 publication entitled "American National Standard for High-Visibility Safety Apparel and Headwear" while in work zones exposed either to traffic or to construction equipment.
Rhode Island (Rhode Island DOT, 2004)	Flag persons must wear attire appropriate for construction site work, and high-visibility safety apparel shall be worn by all flag persons actively engaged in providing traffic control. The apparel background (outer) material color shall be either fluorescent orange-red or fluorescent yellow-green, and the retroreflective material shall be either orange, yellow, white, silver, yellow green, or a fluorescent version of these colors, and shall be visible at a minimum distance of 1000 feet. The retroreflective safety apparel shall be designed to clearly identify the wearer as a person.
South Dakota (South Dakota DOT, 2015)	All workers within the work area shall wear high-visibility safety apparel intended to provide conspicuity during both daytime and nighttime usage and meeting the Performance Class 2 or 3 requirements of the ANSI/ISEA 107 publication entitled "American National Standard for High-Visibility Safety Apparel and Headwear" or equivalent revisions.

Tennessee (Tennessee DOT, 2015)	Ensure that all workers wear high-visibility safety apparel. Consider high-visibility apparel to be personal protective clothing that meets performance Class 2 or Class 3 of the ANSI/ISEA 107 publication. Provide Class 3 apparel for night work.
Texas (Texas DOT,2014	When directing traffic, flaggers must dress appropriately, wear high-visibility safety apparel, and follow the flagging procedures in the TMUTCD. Comply with the requirements of Section 7.2.6.5., "Training."
Utah (Utah DOT, 2017)	Flagger vest and hard hat – Orange, red-orange, or fluorescent version of these colors. Wear safety apparel meeting the requirements of ANSI/ISEA "American National Standard for High-Visibility Apparel and Headwear" or equivalent revisions and labeled as meeting the ANSI 107-2004 or current ANSI/ISEA publication year, standard performance for Class 3 risk exposure for nighttime activity.
Vermont (Vermont DOT, 2018)	Safety apparel shall be maintained so as to have a clean appearance and provide visibility at a minimum distance of 1,000 feet. Traffic control personnel deemed to have unsuitable safety apparel, by the Engineer, shall be considered ineffective and shall be removed. (1) Daytime. When operating during daytime hours, between sunrise and sunset, traffic control personnel shall wear safety apparel meeting or exceeding performance Class 2 requirements of the latest revision of ANSI/ISEA 107 – American National Standard for High-Visibility Safety Apparel and Accessories. (2) Nighttime. When operating during nighttime hours, between sunset and sunrise, traffic control personnel shall wear safety apparel meeting or exceeding performance Class 3 requirements of the latest revision of ANSI/ISEA 107, including Class E pants or gaiters.
Washington (Washington DOT, 2020)	During daylight hours with clear visibility, workers shall wear a high-visibility ANSI/ISEA 107 Class 2 or 3 vest or jacket, and hardhat meeting the high-visibility headwear requirements of WAC 296-155-305; and During hours of darkness (ó hour before sunset to ó hour after sunrise) or other low-visibility conditions (snow, fog, etc.), workers shall wear a high-visibility ANSI/ ISEA 107 Class 2 or 3 vest or jacket, high-visibility lower garment meeting ANSI/ISEA 107 Class E, and hardhat meeting the high-visibility headwear requirements of WAC 296-155-305.
Wisconsin (Wisconsin DOT, 2021)	Ensure that when performing flagging work on the project flaggers; are certified and wear a high visibility class 3 vest/pants ensemble that meets or exceeds ANSI/ISEA 107-2015 type R. Provide flagger certification documentation to the engineer before flagging.
Wyoming (Wyoming DOT, 2010)	Ensure that flaggers wear a strong yellow-green vest or an orange and strong yellow-green combination vest with reflectorizing on the front, back, and sides and a strong yellow-green hard hat (full hard hat covers are acceptable), and they have a paddle and flag (optional) in their possession at all times. The color of strong yellow green for vests and hard hats is for flagger use only. Supply and maintain the vest, hard hat, paddle, and flag in a "like new condition." Do not place company name or logo on the flagger vest.

3.4- Summary

The purpose of this chapter was to synthesize the construction standards and provisions by all of the state's Department of Transportation (DOTs) regarding the lighting and retroreflective marking of construction and maintenance vehicles and equipment during operations.
Most of the states use amber warning lights. Some states use a combination of warning light colors. These warning lights are either rotating or strobe lights. Although, most of the states didn't mention the color of the reflective tape, the ones that mentioned they required black and yellow reflective tapes on the rear and down both sides of their larger vehicles, such as California. Also, some states apply reflective tapes to their small vehicles, such as Alaska. Highway maintenance vehicles are generally distinguishable by their distinct colors. Most state DOT standards didn't specify a color for their maintenance vehicles. To improve the visibility of flaggers, they are required to wear a high visibility class 2 or 3 vest/pants ensemble that meets or exceeds ANSI/ISEA.

Chapter 4 - Best Practices Summary

4.1- Introduction

This chapter synthesizes the findings of previous research projects/literature and the state's DOT construction standards and provisions. As found in the literature, lighting, marking, and equipment color have an impact on work zone safety, especially during nighttime construction. Based on the literature, this chapter provides best practice recommendations that will help MDOT implement improved lighting and marking standards for both its own fleet of vehicles and equipment as well as the equipment and vehicles used by contractors on DOT projects. These include choosing appropriate colors for equipment and lights, as well as selecting the right type, pattern, and location. Additionally, retroreflective marking tape should be used in the correct color, material, pattern, and location. Finally, it is recommended to implement programmable warning lights to facilitate the use of various warning light configurations, intensities, and flash patterns to further enhance safety measures.

4.2- Best Practice Findings

4.2.1- Warning Lights Construction and Maintenance Vehicles and Equipment

To ensure that a properly functioning warning light on construction and maintenance vehicles and equipment is installed, erected, constructed, and assembled in accordance with this best practice recommendation, all materials must be furnished, installed, erected, constructed, and assembled. Warning lights on construction and maintenance equipment should not interfere with traffic or cause glare.

4.2.1.a- Construction and Maintenance Vehicles and Equipment Warning Lights Color

The contractor should only use construction and maintenance vehicles and equipment that have warning lights installed and are operating properly during the day-work and/or night-work. The warning lights on the construction and maintenance vehicles and equipment should be in amber color. The reason for selecting amber is that it produces less glare (Zockaie Et al., 2020) and less brake activations (Ullman, G. L., 2000) which are desirable.

4.2.1.b- Construction and Maintenance Vehicles and Equipment Warning Lights Patterns and Intensity

The warning lights on the construction and maintenance vehicles and equipment should be LED high intensity and should be operating during the day-work and/or night-work. All warning lights on construction and maintenance vehicles and equipment should be rotating or flashing. The reason for selecting high-intensity is that it provides higher attention-getting than a light source with a lower effective intensity (Gibbons, R. B., et al. 2008). Also, drivers interpret flashing lights as conveying the message of alert/caution and faster flash rates and intensities as conveying a higher sense of urgency (Steele D., et al. 2013).

4.2.1.c- Construction and Maintenance Vehicles and Equipment Warning Lights Location

All construction and maintenance vehicles and equipment used for day-work and/or night-work should have at least one warning light bar/strobe on top of the cab. The reason for using warning lights on top of maintenance vehicles is because this provides a high conspicuity, especially at night against a dark background (Gibbons, R. B., et al. 2008). Additionally, it was found in the

DOTs' construction standard and/or provisions that most states have warning lights on top of maintenance vehicles.

4.2.1.d- Construction and Maintenance Vehicles and Equipment Warning Lights Smart Technology

All construction and maintenance vehicles and equipment used for day-work and/or night-work are recommended to have programmable warning lights with customizable color options (such as amber or blue). The reason for using programmable warning lights is to help reduce glare based on conditions and control the intensity of the light (Zockaie et al., 2020).

4.2.2- Retroreflective Marking of Construction and Maintenance Vehicles and Equipment

Providing all materials, installing, and applying retroreflective markings for construction and maintenance equipment and vehicles in accordance with this best practice recommendation (in this section) will ensure proper and good quality retroreflective marking on construction and maintenance equipment. As part of the work, all maintenance associated with the retroreflective markings should be in good condition, and if damaged, they should be removed and replaced.

4.2.2.a- Construction and Maintenance Vehicles and Equipment Colors

All construction and maintenance vehicles and equipment are recommended to be white. The reason for this recommendation is that the high contrast of white with most background colors in the roadway environment reduces the risk of accidents (Datta, T., et al. 2008). Likewise, darker colors were found to have a higher risk of crash involvement, likely due to the lower color contrast of the vehicle with the background surroundings (Datta, T., et al. 2008).

4.2.2.b- Construction and Maintenance Vehicles and Equipment Retroreflective/Marking Color and Patterns

All construction and maintenance vehicles and equipment should have chevron pattern retroreflective markings installed in red and white color. The reason for the chevron pattern recommendation is that the NFPA guidelines state the chevron pattern (NFPA 1917, 2021). Furthermore, other states' DOT recommends the use of chevron patterns such as Tennessee DOT (TDOT, 2018). The combination of red and white is recommended because it is commonly associated with danger (Datta, T., et al. 2008).

4.2.2.c- Construction and Maintenance Vehicles and Equipment Retroreflective/Marking Material

All construction and maintenance vehicles and equipment should have retroreflective Type 1 (engineer grade) retroreflective surface sheeting. The reason for this recommendation is that this is the minimum acceptable type, according to the National Fire Protection Association (NFPA, 2021).

4.2.2.d- Construction and Maintenance Vehicles and Equipment Retroreflective/Marking Locations

All construction and maintenance equipment should have retroreflective tape on the sides and the back of the vehicle. The reason for this recommendation is that the code of federal regulations (eCFR, 2023), the Canadian Centre for Occupational Health and Safety (Canadian Centre for

Occupational Health and Safety, 2020), and some literature such as Kamyab, A., et al. 2022 make this suggestion.

4.3- Summary

This chapter presented a best practices recommendation synthesis based on (1) a qualitative systematic literature review; (2) data obtained from the DOT standards and/or provisions; (3) an analysis of the data and the literature findings.

References

Abdel-Aty, M. (2003). Analysis of driver injury severity levels at multiple locations using ordered probit models. Journal of safety research, 34(5), 597-603.

Anani, S. (2015). Work zone illumination design guidance strategies to specify appropriate work zone lighting plan (Order No. 1599172). Available from ProQuest One Academic. (1721998247). Retrieved from https://libweb.lib.utsa.edu/login?url=https://search-proquest-com.libweb.lib.utsa.edu/docview/1721998247?accountid=7122

Arditi, D., Ayrancioglu, M., & Shi, J. (2004). Effectiveness of Safety Vests in Nighttime Highway Construction. The Journal of Transportation and Engineering, 130(6).

Arditi, D., Lee, D. E., & Polat, G. (2007). Fatal accidents in nighttime vs. daytime highway construction work zones. Journal of Safety Research, 38(4), 399-405.

ARTBA (2020), "Scope of the U.S. Highway Network" American Road & Transportation Builders Association, Retrieved from: https://www.artba.org/government-affairs/policy-statements/highways-policy/, Last Retrieved, July 2020

ASAA (2020). "Night time construction work" American Sleep Apnea Association. Retrieved from https://www.sleepapnea.org/how-pollution-can-have-an-impact-on-sleep-, Last Retrieved on: August 06, 2020

ATTSA (2013). Nighttime Lighting Guidelines for Work Zones.

ATSSA. (2015, December 15). Nighttime Lighting Guidelines for Work Zones: A guide for developing a lighting plan for nighttime work zones. Retrieved from https://www.workzonesafety.org/training-resources/fhwa_wz_grant/atssa_night_lighting_guide/, Last Retrieved: August 07, 2020

Alabama DOT (Department of Transportation). (2018). Standard Specifications for Highway Construction

Alaska DOT (Department of Transportation and Public Facilities). (2017). Standard Specifications for Highway Construction

Arizona DOT (Department of Transportation). (2021). Standard Specifications for Road and Bridge Construction

Arkansas DOT (Department of Transportation). (2014). Standard Specification for Highway Construction

Bai, Y., and Li, Y. (2006). Determining Major Causes of Highway Work Zone Accidents in Kansas, Report No. K-TRAN: KU-05-1, Kansas Department of Transportation, Topeka, KS.

Baumeister, R. F., & Leary, M. R. (1997). Writing narrative literature reviews. Review of general psychology, 1(3), 311-320.

Brewer MA, Pesti G, Schneider W. (2006). Improving compliance with work zone speed limits: Effectiveness of selected devices. Transportation Research Record (1948): 67-76.

BriargateSupply (2020), Vehicle Chevron Kits. https://briargatesupply.com/vehicle-chevron-kits/ Retrieve: July 2020

Brown, H., Sun, C., Edara, P., Zhang, S., & Qing, Z. (2018). Evaluation of Green Lights on TMAs.

Bullough JD, Freyssinier JP, Rea MS. (2008). Implementing semipermanent high-mast lighting for highway construction projects. Transportation Research Record (2055): 49-52.

Bullough, J. D., & Rea, M. S. (2014). Nighttime highway construction illumination: final report. Troy, NY: Lighting Research Center, Rensselaer Polytechnic Institute.

Bullough, J., & Rea, M. (2016). Impacts of Fog Characteristics, Forward Illumination, and Warning Beacon Intensity Distribution on Roadway Hazard Visibility. The Scientific World Journal, 2016, 1-8. doi: 10.1155/2016/4687816

California DOT (Department of Transportation). (2021). Standard Specifications

Canadian Centre for Occupational Health and Safety. “Road Work - Traffic Control Zone”. Retrieved from https://www.ccohs.ca/oshanswers/safety_haz/road_work/traffic_control.html, Last Retrieved: August 07, 2020

Carlos, A., & Lopez, P. (2004, August 01). Pavement Marking Handbook. Retrieved from http://onlinemanuals.txdot.gov/txdotmanuals/pmh/pavement_marking_material_descriptions.ht, Last Retrieved: August 06, 2020

Cillessen & Sons. (n.d.). Pavement Marking: Kansas & Oklahoma. Retrieved August 07, 2020, from https://cillessen.us/pavement-marking/

CDOT (2019) Addition of green flashing warning lights to Connecticut Department of Transportation Feet

Colorado DOT (Department of Transportation). (2018). Standard Specifications for Road and Bridge Construction

Connecticut DOT (Department of Transportation). (2016). Standard Specifications for Roads, Bridges, Facilities, and Incidental Construction

Cole, S. (2020). Which Retro Reflective Tape Is The Brightest?, All About Reflective Tape. Retrieved March 22, 2021, from https://reflectivetape.info/which-retro-reflective-tape-is-the-brightest/

Datta, T., Savolainen, P., Grillo, L., & Schattler, K. (2008). Utility Work Zone Traffic Control.

Delaware DOT (Department of Transportation). (2016). Standard Specifications for Road and Bridge Construction

District of Columbia DOT (Department of Transportation). (2013). Standard Specifications for Highways and Structures

Ellis, R., Amos, S., & Kumar, A. (2003). Illumination Guidelines for Nighttime Highway Work. doi:10.17226/21955

eCFR. (2023). 49 CFR Part 393 Subpart B -- Lamps, Reflective Devices, and Electrical Wiring. Retrieved from https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=&SID=d1f858f3c2dc3d669d0908a98a99c561&mc=true&n=pt49.5.393.b&r=SUBPART&ty=HTML, Last Retrieved: August 06, 2023

FEMA. (2009). U.S Fire Administration, FEMA Emergency Vehicle Visibility and Conspicuity Study

FHWA, (2001). European Road Lighting Technologies, Report No. Federal Highway Administration. FHWA-PL-01-034, Washington, DC

FHWA, (2004). Signalized Intersections: Informational Guide. Federal Highway Administration. Report No. FHWA-HRT-04-091, Washington, DC

FHWA, (2009). "Manual on Uniform Traffic Control Devices (MUTCD) for Streets and Highways", Federal Highway Administration, Washington, DC.

FHWA, (2012). FHWA Lighting Handbook. Federal Highway Administration. Retrieved from:https://safety.fhwa.dot.gov/roadway_dept/night_visib/lighting_handbook/pdf/fhwa_handbook2012.pdf, Last Retrieved: June 2020.

FHWA, (2014). "Guidance for the Use of Temporary Pavement Marking in Work Zones" Federal Highway Administration. No. DTFH61-06, -G-00004. Retrieved from: https://www.workzonesafety.org/trainingresources/fhwa_wz_grant/atssa_temporary_pavement_markings/, Washington, DC, 2004

Stalnaker, T. (2019). *Fire apparatus emergency lighting study report: Emergency Responder Safety Institute*. Respondersafety.com. https://www.respondersafety.com/news/news/2019/06/fire-apparatus-emergency-lighting-study-report/.

Finley, M. D., Ullman, G. L., Miles, J. D., & Pratt, M. P. (2013). Studies to assess the impact of nighttime work zone lighting on motorists. College Station, TX: Texas A & M Transportation Institute.

Finley, M. D., Weimert, K. D., & Miles, J. D. (2014). Impact of work zone lighting on driver's detection of objects. Transportation Research Record, (2458), 56-64. doi: http://dx.doi.org.libweb.lib.utsa.edu/10.3141/2458-07

Flagger Force. (2018). Tapers: The Transition Areas in Work Zones. Retrieve from https://flaggerforce.com/blog/tapers-transition-areas-in-work-zones/, Last Retrieved: August 07, 2020

Florida DOT (Department of Transportation). (2019). Standard specifications for road and bridge construction

Fontaine MD, Carlson PJ, Hawkins HG. (2000). Evaluation of Traffic Control Devices for Rural High-Speed Maintenance Work Zones: Second Year Activities and Final Recommendations, 1879-2. College Station, TX: Texas Transportation Institute.

Fontaine, M. D., Carlson, P., & Hawkins Jr, H. (2000). Evaluation of traffic control devices for rural high-speed Maintenance work zones: Second-year activities and final Recommendations.

For Construction Pros. (2012). "Nite Lite From Work Area Protection". Retrieved from https://www.forconstructionpros.com/equipment/worksite/portable-lighting/product/10085694/work-area-protection-nite-lite, Last Retrieved August 12, 2020

Freyssinier JP, Bullough JD, Rea MS. (2008). Performance evaluation of semipermanent high-mast lighting for highway construction projects. Transportation Research Record (2055): 53-59.

Gambatese, J. A. (2005). Optimum illumination for nighttime flagger operations: Final report. Salem, Or.: Oregon Dept. of Transportation, Research Unit.

Gambatese, J., & Jafarnejad, A. (2018). Use Of Additional Lighting for Traffic Control And Speed. Retrieved August 7, 2020, from https://www.oregon.gov/ODOT/Programs/ResearchDocuments/SPR791_AdditionalWorkzoneLighting.pdf

Garber, N. J., & Zhao, M. (2002). Distribution and characteristics of crashes at different work zone locations in Virginia. Transportation Research Record, 1794(1), 19-25.

Gates TJ, Carlson PJ, Hawkins HG. (2004). Field evaluations of warning and regulatory signs with enhanced conspicuity properties. Transportation Research Record (1862): 64-76.

Georgia DOT (Department of Transportation). (2021). Standard Specifications Construction of Transportation Systems

Gibbons, R. B., Lee, S. E., Williams, B., & Miller, C. C. (2008). Selection and Application of Warning Lights on Roadway Operations Equipment. doi:10.17226/14190

Goree, A. (2019). "Heads up! I-84 closes overnight for Cloverdale overpass construction". Retrieved from https://idahonews.com/news/local/heads-up-i-84-closes-overnight-for-Cloverdale, Last Retrieved on: August 06, 2020

Grant, M. J., & Booth, A. (2009). A typology of reviews: an analysis of 14 review types and associated methodologies. Health Information & Libraries Journal, 26(2), 91-108

Gray, R. C., Quddus, M. A., & Evans, A. (2008). Injury severity analysis of accidents involving young male drivers in Great Britain. Journal of safety research, 39(5), 483-495.

Gurusgearllc. (2021, August 20). *ANSI/ISEA 107-2020: Detailed reference guide.* Guru's Gear. https://www.gurussafetygear.com/post/go-green-sustainability-and-the-future-of-shopping

Hancher, D. E., & Taylor, T. (2001). Nighttime Construction Issues. Transportation Research Record: Journal of the Transportation Research Board, 1761(1), 107–115. doi: 10.3141/1761-14

Hassan MW, Odeh I, El-Rayes K. (2011). New approach to compare glare and light characteristics of conventional and balloon lighting systems. Journal of Construction Engineering and Management 137(1): 39-44.

Hill, C. (2016). Green lights boost visibility of Michigan DOT winter maintenance vehicles. from https://www.equipmentworld.com/better-roads/article/14966312/green-lights-boost-visibility-of-michigan-dot-winter-maintenance-vehicles. Retrieved 2 February 2021

Hirasawa, M., Takemoto, A., Asano, M., & Takada, T. (2007). Study on Improving Worker Safety at Roadway Sites in Japan. Transportation Research Record: Journal of the Transportation Research Board, 2015(1), 41-54. doi:10.3141/2015-06

Howell, B., Pigman, J., & Agent, K. (2015). Work Vehicle Warning Lights: Color Options and Effectiveness. doi://dx.doi.org/10.13023/KTC.RR.2015.06

Hummer JE, Scheffler CR. (1999). Driver performance comparison of fluorescent orange to standard orange work zone traffic signs. Transportation Research Record (1657): 55-62.

Hyari, K., & El-Rayes, K. (2002). Automated DSS for Lighting Design of Nighttime Operations in Highway Construction Projects.

Hyari, K., & El-Rayes, K. (2006). Lighting Requirements for Nighttime Highway Construction. Journal of Construction Engineering and Management, 132(5), 435-443. doi:10.1061/(asce)0733-9364(2006)132:5(435)

IIHS (2020), "Fatality Facts 2018 State by state", Insurance Institute for Highway Safety, Highway Loss Data Institute, Retrieve from: https://www.iihs.org/topics/fatality-statistics/detail/state-by-state, Last Retrieved: June 2020.

Idaho DOT (Department of Transportation). (2018). Standard Specifications for Highway and Bridge Construction.

Illinois DOT (Department of Transportation). (2022). Standard Specifications for Road and Bridge Construction.

Iowa DOT (Department of Transportation). (2015). Standard Specifications for Highway and Bridge Construction.

Indiana DOT (Department of Transportation). (2020). Standard Specifications

Jackett, M., & Frith, W. (2013). Quantifying the impact of road lighting on road safety — A New Zealand Study. *IATSS Research, 36*(2), 139-145. doi:10.1016/j.iatssr.2012.09.001

Johansson, O., Wanvik, P. O., & Elvik, R. (2009). A new method for assessing the risk of accidents associated with darkness. Accident; analysis and prevention, 41(4), 809–815.https://doi.org/10.1016/j.aap.2009.04.003

Kamyab, A., McDonald, T., & Storm, B. (2002). Synthesis of best practices for increasing protection and visibility of highway maintenance vehicles.

Kansas DOT (Department of Transportation). (2015). Standard Specifications for State Road and Bridge Construction

Kentucky DOT (Department of Transportation). (2019). Standard Specifications for Road and Bridge Construction

Kennaugh, D. "Roadway Lighting Design". Retrieved from https://www.cedengineering.com/userfiles/Roadway%20Lighting%20Design.pdf, Last Retrieved: August 07, 2020

Konica Minolta, (2020) "Luminance vs. Illuminance." Retrieved from: https://sensing.konicaminolta.us/us/blog/luminance-vs-illuminance/, Last Retrieved on February 07, 2020,

Lan, T. T., Kanitpong, K., Tomiyama, K., Kawamura, A., & Nakatsuji, T. (2019). Effectiveness of retroreflective tape at the rear of heavy trucks to increase visibility and reduce rear-end collisions. IATSS Research. https://www.sciencedirect.com/science/article/pii/S0386111218300591.

Liberal Dictionary, (2020). "Foot-candle". Liberal Dictionary. Retrieved from https://www.liberaldictionary.com/foot-candle/, Last Retrieved August 06, 2020

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P., .. & Moher, D. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. Journal of clinical epidemiology, 62(10), e1-e34.

Louis J. (2010). Impact of Lighting on the Safety and Productivity of Nighttime Construction Workers [thesis]. West Lafayette, IN: Purdue University

Louisiana DOT (Department of Transportation). (2016). Standard specifications for roads and bridges

Maine DOT (Department of Transportation). (2014). State of Maine Department of Transportation standard specifications.

Massachusetts DOT (Department of Transportation). (1988). Standard specifications for highways and bridges

MDOTSHA (Maryland Department of Transportation State Highway Administration). (2018). Standard specifications for construction and materials.

MDOT (2020a), "Mississippi Department of Transportation", Retrieved from: https://mdot.ms.gov/ Last Retrieved: July 2020

MDOT (2010b), "MDOT continues core operations during COVID-19 outbreak", Mississippi Department of Transportation, Last Retrieved from: https://mdot.ms.gov/portal/news_release_view/149, Last Retrieved: July 2020

Michigan DOT (Department of Transportation). (2012). Standard specifications for construction.

Minnesota DOT (Department of Transportation). (2018). Mn/DOT standard specifications for construction.

Mississippi. (2013). Mississippi Code Title 45 - PUBLIC SAFETY AND GOOD ORDER. In LexisNexis (Ed.), 2013 Mississippi Code. Retrieved from https://law.justia.com/codes/mississippi/2013/title-45/chapter-3, Last Retrieved: 2023

Mississippi DOT (Department of Transportation). (2017). Standard specifications for road and bridge construction

Missouri DOT (Department of Transportation). (2018). Missouri standard specifications for highway construction. Jefferson City, MI: Modot.

MoDOT. (n.d.). 616.27.1 Fleet Lighting Levels and Conspicuity Tape. In MoDOT Engineering Policy Guide (EPG). Retrieved from https://epg.modot.org/index.php/616.27_Fleet_Lighting Top of Form, Last Retrieved: 2021

MnDOT, Office of Maintenance. (2013, November). Impact of Work Zone Warning Light Configurations on Driver Behavior.

Meyer E. (2000). Evaluation of orange removable rumble strips for highway work zones. Transportation Research Record (1715): 36-42.

MoDOT. (2020) “Autonomous Truck-Mounted Attenuators and Flagger Vehicles”. Retrieved from https://www.modot.org/autonomous-truck-mounted-attenuators-and-flagger-vehicles, Last Retrieved: August 07, 2020

Morgan, C. (2001). The Effectiveness of Retroreflective Tape on Heavy Trailers.

Neale VL, Barker JA, Dingus TA, Brich SC. 1999. Evaluation of unassigned sign colors for incident management trailblazing. Transportation Research Record (1692): 17-23.

Nevada DOT (Department of Transportation). (2014). Standard specifications for road and bridge construction.

New Hampshire DOT (Department of Transportation). (2016). Standard specifications for road and bridge construction

New Jersey DOT (Department of Transportation). (2007). Standard specifications for road and bridge construction

New Mexico DOT (Department of Transportation). (2019). Standard specifications for road and bridge construction

NEW York DOT (Department of Transportation). (2019). Standard specifications for construction and materials.

North Carolina DOT (Department of Transportation). (2018). Standard specifications for road and structures

North Dakota DOT (Department of Transportation). (2014). Standard specifications for road and bridge construction

NFPA, NFPA (1917 – AMBULANCE REFLECTIVE STRIPING. Retrieved from: https://reflectivetape.info/nfpa-1917-ambulance-reflective-striping/, Last Retrieved: April 2021.

NFPA,1901 CHEVRON REFLECTIVE STRIPING REQUIREMENTS FOR EMERGENCY VEHICLES. Retrieved from:https://reflectivetape.info/nfpa-1901-chevron-striping-requirements/, Last Retrieved: April 2021

Ng, E., Long, S., Smith, B., & Sun, C. (2013). A framework for improving roadway work zone safety using action research. IIE Annual Conference. Proceedings, 746-752.

NSC (2020), Motor Vehicle Deaths Estimated to Have Dropped 2% in 2019”, National Safety Council, Retrieve from: https://www.nsc.org/road-safety/safety-topics/fatality-estimates, Last Retrieve: June 2020

ODOT Multi-Colored Warning Light System (2021). Last Retrieved: February 02, 2021

Ohio DOT (Department of Transportation). (2019). Construction and materials specifications

Ohio DOT (Department of Transportation). (2023). Equipment Lighting, Marking And Conspicuity Policy

Oklahoma DOT (Department of Transportation). (2009). Standard specifications for highway construction

Oregon DOT (Department of Transportation). (2018). Standard specifications for construction

Pennsylvania DOT (Department of Transportation). (2020). Specifications

PK Construction. (2020) "TEMPORARY PAVEMENT MARKINGS". Retrieved from https://pkcontracting.com/service/temporary-pavement-markings/, Last Retrieved: August 07, 2020

Pigman, J. G., & Agent, K. R. (1990). Highway accidents in construction and maintenance work zones. Transportation Research Record, (1270).

Rea MS, Freyssinier JP. (2008). Color rendering: A tale of two metrics. Color Research and Application 33(3): 192-202.

Rhode Island DOT (Department of Transportation). (2004). Standard Specifications for Road and Bridge Construction

Roads&Bridges. (2019). Oregon DOT using new auto flagging technology to protect road workers. Retrieved August 07, 2020, from https://www.roadsbridges.com/oregon-dot-using-new-auto-flagging-technology-protect-road-workers

Pratt, S. G., Fosbroke, D. E., & Marsh, S. M. (2001). Building safer highway work zones: Measures to prevent worker injuries from vehicles and equipment. (No. DHHSNIOSHPUB2001128; PB2001106485).

Pritchard, D. (2015). Lighting (Sixth edition.). Routledge. https://doi.org/10.4324/9781315839264

Safety Lights and Signals. (n.d.). What Is the Difference Between SAE Class 1, SAE Class 2, and SAE Class 3 Warning Lights? Retrieved from https://www.safetylightsandsignals.com/p-1167-what-is-the-difference-between-sae-class-1-sae-class-2-and-sae-class-3-warning-lights.aspx, Last Retrieved 2023DOT

Sayer, J. R., & Mefford, M. L. (2004). High visibility safety apparel and nighttime conspicuity of pedestrians in work zones. Journal of Safety Research, 35(5), 537-546. doi:10.1016/j.jsr.2004.08.007

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. Journal of Business Research, 104, 333-339.

Steele, D., Zabecki, J. M., & Zimmerman, L. (2013). Improving the effectiveness of nighttime temporary traffic control warning devices, volume 2: Evaluation of nighttime mobile warning lights. ict-13-032 uilu-eng-2013-2033.

Smith, J. H., Edwards, R., O'Neill, S., & Goluchowski, M. (2006). Best Practice for Use and Design of Truk Mounted Attenuators (TMA) for New Zealand Roads.

South Carolina DOT (Department of Transportation). (2007). Standard specifications for highway construction

South Dakota DOT (Department of Transportation). (2015). Standard specifications for roads and bridges

Takemoto A, Hirasawa M, Asano M. (2008). Improving the nighttime visibility of signs and workers in road work zones in Japan. Transportation Research Board Annual Meeting, Washington, DC.

TDOT (Tennessee Department of Transportation.) (2018). TDOT Dump Truck and Light Duty Pickup Truck Reflective Striping Recommendations for the TDOT Occupational Health and Safety Division

Tennessee DOT (Department of Transportation). (2015). Standard specifications for road and bridge construction

Texas Department of Transportation (TxDOT). (2019). Lighting standards for highway maintenance or construction vehicles and service vehicles. Chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://ftp.dot.state.tx.us/pub/txdot/fod/vehicle-lighting-standards.pdf

Texas Department of Transportation (TxDOT) (2014). Standard Specifications For Construction and Maintenance of Highways, Streets, and Bridges

The Federal Register https://www.ecfr.gov/current/title-49/subtitle-B/chapter-III/subchapter-B/part-393/subpart-B, Last Retrieved: 2023

Traffic Safety District. (2018). DOT Reflective Tape Placement on Large Truck Trailers. Retrieved from https://trafficsafetydirect.com/dot-reflective-tape-placement-on-large-truck-trailers, Last Retrieved: August 07, 2020

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge by means of systematic review. British journal of management, 14(3), 207-222.

TransLine. (2019). Reflective Flexible Road Tabs. Retrieved August 07, 2020, from https://translineinc.com/products/pavement-marking-supplies/reflective-pavement-markers/reflective-flexible-road-tabs/

Trench, N., Wieder, M.A., Janing, J., Parker, C., Robinson, C. Emergency Vehicle Safety Initiative; United States Fire Administration: Emmitsburg, MD, USA, 2014; pp. 1–160.

Turner, J. D., Simmons, C. J., & Graham, J. R. (1997). High-Visibility Clothing for Daytime Use in Work Zones. Transportation Research Record: Journal of the Transportation Research Board, 1585(1), 1-8. doi:10.3141/1585-01

Ullman, G., Ragsdale, J., & Chaudhary, N. (1998). Highway construction, maintenance, and service equipment warning lights and pavement data collection system safety.

Ullman, G. (2000). Special Flashing Warning Lights for Construction, Maintenance, and Service Vehicles.

Utah DOT (Department of Transportation). (2017). Standard specifications for road and bridge construction

Vermont DOT (Department of Transportation). (2018). Standard specifications for construction

Virginia DOT (Department of Transportation). (2016). Road and bridge specifications

Wang C, Dixon KK, Jared D. (2003). Evaluating speed-reduction strategies for highway work zones. Transportation Research Record (1824): 44-53.

WarrenCat (2018) “Night Time Construction Guide. Retrieved from: https://www.warrencat.com/news/night-time-construction/, Last Retrieved on: July 2020

Washington DOT (Department of Transportation). (2020). Standard Specifications for Road, Bridge, and Municipal Construction

Webster, J., & Watson, R. T. (2002). Analyzing the past to prepare for the future: Writing a literature review. MIS quarterly, xiii-xxiii.

West Virginia DOT (Department of Transportation). (2017). Standard Specifications Roads and Bridges

Wong, G., Greenhalgh, T., Westhorp, G., Buckingham, J., & Pawson, R. (2013). RAMESES publication standards: meta-narrative reviews. BMC medicine, 11(1), 20.

Wisconsin DOT (Department of Transportation). (2021). Standard Specifications for Highway And Structure Construction

Wyoming DOT (Department of Transportation). (2010). Standard Specifications for Road and Bridge Construction

Zockaie, A., Saedi, R., Fakhrmoosavi, F., Jazlan, F., Ghamami, M., & Gates, T. (2020). Effectiveness Of Green Strobes On Winter Maintenance Vehicles and Equipment. Michigan. Dept. of Transportation. Research Administration.

Zhang K, Hassan M (2019) Crash severity analysis of nighttime and daytime highway work zone crashes. PLOS ONE 14(8): e0221128. https://doi.org/10.1371/journal.pone.0221128

Appendix A - Research on Lighting and Temporary Retroreflective Marking in Work Zones.

A.1- Introduction

This chapter presents the findings of previous research projects, considering the different methods of illumination and retroreflective marking, and how they have been implemented. As we know there is an increase in highway construction and maintenance projects. As well as there is an increase in the number of accidents via passing cars and operating vehicles, putting both workers and road drivers at risk. This increase is related to multiple factors; we can identify some of these factors as the lighting system and the retroreflective/marking used in the work zone.

Illumination, signs, vehicle lighting, markers, and signal lights can be confusing for both pedestrians and drivers, making the nighttime highway construction work zone, even more, complex than the daytime. Based on different research the type and the light level used in different highway construction sites can tell what provides more visibility. Also, there are different levels of glare from work zone illumination that should be taken into consideration to provide clear visibility. As well as the intensity of a retroreflective and its effect on reducing the number of accidents.

A.2- Research Methodology Lighting and Retroreflective Marking in Work Zones

The building block of this best practice research project was the current state-of-the-art knowledge. The state-of-the-art knowledge was accomplished through a literature review of previous research. This was needed to synthesize current research findings (Baumeister & Leary, 1997; Tranfield et al., 2003). A literature review is an excellent way of synthesizing research findings to show evidence on a meta-level and to uncover areas in which more research is needed (Snyder, H. 2019). An effective and well-conducted literature review as a research method creates a firm foundation for advancing knowledge and facilitating theory development (Webster & Watson, 2002).

The specific approach used in this research was a qualitative systematic literature review, which is a method of comparing findings from qualitative studies (Grant & Booth, 2009). A strict systematic review process was used to collect literature including a qualitative approach to analyze them. The qualitative systematic literature review was conducted using the following four phases:

Phase 1 - Design the literature review,
Phase 2 - Conduct the literature review search,
Phase 3 - Analysis of the literature obtained from the search, and
Phase 4 - Structuring and writing up the review.

This process was selected because it was developed from practical experience and is a synthesis of and influenced by various standards and guidelines suggested for literature reviews (e.g., Liberati et al., 2009; Tranfield et al., 2003; Wong et al., 2013).

Phase 1 - Design the Literature Review

During this phase, two comprehensive research databases were selected 1- The University of Texas-San Antonio (UTSA) and 2- Google Scholars (see Table 27). These two databases were selected as they contain the breadth and depth of research of previous research needed for this research project and they provided the researcher access to the full papers. In addition to selecting the databases, specific search terms were defined initially only the terms lighting and marking were used. These two terms did not provide the results needed. Several iterations of multiple search terms were used arriving in the search term shown in Table 28. These terms were used because they provided relevant results in previously conducted research papers relevant to this research project. Finally, inclusion and exclusions were added to the search term as shown in Table 29.

Table 27. Database Used to Find Research Articles/Papers

Database:
Database UTSA – ProQuest
Database – Google scholar

Table 28. Search Term Keywords Used in the Databases to Find Articles/Papers

Keywords:
Work zone lighting
Transportation work zone
Transportation work zone and lighting
Illumination, Highway work zone
Work zone lighting “visual performance”

Table 29. Inclusions/Exclusions Used in the Databases.

Restriction:
Only in Titles
Only in articles

Phase 2 - Conduct the Literature Review Search

At the beginning of this phase, pilot tests using the original search criteria developed during Phase 1 were used to fine-tune the search criteria. After the search criteria were fine-tuned, papers began to be selected. The first screening condition was the title of the paper. In some cases, the papers matched the search criteria from Phase 1 but based on the title they were not relevant for this research project. If based on the title the paper seems to be relevant, the abstract of the paper and the conclusion/summary were read and if the content was considered relevant the full paper was collected (downloaded) for analysis.

Phase 3 - Analysis of the Literature Obtained from the Search

After the papers were collected, each paper was reviewed, and the appropriate content was abstracted to be included in this report on the research project. Since most of the literature found was descriptive in nature, a qualitative approach was used to determine the content to be abstracted. The abstraction consisted of the statement of fact found on the papers with the proper referencing (i.e., authors, years published, title, publication avenue). Additionally, during this

faces the references in the literature found were reviewed and located if relevant to this research project. These additional references were analyzed using the same approach described in this paragraph.

Phase 4 - Structuring and Writing Up the Review
The findings from the research review were organized into two main areas: 1- Lighting/Illumination of work zones, and 2- Temporary retroreflective marking of work zones including flaggers vests. In each one of those two areas, the statement of facts obtained was grouped based on their relevance to inform the best practices for lighting and marking of construction and maintenance vehicles and equipment for safety as shown in the result section of this chapter.

A.3- Results/Findings on Lighting and Temporary Retroreflective Marking in Work Zones

Roadways often contain existing, permanent lighting to help drivers navigate the roadways. During construction, existing roadway lighting may not be sufficient to eliminate the need for additional lighting in the work zone. In some cases, existing lighting may not be present. To provide the necessary lighting during construction, construction crews typically employ light towers, balloon lights, or other types of commercially available lighting systems. Factors such as efficiency, ability to satisfy minimum requirements while controlling glare, amount of light required to perform the tasks and be seen, availability of power, light trespass, and cost also should be considered when selecting the types of lighting that are best suited for the work zone (Gambatese, J., and Jafarnejad, A.,2018).

A.3.1 - Lighting

A.3.1.a- Work Zone Illumination

As highway construction and maintenance projects are increasing during nighttime, lighting is becoming an important factor of safety. It is important that all permanent and temporary roadway lighting constructed for a project be erected as soon as feasibly possible to aid illumination during the nighttime construction process. Research indicates that workers' perceptions of their safety improved when roadway lighting was present (Louis J. 2010).

The illumination produced by lighting equipment is extremely important when light decreases vision, and the detection of information is severely impaired or nonexistent. Likewise, as light increases vision and the detection of information are improved (Kennaugh, D., 2020). In a study, illuminated roadway section results showed that properly installed temporary work zone lighting can increase worker and low-contrast object detection distances. The results also confirmed a negative impact on worker and low-contrast object detection distances from improper positioning of portable light towers and supported the theory that workers can be washed out visually when directly illuminated by portable light towers, making them more difficult to detect.

Overall, all the temporary work zone lighting conditions (even those with glare) resulted in worker detection distances greater than the stopping sight distance for the conditions studied. In contrast, only two of the temporary work zone lighting conditions resulted in low-contrast object detection distances greater than the stopping sight distance for the conditions studied. So, improperly implemented lighting that produces glare conditions for motorists can severely limit

the ability of drivers to detect low-contrast objects immediately after the light source (Finley, M. D., et al. 2013)

Normally, attention is focused on the primary construction or maintenance activities. Lighting plans and configurations are established to accommodate these key production activities, such as the placement and compaction of asphalt pavement. Care must be taken to ensure that other ancillary activities also have adequate lighting. For example, an inspection of asphalt pavement typically occurs at a considerable distance from the location of the paver and the following rollers. Provisions must be made so that the quality control and acceptance activities are also properly lit (Ellis, R., et al. 2003). Another example occurs in the construction of Portland cement concrete pavements. Management attention generally focuses on the paving operation receiving adequate lighting. However, several hours after the paving operation has passed, joints must be cut in the pavement; the saw-cutting crew may be left without adequate lighting (Ellis, R., et al. 2003).

Work zone illumination can be divided into three levels: **Level I** is required throughout the work zone, while active work areas where equipment is operating require **Level II** or **Level III**, depending on the difficulty of the work and how much it depends on the worker's visual performance (Anani, S., 2015). The table below shows the general description and sample construction and maintenance activities for each of the three levels and their corresponding recommended minimum illumination (see Table 30).

Table 30. Work Zone Illumination Based on Work Being Performed (Anani, S., 2015)

Level	General Description	Sample Construction / Maintenance Activities	Minimum Illumination
Level 1	General construction operations with personnel outside traveling vehicles area (Throughout the work zone).	● Layout and measurements ahead of the actual work ● Excavation - Regular, Lateral Ditch, Channel ● Subgrade, Stabilization, and Construction ● Base Course Rolling ● Sweeping and Cleaning ● Landscaping, Sod and Seeding ● Embankments, Maintenance of Fill and/or Compaction ● Reworking Shoulders ● Area of lane or road closures continuously throughout the period of closure, including the setup and removal of the closures. ● Stockpiles	54 lux (5 fc)
Level 2	Areas on or around construction personnel and/or equipment	● Barrier wall, Traffic Separators ● Milling, Removal of Pavement ● Asphalt Paving and Resurfacing ● Concrete Pavement ● Base Course Grading and Shaping ● Surface Treatment ● Waterproofing and Sealing ● Sidewalk Construction ● Guard Rails and Fencing ● Striping and Pavement Marking ● Highway Signs ● Bridge Decks ● Drainage Structures and Drainage Piping	108 lux (10 fc)

		• Other Concrete Structures	
Level 3	Construction work that required high level of visual performance (Also, for situations require extreme caution)	• Joint repair, crack filling pavement patching and repairs • Highway Lighting Systems	216 lux (20 fc)

A.3.1.b- The Glare and Glare Control

Many highway designers are unfamiliar with lighting design. Perhaps for this reason, in the past, designers often left the selection of work zone illumination systems to the discretion of the contractor or field engineering staff, who may also be unfamiliar with illumination. Too often, this has resulted in work zones with an excessive glare that creates a serious safety hazard. Therefore, illumination should be considered during the design phase whenever night construction is required or allowed (Anani, S., 2015).

When installing lighting within a work zone, ensure proper illumination for the workspace, while controlling glare so as not to blind workers and passing motorists. For example, lowering the height of lighting equipment to reduce glare for motorists, and considering using glare-free light balloons and glare screens (Pratt, S., et al. 2001).

Suggested requirements for glare control and avoidance are presented in Table 31, of the recommendations, proper aiming and the use of glare control shading hardware appear to be the most effective countermeasures (Ellis, R., et al. 2003).

Table 31. Glare Control Check List (Ellis, R., et al. 2003)

Beam Spread	Select vertical and horizontal beam spreads to minimize light spillage. Consider using cutoff luminaires.
Mounting Height	Coordinate minimum mounting height with source lumens (see).
Location	Luminaire beam axis crosses normal lines of sight between 45° and 90°.
Aiming	Angle between main beam axis and nadir less than 60° (see) Intensity at angles greater than 72° from the vertical less than 20,000 candela.
Supplemental Hardware	Visors, Louver, Shields, Screens, Barriers

Determination of proper mounting height is also crucial in controlling glare. Mounting luminaires at lower-than-optimum levels can cause severe problems. In general, mounting height is related to the lumen rating of the light source as shown in Figure 31 High luminance sources require increased mounting heights (Ellis, R., et al. 2003).

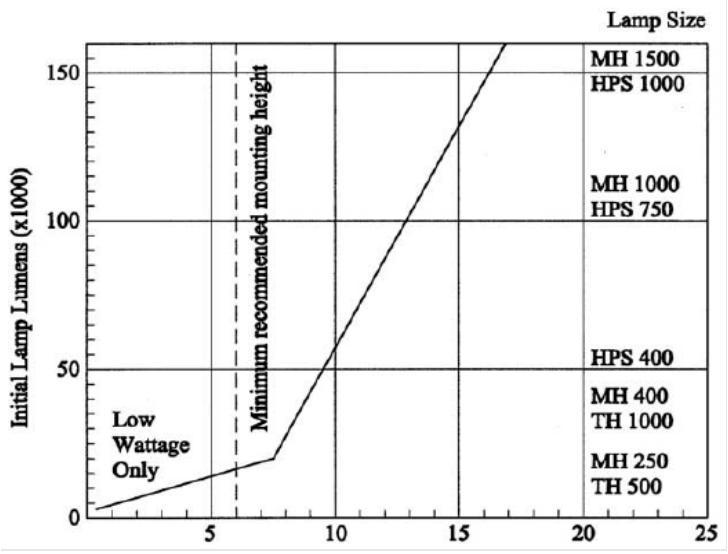


Figure 31. Recommended Relationship Between Mounting Height and Source Lumens (Ellis, R., et al. 2003).

Recommended lighting levels will normally be specified in terms of average maintained illumination and can be found in the project specifications or recommended practices discussed previously. To determine watts/m2, see Figure 32 and enter the recommended illumination level on the left axis, and project horizontally to the appropriate lamp line, and then drop down to recommended watts/sq on the horizontal axis (Ellis, R., et al. 2003).

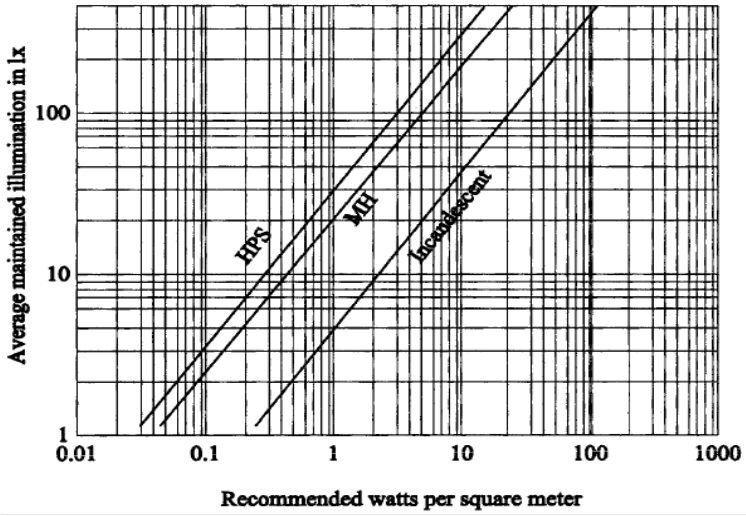


Figure 32. Square Recommended Watts Per Meter for Different Illumination Levels and Lamp Types (Ellis, R., et al. 2003)

A.3.1.c- Lighting Technologies for Work Zones

In a study, (A total of 46 responses were received) participants were asked about the equipment they used for nighttime construction Illumination. As shown in Figure 33, survey respondents have used the following technologies: trailer-mounted light towers (91%), portable flashlights and clip-on lights (52%), vehicle headlights (46%), semi-permanent mast lighting (26%), balloon lighting (13%), and 21% reported using other sources including equipment-mounted lights,

vehicle-mounted lights, and existing street lighting (Bullough, J. D., and Rea, M. S. 2014) (see Figure 33).

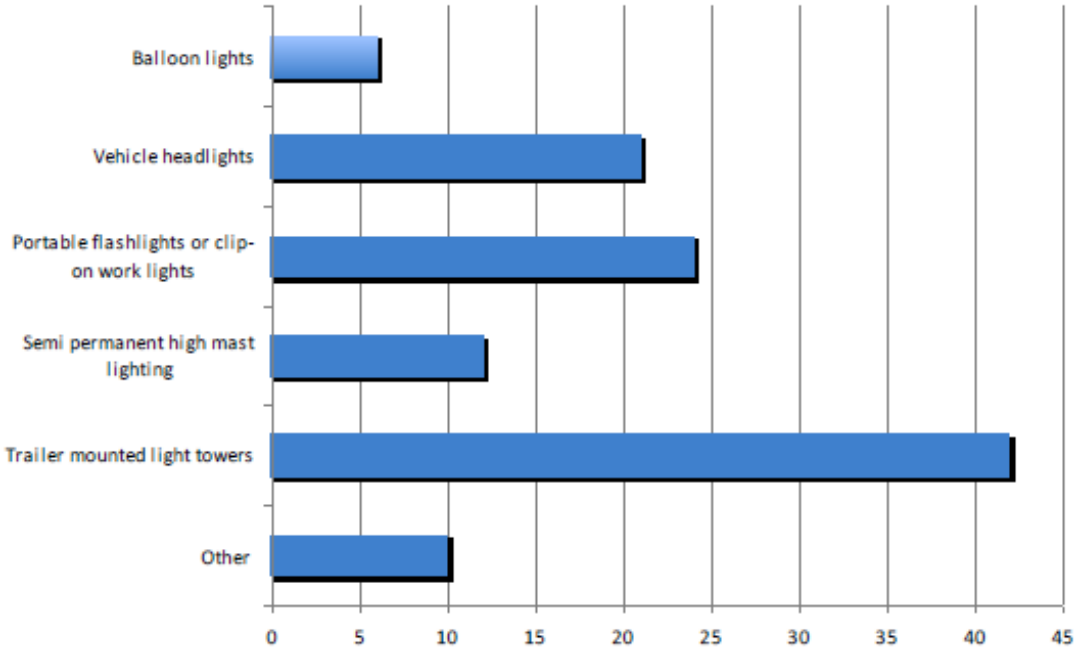
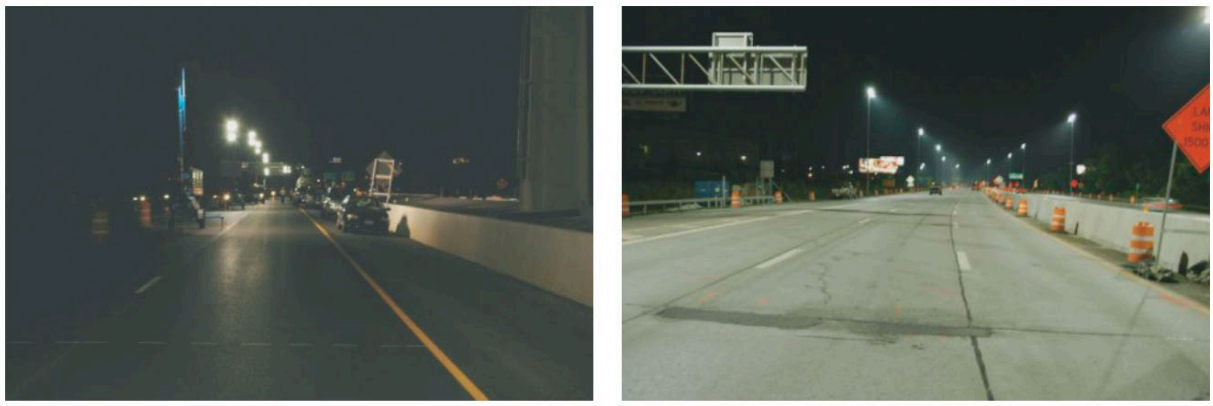


Figure 33. Traffic Control Technologies Recommended for Use in Work Zones (Bullough, J. D., and Rea, M. S. 2014).

There are different lighting approaches for providing adequate visual performance (Freyssinier JP, et al. 2008).

- **High mast illumination:** an evaluation was conducted of semi-permanent high mast illumination along with a long-term highway reconstruction project. The system consisted of a large installation of pole-mounted floodlight-type roadway luminaires that provided high levels of very uniform illumination along the entire stretch of highway under construction. The high mounting locations and illuminance uniformity resulted in high visual performance of workers with few shadows and low glare to workers and drivers. The high mast lighting approach is expensive in terms of installation and operation, about 15%-20% higher than conventional illumination using light towers, but substantially reduced setup and takedown time and shaved time from the project while using less fuel to generate power and produced less noise than light tower generators. On a per-distance basis, the high mast approach produced less light pollution as well. Overall, it was found to be a sound approach for large-scale projects but would not be cost-effective for shorter ones (Bullough JD, et al. 2008) (See Figure 34).



(a) (b)

Figure 34. Similar Work Zones are Illuminated By A) Portable Light Towers And (B) High-Mast Lighting (Freyssinier JP, Et al. 2008).

- **Balloon lighting:** A light source is surrounded by a large, translucent covering that diffuses the light, producing softer and fewer shadows, and in principle, less glare. (Hancher, D. E., and Taylor, T., 2001). Balloon lighting systems can produce similar amounts of light for a given wattage, although they tend to result in lower average illuminances in the work area. Hassan et al., (2011) confirmed that the balloon systems indeed produce less disability glare to comparable systems using conventional light towers and they also are less glaring than equipment-mounted lights or vehicle headlamps. (Hassan MW, et al. 2011). A new lighting technology now available for highway contractors that greatly reduces the harmful effects of glare while providing ample site illumination is the Airstar Balloon Light manufactured by Airstar, Inc. The light uses an outer balloon to diffuse glare from the light source. Several Kentucky highway contractors have begun using this new technology. At this time, however, there has been no notable research into the use of balloon lighting (Hancher, D. E., and Taylor, T., 2001) (see Figure 35 and Figure 35)

Figure 35. Balloon Lights Mounted on Tripod (Gambatese, J., And Jafarnejad, A.,2018).

Figure 36. Balloon Lights Mounted on Paver (Gambatese, J., And Jafarnejad, A.,2018).

- **Portable trailers light towers:** Portable light towers also referred to as light plants, consist of numerous luminaires (typically two to six light fixtures) mounted to a mast arm that can hold the luminaires at various mounting heights. The mast arm is attached to a trailer with a generator that can be towed by a vehicle (). The light fixtures are typically outfitted with 1,000 or 1,500-watt metal halide bulbs. If the number of watts is increased, the area illuminated also increases. The bulbs are not limited to metal halide and some light towers have the option of using high-pressure sodium or tungsten halogen lights (Gambatese, J., and Jafarnejad, A.,2018) (see Figure 37).

Figure 37. Portable Trailer-Mounted Light Tower with Mast Lowered and Mast Raised (Gambatese, J., And Jafarnejad, A.,2018).

- **Other Trailer-Mounted Lights:** Other types of trailer-mounted lights are available. For example, the Nite Lite is a portable construction light with a 400-watt metal halide lamp in a dome-shaped luminaire that is coated with a light-diffusing compound. The luminaire weighs 26 lbs. (11.8 kg) with a diameter of 25 inches (0.635m) and stores securely in a custom foam-padded carry/storage case. The Nite Lite provides non-glaring,

white light from a high-intensity gas-filled lamp ignited by microprocessor-controlled electronics. This technology allows the Nite Lite to provide a highly visible non-glaring light that can be powered by a 120-volt AC, 60-Hertz electrical source using a standard plug. Light output is rated at 42,000 lumens which can illuminate an area of 0.34 acres (1,395 m2) (Gambatese, J., and Jafarnejad, A.,2018) (See Figure 38)

Figure 38. The Nite Lite Portable Work Zone Light Provides a Non-Glaring White Light for All Moving and Static Nighttime Construction Projects (For Construction Pros, 2012).

- **Light Stands:** Several other types of lighting equipment exist that are not classified as lighting towers or balloon lights. Light stands are common examples of other types of equipment available. These types of lighting systems are typically used for flagging operations or for smaller, focused areas of work. Most of these systems do not have a generator permanently attached to them and, if so, require a power source for their operation. Light stands generally have one to two luminaires containing lamps that provide output ranging from 500 to 1,500 watts each. The stands can be extended to a height of 6 to 12 feet (Gambatese, 2005). Figure 39 shows a tripod-mounted floodlight and a spotlight.

Figure 39. Tripod-Mounted Floodlights (Left) And Spotlights (Right) (Gambatese, 2005)

A.3.1.d- The Intensity and Lighting Source

Illuminance can be increased by increasing the intensity of a light source, increasing the number of light sources, or decreasing the distance of the light sources from the work surface (Anani, S., 2015). Once the work activities have been identified, it is necessary to determine the type of lighting source to use. Based on the planned work activities and whether the work is mobile,

stationary, or long duration, a lighting source using balloon luminaires, portable light plant towers, or roadway luminaires should be chosen (ATTSA, 2013).

Due to their almost horizontal orientation, vehicle headlights are not good sources for work zone lighting. They can also be a major distraction to oncoming vehicles, especially if the work operation involves counter-directional travel on a divided highway. Contract specifications should prohibit the use of headlights while work vehicles are stationary in a lighted work area. Counter-directional travel should be avoided, when necessary, it should be done at low speed with headlights off (Anani, S., 2015). The more objects there are in a driving scene, the more mental effort is required for drivers to process incoming visual information and decide which objects are important to the driving task. Drivers, in general, tend to ignore objects in their peripheral vision. Visual overload is particularly likely if there are large variations in lighting intensity in different parts of the scene.

Flashing lights on work vehicles are intended to draw attention—but they can be an unnecessary distraction if they encourage the driver to focus on a part of the scene that is not relevant to navigating safely through the site. Therefore, the recommendation is that vehicle headlights are not good sources for production lighting. They can also be a major distraction to oncoming vehicles, especially if the work operation involves counter-directional travel on a divided highway Contract specifications should prohibit the use of headlights while work vehicles are stationary in a lighted work area. Counter-directional travel should be avoided, and when necessary, it should be done at low speed with headlights off (Anani, S., 2015).

Different light sources can also influence color perception. For example, light from low-pressure sodium (LPS) lamps is monochromatic (589 nm, producing yellow light). All objects, regardless of their color, look either varying levels of the same shade of yellow or else appear to be black. Most light sources permit much better color identification than LPS lamps. Although there are currently proposals to replace or refine the Color Rendering Index (CRI) in the lighting and color communities, CRI appears to have some relationship with color identification. However, once the CRI value was above about 60, color identification did not improve but was near a maximal value (Rea MS, and Freyssinier JP., 2008).

There are three general types of light sources: LED, filament, and arc-discharge (Kennaugh, D., 2020) each with different types of light as shown in Table 32.

Table 32. Light Sources (Kennaugh, D., 2020)

Light Source	Type	Lumens	Life (hrs.)
LED	LED	2-90	50,000
Filament Lamp	Incandescent	10-15	12,000
Discharge Lamp	Fluorescent	60-70	7,500-24,000
	Mercury Vapor	50-65	24,000
	Metal Halide	90-110	10,000-20,000
	High-Pressure Sodium	125-140	24,000
	Low Pressure Sodium	180	18,000

- **LED (Light-Emitting Diode):** An LED roadway light is an integrated light that uses light-emitting diodes (LED) as its light source. These are considered integrated because the luminaire and fixture are not separate parts. Most LED roadway lights have a lens on the LED panel, which is designed to cast its light in a rectangular pattern aiming most of the light to the street side. The primary appeal of LED roadway lighting is energy efficiency compared to conventional roadway lighting fixture technologies. An LED fixture uses considerably less electricity than traditional light fixtures. In addition, an LED fixture will have a longer life than the traditional light fixtures. This results in a reduction in maintenance costs. A disadvantage of LED lighting is increased glare (Kennaugh, D., 2020).

- **Incandescent Lamp:** The incandescent lamp has a filament that is an electrical resistance wire enclosed in a gas-filled bulb. Current passing through the filament heating the filament to incandescence produces light. The gases are inert, usually nitrogen or krypton, which reduce evaporation of the filament and act as a thermal barrier (Kennaugh, D., 2020).

- **Discharge Lamp:** The discharge lamp produces light by exciting gases or metal vapors in a lamp or tube. Electrical potential is applied to electrodes. Gas is ionized and current flows between the electrodes. The lamps have a negative resistance and must have a ballast to maintain the proper current level. The ballast regulates the input power of the lamp. Fluorescent Lamp - The fluorescent lamp produces light through a fluorescent coating on the inside of the tube which is activated by ultraviolet energy generated by an arc (Kennaugh, D., 2020).

- **Mercury Vapor:** The mercury vapor lamp consists of an arc tube inside the outer bulb containing mercury vapor and electrodes. Light is produced from the ionization of mercury vapor. Lamps may be clear or coated with phosphors to improve color rendition (Kennaugh, D., 2020).

- **Metal Halide** - Metal halide light is produced by a combination of metallic vapors. The lamp has excellent color rendition but has a short lamp life (Kennaugh, D., 2020).

- **High-Pressure Sodium** - The high-pressure sodium lamp produces light from sodium vapor. The arc tube is normally filled with sodium, mercury, and xenon. Xenon is used for starting the light and mercury for coloring. This lamp has no starting electrode and produces a high-voltage pulse of 2,500 to 4,000 volts (Kennaugh, D., 2020).

- **Low Pressure Sodium** - The low-pressure sodium lamp is very efficient. However, it is monochromatic (single color only). It has a large physical size, and the light is hard to control. It also has a lower lamp life (Kennaugh, D., 2020).

A.3.1.e- Lighting Plan

El-Rayes and Hyari (2002) identified seven decision variables to be considered in the development of a lighting plan: 1) lighting equipment selection; 2) type of luminaire; 3) lamp lumen output; 4) luminaire height; 5) light tower positioning; 6) aiming angle of luminaires, and 7) light tower rotation around a vertical axis.

A.3.2 –Temporary Retroreflective Marking of Work Zones

Marking is a method to communicate with both road travelers and workers during the day and nighttime in different conditions to ensure the safety of both. The retroreflective devices include materials containing (a) spherical glass bead elements or (b) cube corners or prismatic elements. In both cases, it is the elements that reflect the incident light. Glass bead materials include those with beads that are partially embedded within a supporting surface, such as paint and partially exposed to the atmosphere, and those with beads that are completely embedded within a transparent material. Exposed-bead designs generate greater brightness but are more easily damaged by abrasion and completely lose their reflectivity when wet. Newer versions of enclosed-bead materials, referred to as encapsulated lens sheeting, have provided greater brightness while retaining their protective characteristics (William J., et al. 1999).

International and domestic historical literature and experience indicate that the use of currently available reflective material on freight cars in a railroad environment may be successful in reducing nighttime motor vehicle run-into-train (RIT) collisions (See Figure 40) Specific findings include: (DOT)

- Reflective materials can enhance motorists' ability to detect the presence of a train in a highway-railroad grade crossing.
- A material with the maximum intensity available should be used (prismatic) to provide the highest level of illuminance to the observer and to reduce maintenance requirements.
- A uniform pattern will enhance the motorist's recognition of a train in time to avoid a collision.

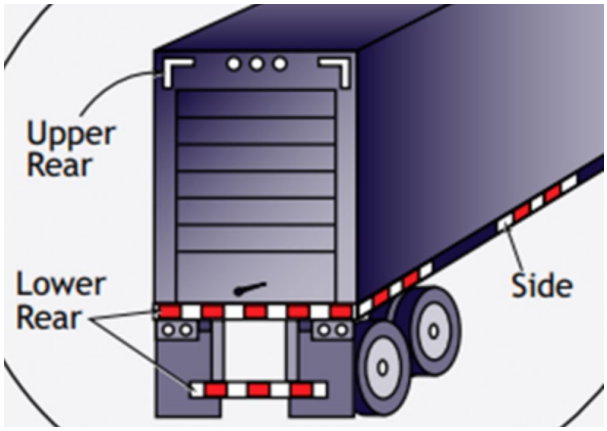


Figure 40. Reflective Tape Placement on Large Truck (Traffic Safety District, 2018).

A.3.2.a- Daytime and Nighttime

The dark scenario treatments confirmed that a worker wearing a retroreflective vest could be detected at significantly longer distances than low-contrast objects (i.e., box, target, and tire) (Finley, M., et al. 2003). Researchers found in the study that illuminated roadway sections showed that properly installed temporary work zone lighting can increase the distance at which workers and low-contrast objects can be detected. The results also confirmed that improper positioning of portable light towers had a negative impact on the distance at which workers and low-contrast objects could be detected and supported the theory that direct illumination by portable light towers can visually wash out workers and thus make them more difficult to detect (Finley, M. D., 2014).

A.3.2.b- The Placement of the Retroreflective and Traffic Control.

As part of traffic management plan efforts in work zones, more agencies are conducting construction activities during nighttime hours to avoid the highest traffic volumes. Working at night reduces work zone impacts on the traveling public. However, traffic control plans for nighttime work zones must provide additional visual cues for drivers, in particular, the higher percentage of high-risk drivers at night (e.g., impaired, drowsy). To fully capitalize on nighttime construction activities, the permanent marking needs to remain in place when the work zone is moved off the roadway and all the lanes are opened to traffic for normal operations. In most cases, temporary marking is not a viable option for these work zones. One option with similar benefits to temporary pavement marking is the use of sequential lighting at the taper and along the work zone (FHWA, 2014).

Sequential warning work zone lighting can improve visibility and provide improved visual cues for drivers on merging tapers and lane shifts. Sequential warning work zone lights direct the driver through the merging taper and work zone. The devices are self-calibrating once installed at the work zone. For example, if one of the lights stops functioning, the devices will self-adjust the sequence to account for any outages. Additionally, if workers move the devices in a different order, the devices will adjust to the proper sequence based on their proximity to each other in the work zone (FHWA, 2014). The more objects there are in a driving scene, the more mental effort is required for drivers to process incoming visual information and decide to decide (Anani, S., 2015). Conventional traffic engineering solutions include increasing the upstream distance from the work zone where illumination or fluorescent devices, cones, and barrels are placed, as well as enhancing visibility and reducing the speed limit (Zhang, K., and Hassan, M., 2019).

Traffic control device: A traffic control device is a sign, signal, marking, or other device placed on, over, or adjacent to a street or highway, pedestrian facility, or bikeway (by the authority of a public agency having jurisdiction) to regulate, warn or guide traffic (FHWA 2000) (Pratt, S. G., et al. 2001) (See Figure 41).

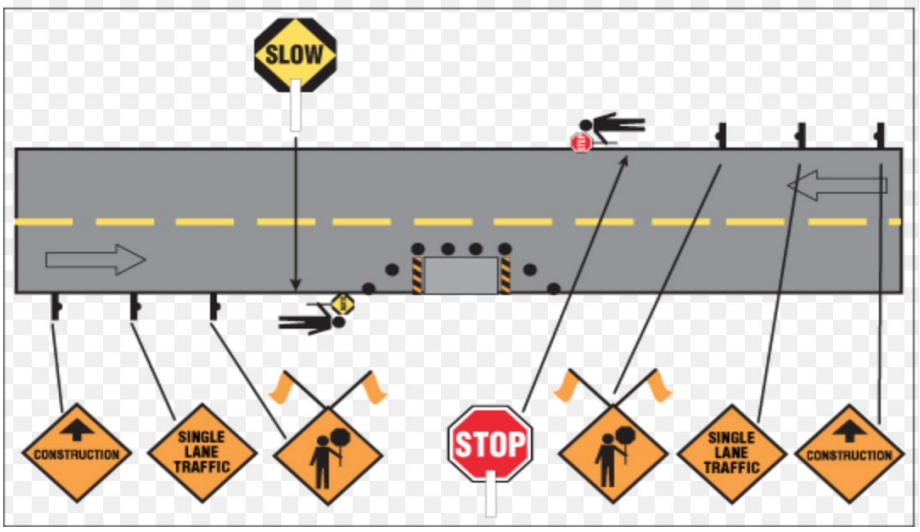


Figure 41. Traffic Control Signs (Canadian Centre for Occupational Health and Safety, 2020).

Truck-mounted attenuator (TMA): A safety device mounted on the rear of a truck that dissipates the energy of rear-end collision (Pratt, S. G., et al. 2001) (see Figure 42).

Figure 42. Autonomous Truck-Mounted Attenuators (MoDOT, 2020).

Channelizing devices: The function of channelizing devices is to warn road users of conditions created by work activities in or near the roadway and to guide road users. They are also used to separate motor vehicle traffic from the workspace, pavement drop-offs, pedestrian, or bicycle paths, or opposing directions of motor vehicle traffic. Channelizing devices include cones, tubular markers, vertical panels, drums, barricades, and temporary raised islands (FHWA 2000) (Pratt, S. G., et al. 2001).

The MUTCD also requires channelizing devices (such as Cones, tubular makers, etc.) to use retroreflective materials (FHWA, 2009).

- **Tubular Markers**: that are less than 42 inches shall be provided by two 3-inch-wide white bands placed a maximum of 2 inches from the top with a maximum of 6 inches between the bands. Tubular markers that have a height of 42 inches or more shall be provided by four 4- to 6-inch-wide alternating orange and white stripes with the top stripe being orange (FHWA, 2009) (See Figure 42).

- **Cones**: that are more than 36 inches in height shall be provided by horizontal, circumferential, alternating orange, and white retroreflective stripes that are 4 to 6 inches wide. Each cone shall have a minimum of two orange and two white stripes with the top stripe being orange. Cones that are 28 to 36 inches in height shall be provided by a 6-inch-wide white band located 3 to 4 inches from the top of the cone and an additional 4-inch-wide white band located approximately 2 inches below the 6-inch band (FHWA, 2009) (See Figure 43).

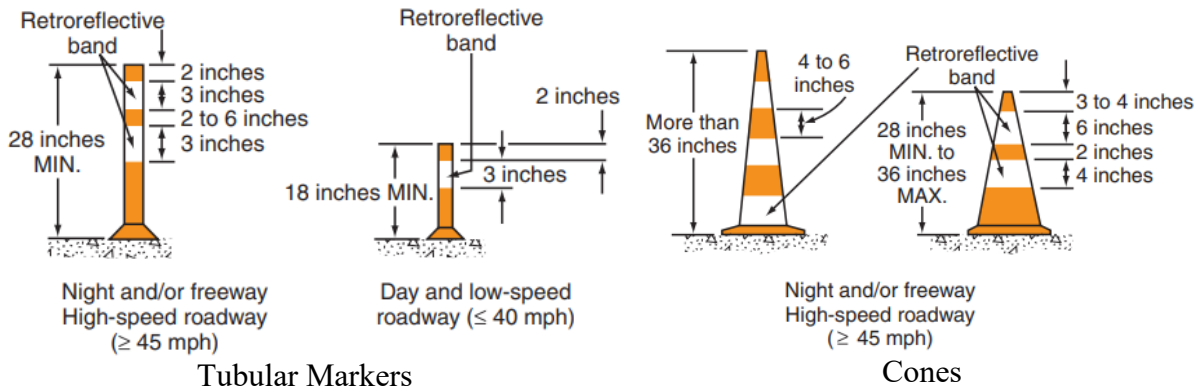


Figure 43. Use of Retroreflective Materials in Channelizing Devices (FHWA, 2009).

- **Taper:** Tapers may be used in both the transition and termination areas. Tapers are created using a series of channelizing devices and/or pavement markings to move traffic out of or into the normal path (Pratt, S. G., et al. 2001) (See Figure 43).

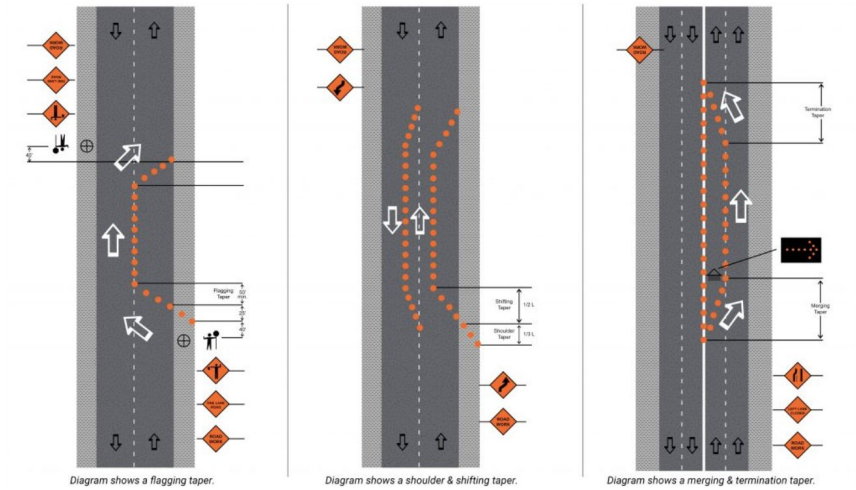


Figure 44. Taper (Flagger Force, 2018).

A.3.2.c- Wearing Retroreflective with High Contrast Cloths, Retroreflective Color.

The study, in the nighttime scenario, has confirmed that a worker wearing a retroreflective vest could be detected at significantly longer distances than low-contrast objects (Finley, M., et al. 2003). The results of this study revealed that the blaze orange trim was significantly more conspicuous than the fluorescent red trim (288 m), but not significantly different from white/silver. The difference between the white/silver and fluorescent red trim was not significant. It also, includes that retroreflective trim on the sleeves of a garment significantly improves conspicuity (Sayer, J. R., and Mefford, M. L. 2004). Several explorations of fluorescent-colored sign materials have been conducted. Schnell et al., (2001) reported that clear daytime visibility distances were slightly longer for fluorescent than non-fluorescent signs, and fluorescent signs were more reliably detected in the visual periphery.

Fontaine et al., (2000) found that fluorescent orange signs often were felt by work crews to be more visible than conventional orange signage (Fontaine MD, et al.,2000). Hummer and Scheffler (1999) found that fluorescent orange signs were associated with slightly fewer traffic

conflicts in work zones, with fewer vehicles in closed lanes and less variable (but higher) driving speeds (Hummer JE. and Scheffler CR. 1999). In contrast, Wang et al.,(2003) found that fluorescent orange signs reduced driving speeds in work zones, although the effect was diminished over time (Wang C, et al., 2003). Gates et al., (2004) investigated the use of fluorescent red stop signs in conjunction with flashing red light-emitting diodes (LEDs) and found these to be effective at encouraging traffic to stop when this was desired (Gates TJ, et al 2004). The use of non-fluorescent sign color has also been evaluated by several researchers. Brewer et al., (2006) reported that the use of orange borders around speed limit signs made them more conspicuous and visible, although they did not find any observed effects on driving speeds in work zones (Brewer MA, et al., 2006). Gates et al., (2004) studied the effect of a red reflectorized border around speed limit signs in work zones and reported that they had positive effects, increasing speed compliance. In a context somewhat different from work zone applications (Gates TJ, et al 2004). Neale et al., (1999) found that several unconventional sign color combinations (yellow letters on purple, and black letters on light blue) resulted in reductions in late-breaking maneuvers and were preferred by drivers (Neale VL, et al., 1999). The colors of other visual elements have also been investigated. Orange-colored portable rumble strips made from plastic or rubber were found to reduce driver speeds in work zones compared to uncolored asphalt rumble strips. Meyer E. (2000) suggests that visual appearance was an important factor in speed reduction. He reported that the portable rumble strips were ineffective at producing vibration or sound (Meyer E. 2000). Below example of high visibility apparel (See Figure 45).

Figure 45. High Visibility Apparel (Gambatese, J., & Jafarnejad, A.,2018).

Six safety vests (coded Vests I–VI) commonly used nationwide were tested under actual site conditions rather than in a laboratory. The sites were selected to test the vests under different weather conditions, traffic volume, and lighting conditions. The luminance of the front faces and the sides of the vests were measured and analyzed using hardware and software organized into a system called LUMINA. It was found that Vests III and VI were superior to the other four vests. It is not surprising that these two safety vests are tied for the first rank as they are similar to each

other in most respects. It is, however, interesting that of the six vests tested, these two vests did not have the largest amount of retroreflective material on them (Arditi, D., et al., 2004).

When the characteristics of Vests III and VI are presented below, it is found that not surprisingly, the two vests are very similar to each other. Indeed, both vests use the same yellow color fabric and approximately the same amount of silver-colored 3M Scotch lite retroreflective material. There are two minor differences between Vest III and Vest VI: their configuration and the fabric used on the sides. While a Velcro closure is used in the front of Vest III, vest VI uses a zipper. Vest VI has a pocket in the front face whereas Vest III does not have any pockets. The sides of Vest VI are made of solid fabric, whereas the sides of Vest III are mesh fabric. Also, the arm opening appears to be larger in Vest III (see side views in Figure 46). The slight differences in the area (smaller in Vest III) and the type (mesh in Vest III) of fabric on the sides may explain why Vest VI outperformed Vest III when the sides were tested (See Table 33) (Arditi, D., et al. 2004).

Table 33. Properties of Safety Vests Tested (Arditi, D., et al., 2004).

Vest	Retail Price ($ each)	Type of Texture	Color of the Vest	Color of Retroreflective Material	Characteristics of Retroreflective Material
I	13.18	Mesh	Orange	Yellow	3M Scotch lite reflective material
II	40.00–50.00	Mesh	Orange	Yellow	PVC prism sheet
III	45.95	Fabric (mesh on the sides)	Yellow	Silver	3M Scotch lite reflective material
IV	21.99	Mesh	Yellow	Silver	3M Scotch lite reflective material
V	43.59	Fabric	Orange	Yellow	Reflexite retroreflective tape
VI	29.71	Fabric	Yellow	Silver	3M Scotch lite reflective material

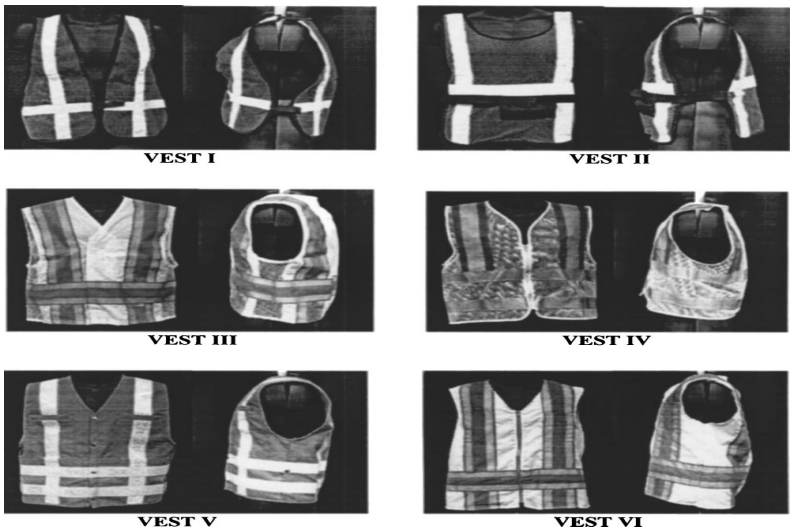


Figure 46. Safety Vests (Arditi, D., et al., 2004)

A survey investigated satisfaction with traffic safety measures taken at roadway work sites. The results identified the visibility of the traffic control personnel at nighttime as an item requiring

priority improvement. Construction workers and traffic control personnel on the road wear orange vests that are highly visible. The problem seems to be their dark blue uniforms. The recognition evaluation experiments confirm that the distance needed for recognizing traffic control personnel largely depends on the uniform color. Results suggest that recognition of the uniform can be improved by changing the color to orange or yellow. Such a change would help to improve the safety of traffic control personnel and can be implemented immediately at a low cost (See Table 34) (Hirasawa, M., et al., 2007).

Table 34. Color Recognition and Confirmation Distances Under Various Conditions (Hirasawa, M., et al., 2007)

Season	Lighting	Color Recognition Distance (m)				Worker Confirmation Distance (m)			
		Dark Blue	Red	Yellow	Orange	Dark Blue	Red	Yellow	Orange
Autumn	Daytime	473	483	652	738	321	315	444	427
	Dusk	415	362	608	643	298	233	360	381
	Night spot lighting	58	81	192	188	119	117	163	194
	Night balloon lighting	48	25	99	98	103	97	125	123
Winter	Daytime	274	325	426	621	304	335	302	375
	Dusk	337	383	513	635	310	292	288	385
	Night spot lighting	100	106	260	192	146	167	215	183
	Night balloon lighting	69	73	156	125	113	127	163	152

The research study validated the use of Fl red-orange as an adequate safety garment color, which had not been previously done. However, when a great deal of work-zone machinery and equipment colored orange exists, the Fl red-orange vest may cause a worker to blend in with the surroundings. This study was unable to replicate the full work-zone environment; therefore, good judgment should be used when selecting a safety vest color. States and regions where a great deal of orange-colored equipment is used may want to consider the use of a safety garment color other than Fl red-orange (Turner, J. D., et al., 1997).

The Fl yellow-green vest is an excellent alternative to the traditional safety garment color. The color appears to work very well in the work-zone environment, and past research has shown the color performs well in twilight or hazy conditions. Also, subjects consistently selected the Fl yellow-green vest as a good color in terms of its perceived safety. This color is recommended for agencies seeking an alternative to the Fl red-orange vest. The garment is expected to be extremely safe initially because of the effect of novelty; however, the Fl yellow green should continue to be very safe even after the newness has worn off (Turner, J. D., et al., 1997).

The combination of Fl red-orange and Fl yellow-green also appears to provide a high level of conspicuity in the work-zone environment. This treatment is recommended for use by personnel who alternate between working in areas with naturalistic or cityscape backgrounds and areas that contain brightly colored traffic-control devices and equipment, as shown in Table 35 (Turner, J. D., et al., 1997).

Table 35. Detection Distance For 11 Colors Collapsed Across Work Zones (Turner, J. D., et al., 1997).

	Mean	Median	Mode	Min	Max	85th Percentile
Fl. Green	200	152	122	61	549	92
Fl. Yellow Green	269	213	152	61	610	152
Fl. Yellow	242	213	213	61	610	122
Semi-Fl. Yellow	216	152	122	61	610	122
Ordinary Yellow	214	152	152	31	671	122
Fl. Yellow Orange	238	213	152	31	610	145
Fl. Red Orange	300	305	183	0	640	175
Fl. Red-Orange w/ Fl. Yellow Green	253	213	183	0	671	145
Fl. Red Mesh on White	272	244	183	0	671	152
Ordinary Orange	203	183	122	31	579	92
Fl. Pink	257	244	152	61	610	122
Note: Distances are given in meters.						

In a study done over two years, the results were the following:

- The maintenance crews responded favorably to the fluorescent yellow-green vests. Of all the mesh vests, the TxDOT fluorescent yellow-green vest provides the greatest field luminance and luminance factor results. Both non-mesh garments tested had larger luminance and luminance factor values than the three mesh garments.
- For all eight different background types, the TxDOT fluorescent yellow-green mesh vest provided the highest luminance ratio values of all three mesh vests tested. Once again, the non-mesh garments consistently provided higher luminance contrast ratios.
- The color of the mesh vests depends on the color of the garment worn underneath. For this evaluation, two types of undergarments were used: a white T-shirt and a navy blue T-shirt. For the mesh vests, the TxDOT fluorescent yellow-green vest maintains the best. conformance with the ANSI and ASTM color specifications. Both non-mesh alternatives, also conform well with the color recommendations of ANSI and ASTM (Fontaine, M. D., et al., 2000).

Worker strobe lights: The worker strobe lights are small, self-contained battery-operated strobe lights that can be attached to worker vests. Lenses can be added to the strobes so that they emit either a white or yellow flash. The strobe lights evaluated were not very visible during the day. These devices may improve nighttime visibility but could also create confusion among motorists if a larger number of individual strobe lights are going off within the work zone. Strobe lights are not recommended for application to short-term work zones (Fontaine, M. D., et al., 2000).

This standard, now in its fifth edition as of 2020, plays a critical role in safeguarding the lives of workers exposed to various occupational hazards. It defines the types of apparel, performance classes, configurations, and marking requirements to enhance visibility and safety in the workplace (Gurusgearllc, 2021).

The ANSI/ISEA 107-2020 standard classifies high-visibility apparel into three distinct types (Gurusgearllc, 2021):

- Type O (“off-road”)

- Type R (“roadway”)
- Type P (“public safety”)

The ANSI/ISEA 107-2020 standard establishes four performance classes (Gurusgearllc, 2021):

- Performance Class 1
- Performance Class 2
- Performance Class 3
- Supplemental Class E

Table 36. Types of Garments (Gurusgearllc, 2021)

Garment Type	Performance Class	Background Material [Square Inches (in2)]	Retroflective or Combined Performance Materials (in2)	Minimum Width Retroreflective Material[Inches (in)]
Type O	Class 1	217	155	1
Type R	Class 2*	775	201	1.38
	Class 3**	1240	310	2
	*For the smallest size offered in Type R, Performance Class 2, a minimum of 540 in2 of background material may be used to accommodate small-sized workers.			
	**For the smallest size offered in Type R, Performance Class 3, a minimum of 1000 in2 of background material may be used to accommodate small-sized workers.			
Type P	Class 2	450	201	2
	Class 3	775	310	2
Supplemental Items	Class E	465	109	2

ANSI/ISEA 107-2020 standard enhances workplace safety by ensuring workers are visible and protected in environments with hazards, reducing risks associated with occupational hazards.

A.3.2.d- Flaggers

A survey of drivers about their needs regarding work zones revealed that providing more information about lane reduction is important and ensuring that some work zone illumination is directed toward flaggers or other workers is also important (Takemoto A., et al., 2008). To make the flagger visible to approaching traffic, special attention should be paid to lighting the flagger station at night. Since positioning the flagger near-permanent roadway lighting normally does not provide adequate illumination, it may be necessary to provide temporary lighting for the flagger station. The use of parked vehicle headlights to illuminate the flagger station is undesirable since it may create glare. The flagger should not be placed in a backlighted situation since this configuration makes it difficult for the motorist to observe the flagger’s instructions. Instead, lights used to illuminate the flagger station should be mounted high enough to light the flagger from the front or above and in such a manner that they do not create glare for approaching motorists or create shadows such that the flagger is not positively illuminated (Finley, M., et al., 2003) (See Figure 47, Figure 48)

Figure 47. Oregon DOT Using New Auto Flagging Technology to Protect Road Workers (Roads & Bridges, 2019).

.

Figure 48. Flagger Under Portable Balloon Light (Gambatese, J., & Jafarnejad, A.,2018).

The Federal Highway Administration (FHWA), in their Manual on Uniform Traffic Control Devices (MUTCD), requires flaggers to wear high-visibility safety apparel that meets the Performance Class 2 or 3 requirements of the ANSI/ISEA 107–2004 publication entitled "American National Standard for High-Visibility Apparel and Headwear".

Safety Apparel: The retroreflective material shall be orange, yellow, white, silver, yellow-green, or a fluorescent version of these colors, and shall be visible at a minimum distance of 1,000 feet (FHWA, 2009). This visibility distance should protect the workers as it takes 820 feet for a vehicle to get to a full stop when traveling at 75 mph as seen in Table 37.

Table 37. Stopping Sight Distance as A Function of Speed (FHWA, 2009)

Speed *	Distance
20 mph	115 feet
25 mph	155 feet
30 mph	200 feet
35 mph	250 feet
40 mph	305 feet
45 mph	360 feet
50 mph	425 feet
55 mph	495 feet
60 mph	570 feet
65 mph	645 feet
70 mph	730 feet
75 mph	820 feet

* Posted speed, off-peak 85th-percentile speed prior to work starting, or the anticipated operating speed.

A.3.2.e- Temporary Pavement Marking

The Center for Transportation Research Excellence (CTRE) at Iowa State University recently conducted research on the connection of pavement marking retroreflectivity to roadway safety. The focus of the study was to evaluate differing segments of retroreflective markings and their impacts on roadway safety. The study did not validate specific retroreflectivity levels, but rather it compared crash data on roadway segments with various retroreflectivity levels to gauge impact. The researchers discovered that pavement marking on freeways provided a significant safety benefit to drivers. For freeways, yellow edge lines reduced nighttime crashes, and white edge lines helped reduce single-vehicle crashes. For two-lane highways, increasing retroreflectivity led to a decrease in crash frequency (See Table 38) (FHWA, 2014).

Table 38. CTRE Iowa State University Study on Roadway Safety and Maintained Pavement Markings (FHWA,2014).

Facility	Retroreflectivity Marking Location	Safety Impacts
Freeway	Yellow Edge Lines	Decrease in all nighttime crashes correlated to increases in retroreflectivity
	White Edge Line	Decrease in SV nighttime crashes correlated to increases in retroreflectivity
	Lane Lines	Decrease in nighttime and SV crashes when retroreflectivity increased
Tow-Lane Highway	Yellow Centerline	Decrease in all nighttime crashes correlated to increases in retroreflectivity
	White Edge Line	Decrease in crashes frequency as retroreflectivity increased

SV= Single Vehicle

Because the marking is temporary and is typically not placed at the same location as the subsequent permanent marking, it is important that the material can be removed from the pavement without leaving a significant “ghost” marking (FHWA, 2014).

Temporary pavement marking is an important element of a Traffic Control Plan (TCP) and provides drivers with clear and defined travel paths through work zones (FHWA, 2014). Temporary markings should be removed without leaving any trace (Pratt, S. G., et al., 2001) (See Figure 49).

Figure 49. Temporary Pavement Marking (FHWA, 2014)

Several materials can be used to provide temporary pavement markings in work zones, including traffic paint, temporary tape, raised pavement markers, buttons, and tabs. The following bullets provide a brief overview of each material (FHWA, 2014):

- **Traffic Paint**. Quick-drying paint with glass beads added to create retroreflectivity is a low-cost material for temporary work zones. This material is best applied at temperatures of 70 degrees F and above with little humidity but can be applied when ambient temperatures are above 50 degrees F. Traffic paint is one of the least durable liquid materials used (FHWA, 2014) (See Figure 50).

Figure 50. Paint on Lane Shift (FHWA, 2014).

- **Temporary Tape.** Preformed tapes are strips of plastic with an adhesive backing. Temporary tape can be removed by pulling the material up and does not require heat or other mechanical methods, although using these methods can result in faster removal. This material may only be used for short-term work zones for up to 6 months to prevent the resin from strongly

adhering to the pavement. Temporary tape used in work zones is produced with retroreflective material incorporated into it (FHWA, 2014) (See Figure 51).

Figure 51. Removal Tape in Work Zone (PK Construction, 2020)

- **Temporary Raised Pavement Markers (TRPM).** TRPMs are commonly used in construction zones. Either an adhesive or a peel-and-stick backing is used to attach the TRPM to the pavement.
    - **Tabs:** are markers that are raised from the pavement and are constructed with enough flexibility to resist the vehicles passing over them. They are used to supplement the flat line markings for conditions such as rain (FHWA, 2014) (See Figure 52).

Figure 52. Retroreflective Road Tabs. (Trans Line, 2019)

    - **Buttons:** are domes and servers' similar functions as the tabs. The buttons can be glued to the pavement and are used to supplement line markings. They are not as impact-resistant as tabs and are not usually used where snowplowing may be a possibility (FHWA, 2014) (See Figure 53).

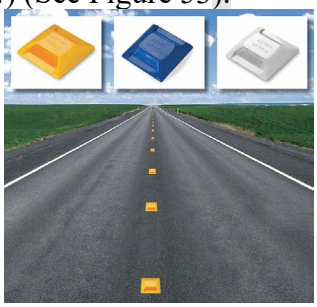


Figure 53. Retroreflective Road Buttons (FHWA, 2014)

- **Epoxy and Thermoplastic**: Long-term work zones and high traffic volumes may warrant the use of these materials. These are highly durable materials that are appropriate for those areas where a visible line is needed for many months or years and are subject to extreme abuse from traffic or other situation-specific conditions. Agencies considering these markings will

typically apply them in the locations where permanent markings will be when the project is complete (FHWA, 2014) (See Figure 54)

Figure 54. Typical inverted-profile thermoplastic marking (Carlos, A., & Lopez, P., 2004)

A.4- Summary

The objectives are to reduce highway construction accidents by comparing the different cases of using different methods of illumination and marking, and how better safety standards for lighting and retroreflective/marking can be implemented.

As mentioned before there are several factors to take into consideration. For instance, illumination should be considered during the design phase whenever night construction will be required or allowed and minimize the glare effect as much as possible. Properly installed work zone lighting can decrease accidents, and nighttime accidents are more severe than both daytime work zone crashes and non-work zone crashes. Also, crashes in rainy conditions during nighttime tend to increase. There are different lighting technologies currently used for illumination and different lighting approaches for providing adequate visual performance. Marking, workers wearing a retroreflective vest could be detected at significantly longer distances than low-contrast objects. Vehicles or machinery using chevron strips can also be identified from longer distances. How to arrange the traffic control devices, as when there are more objects in the driving scene, more mental effort is required for drivers to process incoming visual information. Also, the placement of the retroreflective and the distances have a great impact on reducing accidents.

Safety garments are strictly regulated by standards issued by the American National Standards Institute and the International Safety Equipment Association (ANSI/ISEA 1999). All safety vests used in highway construction and maintenance necessarily satisfy the relevant requirements of the ANSI/ISEA standards. But some safety vests perform better than others in actual site conditions (Arditi, D., et al., 2004).

Appendix B - DOTs Standards and/or Provisions (by States) Lighting and Temporary Retroreflective Marking in Work Zones.

B.1- Introduction

The objective of this chapter is to study the current construction standard and/or provisions, and what can be done to improve it. As mentioned before, the purpose of this paper is to provide a setup of highway work zone safety that contains some better standards for lighting, illumination during nighttime construction, as well as site vehicle marking. This can be achieved by knowing the laws, standards, and/or provisions of each state, and making comparisons to decide the best-used practices. Going through the DOT standards and/or provisions, many of the states didn't focus on the standards of lighting or mention any further details. Also, almost all the states didn't mention anything about vehicles reflecting chevron stripes.

B.2- Research Methodology of DOT Standards and/or Provisions in Work Zones

To achieve the research objectives, a review of existing literature was conducted to identify and document the used lighting systems and markings in different states. The purpose of this chapter is to explain in detail the research methods and the methodology implemented for this study. In this part, we went through all the state's DOT standards and/or provisions using the Google engine. While collecting, the information needed for lighting and marking during construction, I looked at the table of contents first for any indications and then used some keywords such as "illumination, lighting, nighttime, and work zone" to find it faster, sometimes its included under the "scope of work" or "temporary traffic control" in the table of content (see Table 39)

Step 1: Obtained all the State DOT Standards and/or provisions.

Step 2: Reviewed table of contents of each DOT Standard and/or provisions to identify lighting and/or marking in Construction Zones. If the Standard did not have, a section dedicated to this topic, a word search using the keywords in Table 40, was performed to check if the content was distributed in other sections of the standard.

Table 39. Standard and Provision Table of Content

Table Content Sections
Lighting
Marking in Construction Zones

Table 40. Search Term Keywords Used in the Standard and Provisions

Standard Keywords
Illumination
Lightings
Nighttime
Work zone
Lighting system
Artificial lighting
Light towers
Night work
Flood lights

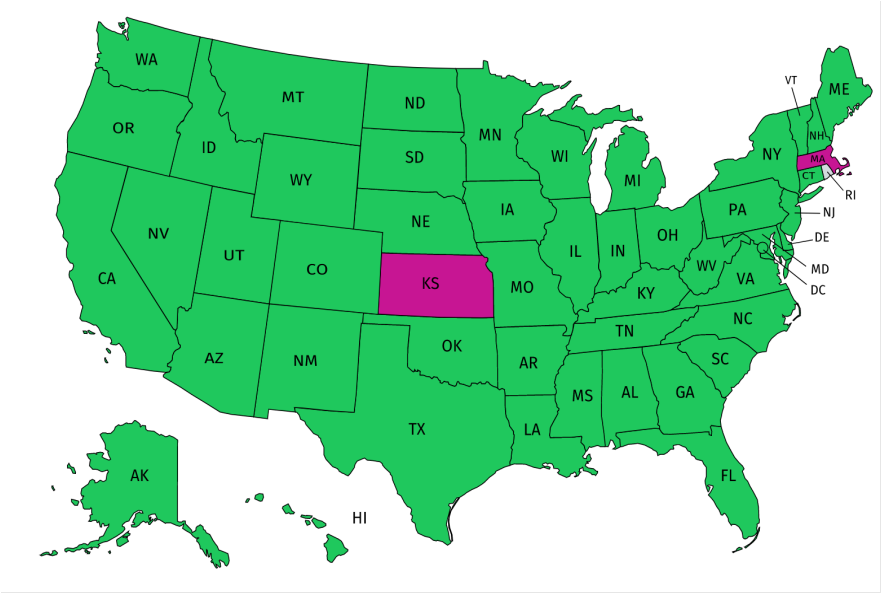
Step 3: Analyzed the sections regarding lighting and/or marking section of the state DOT Standard.

Step 4: The pertinent information was highlighted/extracted as practice in the corresponding state

Step 5: Made a schedule for each state to ease the comparison between the different states.

B.3- Results of DOT Standards and/or Provisions

Two states DOT did not have any standards on lighting and marking during construction, one state DOT had standards only for marking and the remaining states had standards for both lighting and marking as shown in Figure 54.



Legend:

Pink: No Standard Lighting/Illumination and Marking during construction Information
Grey: Only Standard Marking
Green: Standard Lighting/Illumination and Marking during construction

Figure 55. United States of America MAP

B.3.1 – Lighting Information from DOT Standards and/or Provisions

Providing adequate light during nighttime activities is important for the safety of both the public and workers. State standards require lighting, as the contractor is responsible for providing lighting. Some states are more detailed about the type of light, color, covering area, and intensity.

B.3.1.a- Alabama

Illumination	When the Contractor performs any operations after daylight hours, he shall provide and maintain, at his expense, sufficient artificial lighting to permit proper construction and inspection. Area Lighting. Area lighting is designated for use at locations where standard delineation devices are not considered sufficient to properly guide the traveling public through the construction work nor advise them of the hazardous conditions which exist. The primary use will be in the areas of crossovers and intersections which are not clearly distinguishable during hours of darkness. Area lighting may consist of one or more area lights. An area light shall consist of a 250-watt mercury vapor light or equivalent, mounted on a 12 foot {3.6 m} mast arm attached to a Class 7 wood pole of sufficient length to provide a 30 foot {9 m} luminaire mounting height above the elevation of the outside edge of paving, unless otherwise shown by plan details. These lights will be placed at locations designated by the Engineer. If possible, the locations should be such that the lights will adequately light the area, but not present a hazard to the traveling public. Bracing or guying of poles which is unsightly or presents a hazard will not be allowed. It will be the Contractor's responsibility to investigate, procure and bear the expense of the power source for these lights whether by commercial A.C. current or generator, and to ensure that these light sources are installed in a safe workmanlike manner and in accordance with the latest editions of the National Electrical Code, National Electrical Safety Code and/or all local codes.

B.3.1.b- Alaska

Illumination	Illuminate the night work areas according to the Table below. Provide lighting for other operations when necessary. Use balloon lighting as the main light sources. Do not use floodlights without prior approval by the Engineer. When approved, install floodlighting in a manner that minimizes glare for motorists, workers, and residents living along the roadway. Locate, aim, louver, and/or shield light sources to minimize glare. Night work illumination equipment and location requirements

Type of work or equipment	Lighting configuration
Paving, Milling, Striping, Pavement marking removal, Rumble strip installation	at least one machine mounted balloon light at least 2000 watts. provide additional lights or wattage if necessary to provide complete coverage
Rolling, pavement and sweeping	at least 4 sealed beam halogen lamps and the front and 4 in the back which should be at least 55 watts.
Flagging	one balloon light of at least 2000 Watts, located within 30 feet of the flagger location. locate so the flagger and the flagging location are illuminated provide additional lights or Waters if necessary to provide complete coverage of the flagging location.
Truck crossing where haul vehicles Cross or enter a road with more than 10,000 ADT or where the haul vehicle Crossing or entering location is controlled by portable traffic signals or flaggers	at least one balloon bite of at least 2000 Watts, located on the main road on the far-right side of the intersection. locate light within 30 feet of the edge of the side street. If there is a flagger at the Crossing, look at the lights or lights so the lighting requirements of for flagging are also satisfied

B.3.1.c- Arizona

Illumination	In general, all work shall be performed during daylight hours. if the contractor elects to perform work at night or if the contractor is required to do so in the Special Provisions, the contractor shall furnish, erect, and maintain an amount of artificial lighting sufficient for the construction, flagging, inspect ion, etc. and for the safety of the workers and the traveling public. No night work shall be performed until the Engineer is satisfied that an adequate amount of artificial light has been furnished and placed properly.

B.3.1.d- Arkansas

Illumination	Adequate artificial lighting is provided.

B.3.1.e- California

Illumination	**Falsework Lighting** **(1) General** Falsework lighting includes lighting to illuminate the pavement, portals, and pedestrian walkways at or under openings in the falsework required for traffic. **(2) Pavement Illumination** Illumination of pavement at vehicular openings through falsework must comply with the following requirements: 1. Fixture must include R/FL commercial-type flood lamp holder with protective covers. 2. Fixture must be fully adjustable with brackets and locking screws and allow mounting directly to a standard metal junction box. 3. Lamp must be medium-based 120 V(ac), 120 W, minimum, PAR-38 quartz-halogen flood lamp. 4. A continuous row of fixture types required must be installed at locations and spacing specified. Fixtures must be installed beneath falsework structure with the end fixtures not further than 10 feet inside portal faces. Fixtures must be installed and energized immediately after the members supporting them have been erected. 5. Fixtures along the sides of the opening must be placed not more than 4 feet behind or 2 feet in front of the roadway face of the temporary railing. Mounting heights of fixtures must be between 12 and 16 feet above the roadway surface and must present an unobstructed light pattern on the pavement. **(3) Portal Illumination** Illumination of falsework portals must comply with the following requirements: 1. On each side of each entrance portal, plywood sheet clearance guides must: 1.1. Be 4 feet wide by 8 feet high. 1.2. Be fastened vertically, facing traffic, with the bottom of the panel 3 to 4 feet above the roadway. 1.3. Have the center of the panel located approximately 3 feet horizontally behind the roadway face of the railing. 1.4. Have freshly painted panels for each installation with not less than 2 applications of flat white paint. Paint testing will not be required. 2. If ordered, repaint the designated areas to improve the general appearance of the painted surfaces. Repainting is change order work. 3. Falsework portals must be illuminated on the side facing traffic with 150 W, minimum, PAR floodlamps mounted on the structure directly over each vertical support adjacent to the traveled way, as needed to uniformly illuminate the exterior falsework beam, the clearance guides, and the overhead clearance sign. Each lamp must be supported approximately 16 feet above the pavement and approximately 6 feet in front of the portal face. 4. Portal lighting and clearance guides must be installed on the day the vertical members are erected.

	(4) Pedestrian Walkway Illumination Illumination of pedestrian openings through or under the falsework must comply with the following requirements: 1. Fixtures must be flush mounted in the overhead protection shield and equipped with a damage-resistant, clear, polycarbonate diffuser lens. Lamps must be standard incandescent 100 W, 120 V(ac). 2. Fixtures must be centered over the passageway at intervals of not more than 15 feet with the end fixtures not more than 7 feet inside the end of the pedestrian openings. 3. Pedestrian passageway light systems must be installed immediately after the overhead protection shield is erected.

B.3.1.f- Colorado

Illumination	The Contractor shall provide illumination during hours of darkness

B.3.1.g- Connecticut

Illumination	The Contractor shall organize the Project work so that any portion of roadway which has existing roadway illumination and is open for use remain lighted. The Contractor shall also provide illumination on all temporary crossovers, ramps and roadways that are constructed as part of staged construction and that are open for use. Highway illumination may consist of: existing lighting, new lighting, temporary lighting, or any combination thereof. It is the Contractor's responsibility to stage the installation or relocation of service cabinets, poles, lights, and circuitry so that all roadways of the kind described above remain lighted.

B.3.1.h- Delaware

Illumination	Provide a portable light assembly unit that includes four, 1000-Watt lights with a fully self-contained power source mounted to a trailer equipped to be towed by a full-sized pick-up truck and in full compliance with Title 21 Motor Vehicles of the Delaware Code. Provide plastic drums, in accordance with Section 805, used to channelize traffic away from the portable light assembly unless the portable light assembly is placed behind guardrail, barrier or other means of positive protection. Place plastic drums in accordance with the DE MUTCD.

B.3.1.i- District of Columbia

Illumination	The Contractor shall work at night when it is specified or when, in the judgment of the Chief Engineer, such action is necessary and shall maintain illumination levels for safe operations in all active work areas during evening and night work. Temporary lighting for the Contractor's operations shall comply with OSHA regulations, Section 1926, task requirements and as specified in Contract Documents

B.3.1.j- Florida

Illumination	During active nighttime operations, furnish, place, and maintain lighting sufficient to permit proper workmanship and inspection. Use lighting with 5 ft-cd minimum intensity. Arrange the lighting to prevent interference with traffic or produce undue glare to property owners. Operate such lighting only during active nighttime construction activities. Provide a light meter to demonstrate that the minimum light intensity is being maintained. Lighting may be accomplished using portable floodlights, standard equipment lights, existing streetlights, temporary streetlights, or other lighting methods approved by the Engineer. Submit a lighting plan at the Preconstruction Conference for review and acceptance by the Engineer. Submit the plan as a PDF file, in the same scale as the Contract Plans, and formatted on 11 inches by 17-inch sheets. Do not start night work prior to the Engineer's acceptance of the lighting plan. Include compensation for lighting for night work in the Contract prices for the various items of the Contract. Take ownership of all lighting equipment for night work.

B.3.1.k- Georgia

Illumination	Perform night work with artificial light provided by the Contractor and approved by the Engineer.

B.3.1.l- Hawaii

Illumination	633.01 Description. This section describes furnishing Installing, maintaining, and removing temporary lighting under structure. 633.02 materials. materials used in constructing falsework lighting shall confirm to the following: A. Lamp holder with high temperature, glazed porcelain, medium Base socket, and UL approved for outdoor use. B. 150- watt (minimum) Lamps with medium base, incandescent-type parabolic aluminized reflector (PAR) bulbs for pavement and portal face illumination. C. 100- watt (minimum) Lamps with medium base, incandescent-type (PAR) bulbs for pedestrian passageway illumination. 633.03 Construction. Provide fully adjustable lamp holder with built in junction box and wiring chamber. attached conduits directly to lamp holders. protect maps with wire guards. Obtain power full force work lighting. provide generator(s) operate falsework lighting in areas where utility company power service is not available. Maintain and operate falsework lighting. Provide lighting circuits with no less than two branch circuits. provide portal flood lights flood lights between portals with minimum one circuits. Provide each branch circuit with its own protective device. provide lighting conductors within falsework limits in conduits. Provide required materials and equipment for false wall lighting. remove materials and equipment for falsework lighting when falsework is no longer needed. A. Roadway pavement illumination. illuminate roadway pavement beneath or through falsework 24 hours per day or as ordered by engineer. Illuminate roadway pavement between entrance and exit Portals by continuous row of flood lights. Install flood lights beneath falsework at intervals of not more than 15 feet on Center, install and flood lights Within 7 ft or portal face. Provide one row of lights for a single lane, two rows of lights for two to four lanes, and an additional row of lights for each lane over four. Aim And adjust flood lights so that there is no glare to motorists and no dark areas. B. pedestrian walkway illumination. Illuminate pedestrian walkways beneath or through falsework 24 hours per day or as ordered by Engineer. Illuminate pedestrian walkways beneath or through falsework with floodlights centered over passageway at intervals of not more fan 15 feet. install end flood lights with in 7 feet of Portal face. Mount flood lights approximately 10 ft above walkway. C. Falsework portal face illumination. Illuminate falsework portal faces 24 hours per day. Illuminate falsework portal faces on side facing traffic. Mount flood lights over each vertical support next to traveled way and over center of each lane. Locate each floodlight approximately 16 feet above the pavement approximately 6 feet in front of portal face. 633.04 Measurement. The engineer will not measure falsework lighting for payment. 633.05 payment. The engineer will not pay for falsework lightning separately and will consider the coast for falsework lighting as included in the contract prices for the various contract play items under Section 503- concrete structures. The coast is for the work prescribed in this section and the contract documents.

B.3.1.m- Idaho

Illumination	Provide floodlights capable of illuminating flagger stations, work areas, and equipment crossings with at least 5 foot-candles or greater. Ensure floodlights are equipped with a meter that records hours of operation Illuminate flagger stations, work areas, and equipment crossings when nighttime work is being performed. Provide floodlights 30 minutes before sunset and up to 30 minutes after sunrise when workers or operational equipment are present. Ensure floodlighting does not produce a glare condition for approaching road users, flaggers, or workers. Provide an extra floodlight onsite for backup. When a flagger station is moved, use the backup floodlight to illuminate the new station.

B.3.1.n- Illinois

Illumination	The lighting shall consist of mobile and/or stationary lighting systems as required herein for the specific type of construction. Mobile lighting systems shall consist of luminaires attached to construction equipment or moveable carts. Stationary lighting systems shall consist of roadway luminaires mounted on temporary poles or trailer mounted light towers at fixed locations. Some lighting systems, such as balloon lights, may be adapted to both mobile and stationary applications. The lighting system shall be designed to meet the following. (a) Lighting Levels. The lighting system shall provide a minimum of 5 footcandles (54 lux) throughout the work area. For mobile operations, the work area shall be defined as 25 ft (9 m) in front of and behind moving equipment. For stationary operations, the work area shall be defined as the entire area where work is being performed. Lighting levels will be measured with an illuminance meter. Readings will be taken in a horizontal plane 3 ft (1 m) above the pavement or ground surface. (b) Glare Control. The lighting system shall be designed and operated to avoid glare that interferes with traffic, workers, or inspection personnel. Lighting systems with flood, spot, or stadium type luminaires shall be aimed downward at the work and rotated outward no greater than 30 degrees from nadir (straight down). Balloon lights shall be positioned at least 12 ft (3.6 m) above the roadway. As a large component of glare, the headlights of construction vehicles and equipment shall not be operated within the work zone except as allowed for specific construction operations. Headlights shall never be used when facing oncoming traffic. (c) Light Trespass. The lighting system shall be designed to effectively light the work area without spilling over to adjoining property. When, in the opinion of the Engineer, the lighting is disturbing adjoining property, the Contractor shall modify

B.3.1.o- Indiana

Illumination	The temporary highway illumination shall be in accordance with applicable requirements of 807 except as modified herein. The electric energy necessary to power the luminaires on a continuous basis is the responsibility of the Contractor. At the completion of the contract work, the temporary illumination shall be removed and shall remain the property of the Contractor. After the removal of the temporary illumination equipment, all holes and trenches shall be backfilled with B borrow.

B.3.1.p- Iowa

Illumination	Set up and operate either pole mounted or portable, mobile self-contained LED temporary floodlights at locations shown in contract documents. The mounting height of luminaires is no less than 35 feet above the roadway and as shown in the contract documents. Pole length is determined by field measurement to obtain a specified mounting height. Mounted on portable trailers containing solar cell array and storage battery system to power LED luminaire. Ensure the system meets NCHRP 350 Category IV crash testing.

B.3.1.q- Kentucky

Illumination	Provide artificial lighting for each phase when working nighttime.

B.3.1.r- Louisiana

Illumination	All operations that are performed during nighttime hours shall be properly illuminated to allow for the safe performance and inspection of the work. Work area is defined as a minimum of 50 feet ahead and behind the employee, where work is to be performed. A minimum of 5 foot-candles (54 lux) shall be maintained throughout the work area during nighttime construction operations, and during the setup and removal of lane or roadway closures. Lighting shall be adequate to meet the required level of illuminance and uniformity over the work area as following: **Level I (5 foot-candles, 54 lux):** This level of illuminance shall be provided for all work areas of general construction operations, such as excavation and embankment; cleaning and sweeping; landscaping; planting and seeding. Stockpiles shall also be illuminated to Level I to enhance safety and improve work efficiency. . **Level II (10 foot-candles, 108 lux):** This level of illuminance is required for areas on or around construction equipment such as that used for drainage installations, striping, base course construction, milling, asphalt paving operations, and concrete placement and removal. This level is necessary for safe operation of equipment and for obtaining an acceptable level of accuracy. **Level III (20 foot-candles, 215 lux):** This level of illuminance is required for tasks requiring a higher level of visual performance or for tasks with a higher level of difficulty. Such tasks include, pavement or structural crack filling, joint repair, joint cleaning, joint sealing, pavement patching and repairs, saw-cutting, installation of signal equipment or other electrical/mechanical equipment, and other tasks involving fine details or intricate parts and equipment.

B.3.1.s- Maine

Illumination	Night Work lighting requirements: Mobile Operations: For mobile-type operations, each piece of equipment (paver, roller, milling machine, etc.) will carry indirect (i.e., balloon type) lights capable of producing at least 10-foot candles of lighting around the work area of the equipment. Fixed Operations: For fixed-type operations (flaggers, curb, bridge, pipes, etc.), direct (i.e., Tower) lighting will be utilized capable of illuminating the work area with at least 10-foot candles of light. Hybrid Operations: For hybrid-type operations (guardrail, sweeping, in slope excavation, etc.), either direct or indirect lighting may be utilized. The chosen lights must be capable of producing at least 10 foot-candles of light around the work area of the equipment. Inspection Operations: Areas required to be inspected by the Department will require a minimum of 5 foot-candles of lighting. This may be accomplished through direct or indirect means.

B.3.1.t- Maryland

Illumination	Outdoor Lighting Conditions. Make aesthetic treatment inspections for all elements in outdoor lighting conditions. “Outdoor lighting conditions” is defined as during daylight hours in direct sunlight or under artificial lighting providing a minimum illumination of 20 ft candles (20 fc) across the entire inspection area. The Contractor or producer shall provide certified test results by a professional lighting expert acceptable to the Administration that any artificial lighting arrangements meet a minimum of 20 fc across the entire inspection area. Elements failing to conform to these requirements will be rejected.

B.3.1.u- Michigan

Illumination	Lighting for Night Work. Provide, install, and maintain fixed, portable, or equipment-mounted lighting systems to allow workers and inspectors to perform nighttime operations and inspections. Provide a power source capable of operating the lighting system. Provide lighting and perform night work in accordance with subsection 706.03.I.2 and the contract. Submit a lighting plan to the Engineer for review and approval, before starting night work. Provide lighting as specified in the current edition of MMUTCD, Part 6. Ensure lighting does not cause glare, shine, or directly face the eyes of oncoming drivers. After initial setup, drive through and observe the lighted area from each direction on the main roadway. Adjust lighting alignment if lights cause glare, shine, or directly face the eyes of oncoming drivers. Provide backup lighting that meets specifications for the primary system to replace failed lights and equipment during nighttime operations. Maintain the backup equipment on the project and ensure availability during nighttime operations. The Engineer will suspend nighttime operations, except traffic control, if lighting does not meet contract requirements.

B.3.1.v- Minnesota

Illumination	Artificial lighting system with fixtures providing adequate illumination over each desk and all work area. If bridge slab placement and finishing is performed at night, provide a “well-lighted” area to accomplish QC/QA inspections. "Well-lighted" is defined as a minimum of 50-foot candles of artificial light or natural daylight. Use a light meter with readings in foot candles to verify the adequacy of the lighting.

B.3.1.w- Mississippi

Illumination	Portable construction lighting 680.01- description. whenever the contractor’s operations are being conducted at night, the contractor shall provide artificial lighting as may be necessary provide for safe and proper construction and inspection of the work. this works shall consist of furnishing, installing, maintaining, moving, and removing lighting for nighttime work operations. 680.02.1- Tower lights. Tower lights shall consist of lighting fixtures mounted on a tower up just 30 feet in height. Tower lights pictures shall be a heavy-duty flood, Area, old roadway Style with wide beam spread. the tower shall Sturdy and freestanding without the aid of guy wires or bracing. The power supply shall be of sufficient capacity to operate the lights and shall be Located for the shortest safe routing of cables to the fixtures. Tower lights shall be of sufficient wattage and/or quantity to provide an average maintained horizontal luminance in accordance with subsection 680.02.3. 680.02.2- machine lights. all moving equipment used during night-time operations shall have a balloon lighting system or equivalent system and a flashing amber light on the equipment. In Lieu a flashing amber light, the contractor May install for square feet of metal on the equipment in a location that will be seen by The Traveling public. this lighting system shall illuminate the work area in each Direction of travel of the equipment. machine lights shall be heavy-duty flood, Area, or roadway Style with wide beam spread Mounted on supports attached to the construction machine at a Height of no more than 13 feet. the power supply shall be of sufficient capacity to operate the lights and shall be securely Mounted on the machine. electrical grounding of generators to frames of machines on which they are mounted shall be done in conformance with the national electrical code (NEC). The light fixtures shall be of sufficient wattage and/or to provide an average maintained horizontal luminance in accordance with subsection 680.02.3. Machine lights are in addition to Conventional automotive type headlights, which are necessary for maneuverability.

	680.02.3- Lighting levels. it's submitted lighting plan shall indicate how the contractor intends to accomplish the lighting of the work area(s). work areas shall be classified into one of the following categories depending on the type of work to be accomplished: Category one- category 1 work areas will be lit to five foot- candle (5 fc). This category of work includes General work Zone safety and visual tasks with large objects. Category two- Category 2 work areas will be lit to ten foot-candles (10 fc). This category of work includes work around all construction equipment and visual tasks that require greater accuracy such as inspection of Paving and resurfacing activities. Category three- Category 3 work areas will be lit to twenty foot-candles (20 fc). Best category of work includes activities that require the highest visual efficiency. these tasks present higher levels of visual difficulty and require significant attention from The Observer, such as crack and pothole filling, joint Sealing, critical connection, and maintenance involving electrical connections and moving mechanical parts. lighting equipment shall be placed so the uniformity ratio, average maintained to minimum, shall not be greater than 10:1. 680.03.1- Lighting systems. tower lights may be used when the night works is confined to a fairly small area and is essentially a stationary operation. A Balloon lighting system or equivalent system shall be used when the night work is not confined to a small area and is essentially a continuous moving construction operation. Use of tower lights in lieu of balloon lights will be considered when the number of machines, type of work, or need for inspection justify their use as decided by the engineer. The work area where is traffic control devices are being set up or repositioned at night shall be illuminated. If night work requires the use of a flagger, then the flagger must be illuminated by balloon lighting or equivalent system providing 10-foot candle (10 fc), the illuminated work area shall be large enough so that the movements of the personnel and Equipment engaged in the world will be contained in the area. The contractor shall provide sufficient fuel, spare lamps, generators, the personnel qualified to operate the lights to a sure that they will be maintained in operation during night work. Existing roadway lights shall not eliminate the requirement for the contractor to provide lighting. Consideration may be given to the amount of illumination provided by existing lights determining the wattage and/ or quantity of Lights to be provided, noted in the contractors submitted lighting plan. 630.03.2- glare control. all lighting shall be designed, installed an operated to avoid glare interference with roadway traffic or discomfort for residence adjoining the roadway. The contractor shall locate, aim, and adjust the lights to provide the required level of luminance and uniformity in the work area without the creation of objectionable glare. the engineer shall determine when glare exceeds acceptable levels, either for traffic or adjoining residence. the contractor shall provide shields, visors, or louvers on lumineers as necessary to reduce objectionable levels of glare. lighting system should not be aimed higher than 30 degrees from straight down unless the fixture has been specifically designed to prevent glare. in no case shall the main beam of the light being higher than 60 degrees above straight down. the lights shall be set as far from traffic as practical and aimed in the direction of, or perpendicular to, the traffic flow.

B.3.1.x- Missouri

Illumination	**Temporary Lighting.** Temporary lighting shall consist of furnishing, installing, and maintaining wood poles, luminaires, bracket arms, power cable, connection to a power source, mounting hardware, and all other material necessary to provide the temporary installation. Any Commission furnished items shall be installed by the contractor. Temporary lighting specified as part of a temporary signal installation shall be installed on the signal poles unless otherwise shown on the plans. Luminaires shall be 150-watt high-pressure sodium with a Type III medium distribution, semi-cutoff light distribution. Luminaires shall be mounted 30 feet above the pavement unless otherwise shown on the plans. Bracket arms shall be oriented at right angles to traffic flow unless otherwise shown on the plans. Photoelectric controls shall be provided and may be installed in the luminaires or in a separate control box at the option of the contractor unless otherwise shown on the plans. Any existing lighting shall not be taken out of operation until the temporary lighting is ready for operation and with approval from the engineer. All temporary lighting equipment shall be removed by the contractor after the new installation is in operation or as directed by the engineer. Contractor furnished equipment that will remain the property of the contractor may be new or used stock. Contractor furnished equipment that will become the property of the Commission shall be of new stock and shall meet all applicable specifications. Commission owned equipment will remain the property of the Commission and shall be disposed of as shown on the plans or as directed by the engineer.

B.3.1.y- Montana

Illumination	Obtain written approval before starting night work. Provide work area flood lighting for night work and do not rely solely on equipment lights. Night work approval may be rescinded at any time

B.3.1.z- Nebraska

Illumination	The Contractor shall provide adequate lighting for any night work.

B.3.1.aa- Nevada

Illumination	623.03.20- Falsework lighting. where required by the Special provisions, install falsework Lighting where vehicular traffic with or without pedestrian traffic crosses through or understructure falsework. Provide illumination during the hours from Dusk to Dawn. Submit a plan of the proposed lighting installations and do not commence falsework construction until such plans have been reviewed. a subsequent review will be made after. falsework lights have been placed in operation. Provides pictures for illumination of roadway pavement between entrances and exit portals with a RLM standard Dome reflector. the reflector shall have a white porcelain enamel finish on the side and shall be provided with a steel wire guard. Equip fixtures with high-temperature glazed porcelain medium base sockets and 1.8 m (6 ft) long conductors for splicing, approved by UL for outdoor use. Provide fixtures fully adjustable with bracket and locking screws on a mountain plate and provide Mountain directly to a standard metal junction box. Fixtures for pedestrian passageways shall be porcelain box receptacles mounted on standard metal junction boxes and equipped with wire lamp guards. Used for Salon box receptacles rated at 660 W, 250 V. Make wire lamp guards of No. 10 wire as suitable for General construction work. Use lamps of an approved type. Illuminate portal phases of falsework on the side facing traffic with 150 W minimum PAR reflector flood lamps Mounted on the structure directly over each vertical support adjacent to the traveled way and over the center of each lane. Support each approximately 5m (16 ft) above the pavement and approximately 1.8m (6ft) in front of the portal face. the exact position of the lamps will be as directed. In addition to the overhead lighting, illuminate each side of its

	vehicular passageway between portals by a string of yellow, 25 W lamps spaced at 3.6 m (12 ft) Intervals and mounted between 2.4 m (8 ft) and 2.6 m (8.5 ft) above the pavement. Each floodlight in such a manner as to preclude glare to oncoming motorists. Illuminate the overhead clearance sign mounted on the falsework. For illumination of roadway payment between the entrance and exit portals, install a continuous row of 150 W Fixtures over the Center of each lane beneath the falsework structure at intervals of not more than 4.5 m (15 ft), with end fixtures not further than 2.1 m (7 ft) inside the portal faces. Mount the pictures over the pavement at an approved height. Illuminate pedestrian openings through or under false work, with 150w fixtures centered over the passageway at intervals of not more than 4.5 m (15 ft), with the end fixtures not more than 2.1 m (7 ft) Inside the portal faces, Mount the fixtures between 2.9 m (9.5 ft) and 3.2 m (10.5 ft) above the walkway surface. For Roadway pavement on Portal face illumination use number 10 conductors with type S insulation. For pedestrian passageways, use number 10 conductors enclosed in a 40 mm (1.5 in) unpainted zinc-coated metallic conduit. Provide not less than two Branch circuits, Place pedestrian passageway lights on roadway pavement lights on the minimum of one circuit and Portal flood lights on a minimum of one separate circuit. Fuse Each branch circuit, not to exceed 20 a. Install the above specified portal Lighting on the day that horizontal members are erected and before traffic is permitted to pass under the false work during the hour From Dusk to Dawn. install the other falsework lights as soon as the members on which they are to be supported or in place

B.3.1.bb- New Hampshire

Illumination	No work will be permitted at night unless sufficient lighting is provided to ensure a comparable degree of accuracy, workmanship, and conditions regarding safety as would be obtained in daylight.

B.3.1.cc- New Jersey

Illumination	Night operations comprises work performed from 30 minutes before sunset to 30 minutes after sunrise. Before beginning night operations, demonstrate to the RE the method of meeting the specified illuminance levels and visibility requirements for workers and equipment for each planned operation. The Department will determine illuminance levels by taking light meter readings horizontally to the road surface facing the light source. Do not begin night operations until the RE approves the method of meeting the specified illuminance levels and visibility requirements. 1. Lighting Requirements and Illuminance Levels. Maintain the minimum illuminance level throughout the required lighting area as specified in the Table. Provide lighting for all areas of the Work.

Minimum illuminance levels for night operations

Work Description	Minimum Level (foot candles)	Minimum Lighting Area
Embankment, Excavation, Landscaping (seeding and sodding, Mechanical sweeping and cleaning, Subgrade	5	General lighting throughout area of operation
Traffic control setup and removal (excluding barrier curb)	5	Lighting on task
Traffic director	5	Lighting on task plus minimum of 50 feet ahead and 50 feet behind employee
Milling*, HMA Paving operation*, HMA roller operation*	10	Lighting on task and around Equipment Plus minimum 25 feet ahead and 25 feet behind

			equipment plus 10 to each side of equipment
	Crack sealing, Saw cutting and sealing joints, Electrical work, Intelligent transportation system work	20	Lighting on task
	All work not listed in this table*	10	Lighting on task
	* Provide five foot-candles for the indicated lighting area outside the limits for 10 foot-candles to a minimum 100 feet ahead and 100 feet behind equipment		
	Ensure that lighting equipment is in good operating condition, and in compliance with applicable NEC and NEMA codes. Use freestanding portable or trailer-mounted towers capable of being moved as needed to keep pace with construction operations. For moving operations, ensure that lighting and illuminance requirements are maintained where the work is in progress and that lighting keeps pace with the operation. Provide sufficient fuel, spare lamps, generators, and qualified personnel to ensure that required illuminance levels are maintained continuously during night operations. If at any time minimum illuminance levels are not met, cease night operations until the required illuminance levels are attained.		

B.3.1.dd- New Mexico

Illumination	Using artificial lighting, approved by the resident engineer.

B.3.1.ee- New York

Illumination	**Lighting for Nighttime Operations.** Prior to the first night of nighttime operations, the Contractor shall set up and operate the lighting equipment at night as a trial run to demonstrate its ability to establish a safe, properly illuminated, nighttime operation. The Contractor shall furnish the Engineer with a photometer, capable of measuring the level of illumination, for use as necessary to check the adequacy of illumination throughout nighttime operations. 1. Equipment. The Contractor shall supply all lighting equipment required to provide a work zone safe for the workers and traffic. Material and/or equipment shall be in good operating condition and in compliance with applicable safety and design codes. **a. Light Towers. Light** towers shall be provided as a primary means of illumination and shall provide Level I illumination throughout the workspace. They may be supplemented to the extent necessary by lighting fixtures mounted on construction equipment to provide Level II or Level III illumination where required for paving, milling and similar moving operations. Light towers shall be sturdy and free-standing without the aid of guy wires or bracing and shall be capable of being moved as necessary to keep pace with construction operations. Light towers shall be positioned to minimize the risk of being impacted by traffic on the roadway or by construction traffic or equipment. **b. Light Towers on Paving**, Milling, and Finishing Machines. If needed to supplement portable and/or trailer-mounted light towers, towers shall be affixed to paving, milling, and finishing machines to provide the required level of illumination for the specified distance in front of and behind the machine. Luminaires shall be aimed and adjusted to provide uniform illumination with a maximum uniformity ratio of 5:1. The hopper, auger, and screed areas of pavers and the operator's controls on all machines shall be uniformly illuminated. **c. Construction Equipment Lights.** All construction equipment, including rollers, backhoes, loaders, and other equipment operating in areas not illuminated to a minimum of Level I Illumination, shall be equipped with a minimum of two 500-watt flood lights facing in each direction to provide a minimum of 1 foot-candle of horizontal illumination measured 60 feet in front of and behind the equipment. In areas illuminated to a minimum of Level I, construction equipment may move unescorted. In non-illuminated areas, construction equipment shall be equipped with conventional vehicle headlights, shall be illuminated with flood lights on the

	vehicle, or shall be escorted to permit safe movement. Headlights shall not be permitted as the sole means of illumination while working. **d. Equipment Mounting**. The Contractor shall provide suitable brackets and hardware to mount lighting fixtures and generators on machines and equipment. Mountings shall be designed so that light fixtures can be aimed and positioned as necessary to reduce glare and to provide the required illumination. Mounting brackets and fixtures shall not interfere with the equipment operator or any overhead structures and shall provide for secure connection of the fixtures with minimum vibration. **e. Portable Generators.** The Contractor shall provide portable generators to furnish adequate power to operate all required lighting equipment. Fuel tank capacity and availability of fuel on site shall be sufficient to permit uninterrupted operation throughout the planned shift. Adequate switches shall be provided to control the various lights. All wiring shall be weatherproof and installed in accordance with 29 CFR 1926 Subpart K. All power sources shall be equipped with a Ground-Fault Circuit Interrupter. Candle levels: **a. Level I (5 foot-candles).** Level I illumination shall be provided for all areas of general construction operations to include all work operations by Contractor's personnel, including work zone traffic control set-up and operations, staging, excavation, cleaning and sweeping, pavement marking, spoil disposal, landscaping, planting, and seeding, layout and measurements ahead of the actual work, borrow areas, spoil areas, and truck cleanout areas. Level I illumination shall be provided near the beginning of lane closure tapers and at road closures for nighttime work zones, including the setup and removal of the closure tapers. Level I illumination shall be provided a minimum of 400 feet ahead and 800 feet behind a paving or milling machine, or for the entire area of concrete placement or pavement work if less than this distance. This area shall be extended as necessary to incorporate all vehicle and equipment operations associated with the paving operation. The only exception to the requirement for Level I illumination throughout the area of construction operations is that finish rollers can work beyond the area of Level I illumination using floodlights mounted on the roller. **b. Level II (10 foot-candles).** Level II illumination shall be provided for flagging stations, asphalt paving, milling, and concrete placement and/or removal operations, including bridge decks, 50 feet ahead of and 100 feet behind a paving or milling machine. **c. Level III (20 foot-candles).** Level III illumination shall be provided for pavement or structural crack filling, joint repair, pavement patching and repairs, installation of signal equipment or other electrical/mechanical equipment, and other tasks involving fine details or intricate parts and equipment.

B.3.1.ff- North Carolina

Illumination	Whenever the Contractor's operations are being conducted at night, the Contractor shall provide such artificial lighting as may be necessary to provide for safe and proper construction and to provide for adequate inspection of the work as described in Section 1413. The Contractor shall comply with all applicable regulations governing noise abatement. Portable construction lighting: Furnish, operate, and maintain everything necessary to provide lighting for compliance with Article 105-14 Night Work requirement for artificial lighting. Tower light: Use tower lights which consist of mercury vapor, metal halide, high pressure sodium or low-pressure sodium fixtures mounted on a tower approximately 30 feet in height. Use tower light fixtures which are heavy-duty flood, area, or roadway style with wide beam spread, have an output of 50,000 lumens minimum, have the combined outputs of all fixtures on each tower light does not exceed 460,000 lumens, and are weatherproof and supplied with attached waterproof power cord and plug. Use a sturdy tower that is freestanding without the

	aid of guy wires or bracing. Provide sufficient capacity in the power supply to operate the light(s) and locate it for the shortest safe routing of cables to the fixtures. A tower light consisting of the combined fixture(s), tower and power supply is preferred. Provide tower lights of sufficient wattage and/or quantity to provide an average maintained horizontal illuminance greater than 20 footcandles over the work area. Aim and position the lights to illuminate the area for construction work. Make sure that there is not any disabling glare to the motorist. In no case should the main beam of the light be aimed higher than 60° above straight down. The lights should be set as far from traffic as practical and aimed in the direction of, or normal to, the traffic flow. Use machine lights which have mercury vapor, metal halide, high pressure sodium or low-pressure sodium conventional roadway enclosed fixtures mounted on supports attached to the construction machine at a height of approximately 13 feet. Use fixtures for machine lights which have light output between 22,000 and 50,000 lumens. Use a power supply with sufficient capacity to operate the light(s) and securely mount on the machine. Perform electrical grounding of generators to frames of machines on which they are mounted in conformance with the NEC. Use machine light fixtures with sufficient wattage and/or quantity to provide an average maintained horizontal illuminance greater than 10 footcandles on the machine and the surrounding work area. Machine lights are in addition to conventional automotive type headlights which are necessary for maneuverability. Balloon lights are an acceptable alternate luminaire for machine lights

B.3.1.gg- North Dakota

Illumination	Floodlights, if construction activities are performed at night, provide floodlighting for the construction area, inspection area, and flagger stations. Adequately illuminate the area without creating glare in the eyes of drivers.

B.3.1.hh- Ohio

Illumination	Night work. Do not start night work or carry-on day work into night work without operating an adequate and approved lighting system. Night work is defined as work performed from 30 minutes after sunset to 30 minutes before sunrise. Operation of adequate lighting system consists of furnishing, installing, operating, maintaining, moving, and removing nighttime lighting to illuminate construction work areas for night work. Obtain the Engineer's approval of the lighting at the beginning of the project and before starting the paving operation by measuring the luminance. Provide an illuminated zone around all operating machinery. Provide an illuminated zone of at least 5 Foot-candles (55 lux) of lighting luminance in the immediate vicinity of pavers, rollers, grinding equipment, material transfer vehicles, etc., and at least 1 Foot-candle (10 lux) at 25 feet (7.6 m) from this equipment. Provide an illuminated zone of at least 5 Foot-candles (55 lux) of lighting luminance in the immediate vicinity of coring equipment and at least 1 Foot-candle (10 lux) at 10 feet (3 m). Position the light sources so they don't interfere with or impede traffic in any direction and do not cause glare for motorists or point onto adjacent properties. Provide a photometer capable of measuring the level of luminance on each night project. Take luminance measurements at a height of 20 inches (500 millimeters) above the roadway. Obtain the luminance level any time requested by the Engineer. Test the illumination levels on the site each time a change in lighting configuration is made. Replace non-functioning lamps immediately. Check the luminaires aiming daily. Clean the luminaires regularly. Correct any deficient lighting within one hour or the Engineer will terminate construction activities. When the total project includes more than one continuous lane mile (including bridges) of surface course paving in combination with night paving, and no pay item for anti-segregation equipment, provide anti-segregation equipment according to 401.12, for only the surface course. No additional payment will be made for this anti-segregation equipment.

B.3.1.ii- Oklahoma

Illumination	Using artificial lighting, approved by the resident engineer. Mentioned in different phases.

B.3.1.jj- Oregon

Illumination	Provide artificial lighting and good visibility throughout **Work Zone Lighting** - Furnish the following temporary lighting as shown: (a) Flagger Station Lighting - Furnish flagger station lighting from the QPL and meeting the following requirements: Illuminates the flagger so • that the flagger is visible, and is discernable as a flagger, from a distance of 1,000 feet. • Illuminates the flagger from above at a height of 18 feet ± 3 feet. • The light is shielded from approaching traffic. (b) Temporary Illumination - Furnish materials for temporary illumination meeting the requirements of Sections 00960, 00970, 02920, 02926, and the temporary illumination Plans. **Lamps, Ballasts, and Luminaires:** **illumination Lamps** - All high-pressure sodium lamps shall conform to ANSI Standards. All lamps of the same size and type, on a single project, shall be from the same manufacturer's lot number. All lamp bases shall have a brass mogul base mounting with dating system. Lamps shall have an average minimum initial lumen rating (after 100 burning hours) and an average minimum lamp life (based on 10 hours per start) as follows: Minimum Lamp Minimum

	Lamp Initial Lumens Average Watts ANSI Code Vertical Horizontal Lamp Life High-Pressure Sodium – Clear 70 S62ME-70 6,300 6,300 24,000 - 100 S54SB-100 9,500 9,500 24,000 - 250 S50VA-250/S 29,000 29,000 24,000 - 400 S51WA-400 50,000 50,000 24,000 - 1,000 S52XB-1000 140,000 140,000 24,000 - 02926.52 Ballasts - High-pressure sodium ballasts shall be magnetic regulator (lag type regulator) with primary and secondary windings electrically isolated from each other. Unless otherwise shown or specified, the ballast shall be an integral part of the luminaire unit. It shall be of the prewired, built-in type mounted in the luminaire. Provide a manufacturer's nameplate on the ballast housing. The nameplate shall have the manufacturer's name, model number, serial number, hook-up diagram, power supply data, lamp type and operating wattage. The ballast shall operate the lamp within the limits specified below throughout the rated life of the lamp: • The lamp wattage shall not vary more than the allowable range shown in the table below over the line voltage variation shown. • The lamp wattage shall not vary more than plus or minus 5 percent of nominal when the lamp is at its rated nominal voltage (high-pressure sodium lamps only).

B.3.1.kk- Pennsylvania

Illumination	Temporary Highway Lighting. Provide temporary highway lighting as indicated on the TCP. Comply with local government, electric utility, and state codes or requirements; the electrical regulations of the Department of Labor and Industry; and applicable construction requirements of the NEC, NESC, and NBFU. Cooperate with electric utility company or agency furnishing power to the system and meet necessary service requirements. Do not locate lighting fixtures to produce distracting or blinding glare for the driver. Perform the Highway Illumination Test (Conv.) and record test data on Department Test Form CS-4225D. Correct any defects. Perform the test in the presence of an authorized representative of the Department. Provide guide rail, crash cushions, or other devices, as indicated or directed, to protect vehicles from hitting poles or other temporary highway lighting appurtenances. **Lighting** Provide artificial lighting both inside and outside containment if natural light is inadequate to allow proper visibility during cleaning, painting, and inspection activities according to SSPC Technology Guide 12. Provide a minimum illumination of 50-foot candles (538 lux) for inspection and 20-foot candles (215 lux) for surface preparation and coating application, including working platforms, access, and entryways. Provide a minimum illumination in general work areas of 10-foot candles (108 lux). Design and operate exterior illumination to avoid glare that interferes with traffic, workers, and pedestrians. Provide a light meter for Department use with readings in lux or foot candles to verify the adequacy of illumination.

B.3.1.ll- Rhode Island

Illumination	This work consists of illuminating work zone and lane drop areas, and all other areas within which are located channelization devices placed along the roadway for the purpose of directing or restricting traffic, all as required for night work operations. Illumination of these areas will be provided by both floodlighting and equipment-mounted lighting. Materials. **Floodlights.** All floodlights for both the lane drop areas and the equipment mounted lighting shall have cut-off type light distribution and shall have a die-cast aluminum housing with integrally-case heavy-duty hinges. Fixture housing door shall be closed with two or more captive screws and shall have positive gasketing to insure water tightness and dust tightness. The housing shall have no weep holes. The reflector shall be high purity anodized aluminum with a secondary internal reflector element to reflect high angle rays back into the beam to achieve high beam utilization and meet IES definition of cut-off distribution.

	a. Lamp Sockets shall have a pre-wire grip-type mogul base with additional support on the glass gasketed to the fixture housing. Ballast shall be pre-wired regulating type designed for -20OF starting with an operating lamp current crest factor not exceeding 1.65. Mounting shall be accomplished with a die-cast aluminum slip fitter designed for a 2-inch tenon. Surface mounting brackets shall be provided for alternate mounting at the Contractor's option. Fixture shall be U.L. listed. Lamps shall be metal halide of the wattage specified. **b. Fluorescent Fixtures** shall be twin-lamp 4-foot-long fixtures utilizing two high-output cool-white, fluorescent lamps (F48T12/CW/HO). Housing shall be extruded aluminum with high gloss baked white enamel finish. Lens shall be either tempered glass, polycarbonate or virgin acrylic and shall be fully framed and gasketed. Lens frame shall be hinged, or captive latched on one side and shall be toggle-latched on the other side with a stainless-steel spring-loaded bail to apply constant pressure between the lens and fixture housing. All fasteners shall be stainless steel. The lamp holder shall be self-sealing, self-aligning and spring loaded. Lens unlatching and lamp removal shall be accomplished without the use of special tools. The fixtures shall have integral, high-power factor ballasts capable of starting to -200F. Fixtures shall have fittings for standard continuous row mounting and shall have top-mounting brackets for additional support. Approval shall be obtained from the Engineer prior to the purchase or rental of any lighting fixtures. Plan of Operation. Prior to proceeding with any night work, the Contractor shall submit a plan of night work operations, including placement of illumination devices, to the Engineer for review and approval. **illumination Standards.** The following standards shall be maintained at all times during night operations. **a. Lane Drops**. The traveled way within the lane drops areas and all cones, barrels, or other physical barriers placed on the roadway for the purpose of channelizing or restricting vehicular traffic shall be illuminated to a minimum average of 2 footcandles measured on both the horizontal and vertical planes 6 inches above the surface in question. The lane-drop areas to be illuminated shall be defined as beginning at the first cone, barrel, or other physical channelizing device, continuing through the full roadway width transition area, and ending where the traveled way attains the constant width which will be maintained through the construction area. A uniformity ratio average to minimum to one, or better shall be maintained at all times within the illuminated transition area. All portable lighting shall be located off the traveled way opposite the channelizing devices (i.e., when closing the left or high-speed lanes, all lighting should be placed on the right side of roadway). All lighting shall be aimed in such a manner to avoid shadows on the traveled way and prevent excessive glare to the motorist. Illumination of the lane drop areas shall be accomplished using 250-watt, 400-watt, 1,000- watt metal halide floodlights in any combination and any number necessary to achieve the foot candle levels and uniformity ratios specified above. All floodlights shall have flat tempered glass or polycarbonate lenses securely fastened to the housing to prevent personal injury in the event of lamp breakage. Floodlights shall be mounted on portable or fixed poles, tripods or staging in a location off the traveled way. The lighting staging area shall be roped off to all personnel except the lighting technicians. All generator and wiring shall be within the restricted area and shall conform to all applicable electrical codes and pertinent OSHA safety standards. **Equipment lighting.** **a. Rollers.** Each roller shall be equipped with a 2-unit light cluster on both the front and back. A single cluster with 2 units (one wide beam and one narrow beam) aimed towards the front is to be used. All floodlights shall be securely mounted to minimize vibrations during roller operations. Floodlights should be mounted on steel bullhorn style brackets with 2-inch tenons and a 36-inch spread. Mounting height shall be a minimum of 8 inches above the top platform surface of the roller, provided the overall height from ground level does not exceed 15 feet. Mounting height and placement shall be designed to allow the operator to run the roller from a standing position without blocking the lighting beams onto the roadway. Floodlights for the roller shall be 250-watt metal halide fixtures as described below.

	b. Trucks. A minimum of two pickup trucks equipped with floodlights shall be provided by the Contractor. Each truck shall have a minimum of three (1 wide beam and 2 narrow beams) 250-watt metal halide floodlights mounted on supports on the pickup truck bed. The floodlights shall be aimed in a forward direction over the truck cab but shall also have the capability of being adjusted and aimed in any direction, if required. Floodlights for truck mounting shall be as described below. **c. Pavers.** Single width (12-foot nominal) and double width (24-foot nominal) pavers shall be equipped with a continuous twin lamp fluorescent bar consisting of enclosed 4-foot fluorescent fixtures mounted end to end across the full width of the screed area. Fixtures shall be adjustable so that they may be tilted toward the work area. A minimum of 10 footcandles must be provided at the screed area and in the area (minimum 15 feet) immediately behind the screed where manual raking operations are taking place. Two auxiliary floodlights (narrow beam) shall be provided, one to illuminate guideline and one to illuminate the auger area. Care shall be taken in the placement of these floodlights to avoid aiming of the lights into the line of sight or into the mirrors of trucks which are backing into the auger/hopper area to unload bituminous concrete. Floodlights for the pavers shall be as described below. **d. Equipment Mounting.** Mounting shall be designed and constructed by the Contractor at his option to suit the configuration of the equipment to which the lighting is attached. Mounting heights, placement and aiming shall be as hereinbefore described. Mounting shall be secure to prevent excessive vibration and to insure there is no hazard to equipment operators or other personnel. Care shall be exercised to ensure that fixture mounting will clear all overhead structures. Lighting configurations for the equipment lighting may, with the concurrence of the Engineer, vary from those specified herein provided that the specified light output is adhered to. All equipment lighting shall be aimed in such a manner as to maximize the illumination on each individual task. Power Sources. The Contractor shall provide portable generators of type, size, and wattage output required to adequately energize the lighting equipment specified. Generator placement and wiring shall be in compliance with all applicable electrical codes and pertinent OSHA safety standards. It shall be the Contractor's responsibility to ensure that lighting fixture and generator electrical rating are compatible.

B.3.1.mm- South Carolina

Illumination	Furnish, operate, and maintain everything necessary to provide lighting for compliance with Article 105-14 Night Work requirement for artificial lighting. Use tower lights that consist of mercury vapor, metal halide, high-pressure sodium or low-pressure sodium fixtures mounted on a tower approximately 30 feet in height. Use tower light fixtures which are heavy-duty flood, area, or roadway style with wide beam spread, have an output of 50,000 lumens minimum, have the combined outputs of all fixtures on each tower light does not exceed 460,000 lumens, and are weatherproof and supplied with attached waterproof power cord and plug. Use a sturdy tower that is freestanding without the aid of guy wires or bracing. Provide sufficient capacity in the power supply to operate the light(s) and locate it for the shortest safe routing of cables to the fixtures. A tower light consisting of the combined fixture(s), tower, and power supply is preferred. Provide tower lights of sufficient wattage and/or quantity to provide an average maintained horizontal illuminance greater than 20 footcandles over the work area. Aim and position the lights to illuminate the area for construction work. Make sure that there is not any disabling glare to the motorist. In no case should the main beam of the light be aimed higher than 60° above straight down. The lights should be set as far from traffic as practical and aimed in the direction of, or normal to, the traffic flow. Use machine lights which have mercury vapor, metal halide, high pressure sodium or low-pressure sodium conventional roadway enclosed fixtures mounted on supports attached to the construction machine at a height of approximately 13 feet. Use fixtures for machine lights

	which have light output between 22,000 and 50,000 lumens. Use a power supply with sufficient capacity to operate the light(s) and securely mount on the machine. Perform electrical grounding of generators to frames of machines on which they are mounted in conformance with the NEC. Use machine light fixtures with sufficient wattage and/or quantity to provide an average maintained horizontal illuminance greater than 10 footcandles on the machine and the surrounding work area. Machine lights are in addition to conventional automotive type headlights which are necessary for maneuverability. Balloon lights are an acceptable alternate luminaire for machine lights.

B.3.1.nn- South Dakota

Illumination	Artificial lighting system with fixtures providing adequate illumination over all work areas and each desk. **Light Towers:** The following shall apply to light tower poles: **1.** Poles shall be plumb when the installation is complete. **2.** Field repair of damaged galvanizing shall be done in accordance with ASTM A780. They mentioned "light towers under lighting, and I assumed it's a temporary device, as its purpose is to provide light for workers to work at night.

B.3.1.oo- Tennessee

Illumination	When the Contract requires night work, supply sufficient lighting and equipment as specified herein. Provide the equipment specified in Table 712.04-1 with non-glare balloon-style lights or equivalent. The lights will be required on each piece of equipment in operation.

Equipment Type	Illuminance Requirement
Paver, Milling, Machine, Materials transfer devices	One 4000-watt assembly or two 2000-watt assemblies
Grader, Roller, Rumble strip machine, shoulder machine.	One 4000-watt assembly
Paint truck	One 4000-watt assembly or non-glare 300-watt floodlight assembly
Guardrail driver, stationary operation	One 4000-watt assembly or two 4000-watt assemblies or equipment light plant
Trail vehicle	One 4000-watt assembly or two 4000-watt assemblies

B.3.1.pp- Texas

Illumination	Temporary Roadway Illumination. Perform work in accordance with the details shown on the plans, the NEC, the NESC, and the requirements of this Item. Use established industry and utility safety practices when installing, relocating, or removing electrical and lighting equipment located near overhead or underground utilities. Consult with the appropriate utility before beginning work. Tension and sag overhead conductors with guys and anchors in accordance with utility distribution practices. Install conduit and electrical conductors, tray cable, or duct cable as shown on the plans. Install ground boxes as shown on the plans. Install electrical services as shown on the plans. Install concrete foundations as shown on the plans. Install roadway illumination assemblies (poles with luminaire arms and light fixtures) as shown on the plans. The Engineer may shift the locations, within design guidelines, where necessary to secure a more desirable location or to avoid conflict with utilities. Use utility grade materials for overhead electrical work. Maintain a minimum of 22-ft. clearance above the roadway for overhead electrical work. Do not support overhead wiring with existing luminaire poles or breakaway luminaire poles. Operate and maintain the temporary illumination system. Relocate temporary illumination system as shown on the plans. Remove temporary illumination system when no longer needed. Remove abandoned concrete

	foundations to a point 2 ft. below final grade. Backfill the hole with material equal in composition and density to the surrounding area. Replace surfacing material with similar material to an equivalent condition. Replace materials furnished by the Department that are scarred, battered, broken, or lost. Replace damaged temporary illumination materials intended for permanent installation. Return all Department-owned material not used during the Contract upon completion of the work, in original condition, to the location from which the material was obtained, or as directed.

B.3.1.qq- Utah

Illumination	Night Operations: Provide proper lighting from ½ hour after sunset to ½ hour before sunrise according to Section 00555, Section 00555 Night Work 1. Notify the Engineer at least five calendar days before starting night work. 2. Provide adequate lighting for safely performing satisfactory inspection and construction operations. 3. Control noise

B.3.1.rr- Vermont

Illumination	Nights. night work shall be performed in accordance with the NCHRP Report 476 – Guidelines for Design and Operation of Nighttime Traffic Control for Highway Maintenance and Construction. Before beginning night work, the Contractor shall design a lighting plan and present it as an addition to the traffic control plan. The Contractor shall not perform any night work or activities within the Project limits until the lighting system has been found to be in Conformance and is in place on the Project. The designed lighting plan shall be mobile, shall be mounted separately from other construction equipment, shall illuminate the entire work area to daylight intensity with minimal glare, and shall be a surrounding design that minimizes shadows in the work area as much as possible. All costs associated with the lighting plan will be considered incidental to the appropriate Traffic Control items. Field Offices shall be a commercial-type Field Office trailer of standard commercial quality, or a building, in good condition as determined by the Engineer with a minimum width of 10 feet. They shall have a minimum of two means of egress equipped with deadbolt locks and a minimum 4-foot deck with steps and railings in accordance with the VOSHA Safety and Health Standards for Construction. The Contractor shall provide the Engineer with three sets of keys. The Contractor shall not access the Field Office without the approval of the Engineer. For the commercial-type Field Office trailer, Field Offices shall have a minimum of four side windows, one front window, and one rear window. Standard buildings shall have sufficient windows to the satisfaction of the Engineer. All windows shall be glassed and screened with provisions for opening and locking and equipped with adjustable louvered blinds. Field Offices shall have a lighting system capable of providing a minimum of 50-foot candles on all work surfaces and shall have a minimum 400 W exterior security light.

B.3.1.ss- Virginia

Illumination	Mentioned providing light I different phases.

B.3.1.tt- Washington

Illumination	The Contractor shall provide portable lighting equipment capable of sufficiently illuminating

B.3.1.uu- West Virginia

Illumination	Temporary lighting shall consist of furnishing, installing, maintaining, and subsequent removal of various types of lighting systems as necessary due to the maintenance of traffic plan. It shall include but not be limited to lighting to be installed in accordance with Section 662 of the Specifications. When the temporary lighting is no longer needed, it will become the property of the Contractor.

B.3.1.vv- Wisconsin

Illumination	Do not perform work when there is insufficient light to conduct that work safely. If the contract requires or the engineer allows nighttime operations, provide artificial illumination as necessary to safely perform the work. Locate work lights within and around the work zone in a way that provides adequate illumination to perform the work, makes the workers and construction operations visible to the traveling public, and ensures that glare and brightness transition through the work site does not interfere with driver visibility. Provide additional hazard lighting on equipment as well as high visibility apparel conforming to ANSI/ISEA guidelines for workers

B.3.1.ww- Wyoming

Illumination	Provide adequate lights for nighttime work.

B.3.2 – Marking Information from DOT Standards and/or Provisions.

It is crucial for contractors to properly mark their equipment to comply with Department of Transportation (DOT) regulations and ensure safety. Each state has its own DOT requirements for equipment marking, which may include specifications for the materials used, color codes, size, and placement of the markings. Contractors must carefully review and follow these guidelines to ensure compliance and promote a safe work environment.

B.3.2.a- Alabama

Marking	● Signs and warning lights. ● Barricades and warning signs. ● Pilot car, flaggers, and flagging equipment.

B.3.2.b- Alaska

Marking	● High visibility garments Standards. Use high visibility garments conforming to the requirements of ANSI/ISEA 107-2004, Class 2 for tops or Class E for bottoms, and Level 2 retroreflective material. ● Signs, Portable Sign Supports ● Barricades and Vertical Panels. ● Portable Concrete Barriers. Use yellow tabs or stripe when barriers are placed at centerline. Use white tabs or stripe when barriers are placed on the roadway shoulder. ● Warning Lights Use Type A (low intensity flashing), Type B (high intensity flashing) or Type C (steady burn) warning lights that conform to the ATM. ● Drums, use plastic drums that conform to the requirements of the ATM. Use retroreflective sheeting that meets ASTM D4956 Type II or III. ● Traffic Cones and Tubular Markers Use reflectorized traffic cones and tubular markers that conform to the requirements of the ATM. Use traffic cones and tubular markers at least 28 inches high. Use retroreflective sheeting that meets ASTM D4956 Type II or III. ● Interim Pavement Markings ● Temporary raised pavement markers for short-term operations, SEAL COATS, AND SURFACE TREATMENTS.

	1. **Marker**. L-shaped polyurethane body with retroreflective tape on the top vertical section, with a self-adhesive base. Reflectorize both faces of the yellow marker and one face of the white marker. Make the marker body of 60 mil minimum thickness polyurethane meeting Table 712-1 with vertical leg approximately 2 inches high by 4 inches wide and base approximately 1-1/4 inch wide. **2. Reflective Tape**. Metalized polycarbonate micro prism retroreflective material with acrylic backing or equal, a minimum 1/4-inch wide by 4 inches long. Provide the minimum optical performance shown in Table 712-2, for an observation angle of 0.2 degrees. **3. Protective Cover**. Where chip seals, slurry seals or tack coats are to be utilized after placement of the temporary raised pavement markers, furnish markers with a protective cover made of clear flexible polyvinyl chloride. **4. Adhesive.** Pressure-sensitive material, a minimum of 1/8 inch thick and 3/4 inch wide, factory applied to the marker base with release paper. ● High-Level Warning Devices. ● Temporary Crash Cushions Use retroreflective sheeting that meets ASTM D4956 Type III, IV or V. Application of crash cushion must be appropriate for the intended use and be installed per manufacturer's recommendation. Temporary crash cushions that are barrels or barricade filled with sand or water may only be used when the forecasted temperature during their use is above 32 degrees Fahrenheit. ● Sequential Arrow Panels ● Portable Changeable Message Board Signs. Use truck or trailer mounted portable changeable message board signs with a self-contained power supply for the sign. ● Temporary Sidewalk Surfacing ⇒ Provide temporary sidewalk surfacing as required by an approved TCP and the following: ⇒ Use plywood at least 1/2 inch thick for areas continuously supported by subgrade. Use plywood at least 1 inch thick for areas that are not continuously supported. ⇒ Do not use unsupported 1-inch plywood longer than 30 inches. ⇒ Use plywood with regular surfaces. Do not overlap plywood joints higher than 1/2 inch. Bevel overlap joints so the maximum slope of the overlapping edge is 2 horizontals to 1 vertical. ⇒ Fasten so wind and traffic will not displace temporary surfacing ● Temporary Guardrail ● Flagger Paddles Use retroreflective sheeting that meets ASTM D4956 Type VIII or IX. Use background colors of fluorescent orange on one side and red on the other side. ● Truck Mounted Attenuator ● Portable Steel Barriers Use portable steel barriers that conform to the contract. For each direction of traffic, equip each section of barrier with side-mounted retroreflective tabs placed approximately 6 to 8 feet apart, or a continuous 4-inch-wide horizontal retroreflective stripe mounted 6 inches below the top of the barrier. Use yellow tabs or stripe when barriers are placed at centerline. Use white tabs or stripe when barriers are placed on the roadway shoulder. Use retroreflective sheeting that meets ASTM D4956 Type III, IV or V.

B.3.2.c- Arizona

Marking	● Flashing arrow panels: ● Temporary concrete barrier: ● Temporary impact attenuation devices: ● Temporary pavement markings: ● Delineators: ● Barricades ● Drums

B.3.2.d- Arkansas

Marking	• Signs. • Barricades. • Traffic drums. • Precast concrete barrier • Removable construction pavement markings. • Referencing no-passing zones. • Advance warning arrow panels and portable changeable message signs. • Traffic cones. Traffic cones used for night work, or which will be used for delineation during nighttime hours shall be reflectorized with retroreflective sheeting meeting the requirements of ASTM D 4956 for Type III or IV with the additional requirements for Rebound able Sheeting. All traffic cones shall meet the requirements of the MUTCD.

B.3.2.e- California

Marking	• Traffic cones • Plastic traffic drums • Portable delineators • Channelizers • Barricades • Construction area signs • Temporary traffic screens • Impact attenuator vehicles • Flashing arrow signs • Portable flashing beacons • Portable changeable message signs

B.3.2.f- Colorado

Marking

- Signs and barricades. Retroreflective sheeting for all signs requiring an orange background shall be fluorescent.
- Electronic advance warning signs.
- Advance warning flashing or sequencing arrow panels
- Temporary traffic signals
- Traffic cones.
- Temporary channelizing devices.

(a) Stackable Vertical Panels.

Vertical panels shall be retro reflectorized with Type IV sheeting. The stackable vertical panels shall have the following properties.

Property	Specification
Panel material	low density polyethylene
Color	orange and white stripes with orange or white frame and black ballast
Vertical panel height	24, 36, 42 in
Ballast type*	Rectangular or Square
Ballast weight*	9 -30 lbs.
*Note: the ballast type and weight shall be as shown in the contract or as approved by the engineer	

(b) Stackable Tubular Markers.

The stackable tubular markers shall have the following properties:

Property	Specification
Tabular section	low density polyethylene

	Color	orange tubular marker with black base
	Height (min)	42 in
	Ballast type*	Rectangular, octagonal, or Square
	Ballast weight*	15-40 lbs.
	*Note: the ballast type and weight shall be as shown in the contract or as approved by the engineer	

(c) Temporary Portable Rumble Strips.

- Concrete barrier (temporary).
- Flagging and pilot car operation.

B.3.2.g- Connecticut

Marking	• Barricade warning light. • Traffic cone. Traffic cones used at night shall be reflectorized. Retroreflective stripes shall be fabricated from Type IX retroreflective sheeting. All stripes shall be of one type of sheeting. • Traffic drum. Type IX Retroreflective Sheeting. • High mounted internally illuminated flashing arrow. • Changeable message sign remote controlled changeable message sign. • Impact attenuation system. The color of the modules shall be yellow. • Portable impact attenuation system. The TMA unit shall have a chevron pattern that covers the rear face of the unit. The standard chevron pattern shall consist of stripes, alternating non-reflective black and Type IV retroreflective yellow sheeting, slanted at 45 degrees in an inverted "V" pattern, centered on the rear of the unit. The stripes shall be between 4 in and 8 in wide. • Temporary plastic pavement marking tape. The marking tape shall be readily visible during daylight and when viewed with vehicular headlights at night

B.3.2.h- Delaware (providing light in general)

Marking	• Temporary Pavement Markings. • Arrow boards • Portable changeable message sign (PCMS) ⇒ Sign Panel – not to exceed the 144-inch length, 90-inch height, 12-inch depth. ⇒ Capable of displaying three lines of text ⇒ Construct each line of text using either a discrete matrix or a full-matrix display. ⇒ if discrete matrix is used, display each character using a 5 x 7 array with at least eight array modules per line. ⇒ Provide a 4-1/4 inch to 7-inch space between each display line with no glare reflection. ⇒ Capable of displaying eight characters per line ⇒ Capable of LED illumination ⇒ Provide plastic drums, in accordance with Section 805, used to channelize traffic away from the PCMS unless the PCMS is placed behind a guardrail, barrier, or other means of positive protection. Place plastic drums in accordance with the DE MUTCD. ⇒ Do not place PCMS on or near bicycle lanes, sidewalks or shared use paths in a manner that restricts the use of these facilities by pedestrians or bicyclists. Provide a minimum 4-foot buffer between the edge of the travel lane and the farthest extent of the PCMS to allow bicycle traffic to pass without encroaching into the travel lane wherever possible. • Plastic drums ⇒ Only drums made of low-density polyethylene plastic, orange in color, are permitted

	⇒ Minimum dimensions are 18 inches in diameter at the top and bottom and 36 inches high. ● Traffic officers ⇒ Traffic officers outside of their vehicle are required to wear high-visibility safety apparel as required in the DE MUTCD. ⇒ Vehicles are required to be marked police vehicles equipped as follows: 1. Full external light bar that is clearly visible for 360 degrees around the vehicle and at a distance of not less than 3,000 feet under normal atmospheric conditions at night, 2. Radar unit or any other speed-measuring device, ● Temporary safety barrier ● Truck-mounted attenuator (TMA) ⇒ Position the TMA such that the manufacturer's recommended roll-ahead distance is provided between the front bumper of the shadow vehicle and the closest point of the Work area. ⇒ Do not block any open driveways, commercial entrances, streets or cause any sight distance restrictions unless approved by the Engineer. ⇒ Position the TMA in the full down position and set the display for the arrow board to the appropriate designation based upon the type and location of the Work occurring. ⇒ If a distance exists that is twice the roll ahead distance between what the TMA is protecting and the front of the shadow vehicle, then additional TMAs will be required to protect the Work zone. ● Temporary impact attenuator ● Temporary warning signs and plaques ● Flaggers ● Temporary barricades ● Pavement markings ● Sign panels

B.3.2.i- District of Columbia

Marking	● Construction warning and detour signs. Where signs are mounted on light standards, traffic signal supports, etc., work includes furnishing mounting bands or clamps, including all installation hardware. Materials shall meet the following requirements: ⇒ 824.02 And ASTM D 4956: Fluorescent Orange Sheeting, Wide Angle Prismatic Lens ⇒ 824.02 And ASTM D 4956: High Intensity Sheeting, Type III ● Reflectorized traffic cones. Cones shall be a minimum of 36 inches in height. The retro reflectorized band shall be used only during the daytime and not during the nighttime. ● Steady burning amber lights, type c, and flashing amber lights, type b. Steady burning lights shall be used to delineate the travel way only if specified on the TCP or at the direction of the Engineer. Flashing lights shall be mounted on advance warning signs as indicated on the TCP. ● Electronically illuminated traffic devices (arrow panel) ● Work zone barricades ● Traffic drums ● Reflective markers and delineators ● Pavement markings ● Painted lane markings the Contract Documents for non-toxic waterborne traffic paint, epoxy markings, or polyester marking material for white and yellow pavement markings in the lengths and widths, symbols, and letters as specified in the Contract Documents or as directed by the Engineer. The traffic paint, epoxy marking material, and polyester marking material shall be suitable for application on asphalt concrete or PCC surfaces.

	● Truck-mounted attenuator (TMA). The TMA shall also be equipped at the rear panel with a chevron object marker consisting of orange and black stripes 6 inches wide sloped at a 45 degrees angle from the top of the panel in both directions. The orange stripes shall be fabricated from fluorescent orange prismatic lens sheeting conforming to 824.02. The chevron shall cover a minimum of 75 percent of the rear panel area and shall be visible to traffic at all times. The TMA shall be not less than 72 inches wide and not more than 96 inches wide. The color of the TMA shall be yellow or orange, and conspicuity markings shall be provided. The TMA shall be equipped with a hydraulic system for tilting to a vertical position on the truck when not in use. Hand operated jacks with steel swivel casters shall be provided if necessary to facilitate the installation and removal of the TMA from the support truck.

B.3.2.j- Florida

Marking	● Retroreflective sheeting for temporary traffic control devices. ● Portable arrow board: ● Portable changeable message sign ⇒ Message matrix panel shall be a maximum height of 7 feet by a maximum width of 10 feet. ⇒ The matrix must be capable of displaying three lines of 8 characters using an 18-inch font that meets the height to width ratio and character spacing requirements in the MUTCD, Section 2L.04, paragraphs 05, 06, and 08. ⇒ The matrix must display characters that meet or exceed the numeral and letter sizes prescribed in the MUTCD and SHS (Standard Highway Signs) companion document. Fonts and graphics must mimic the characteristics of fonts and graphics defined in NEMA TS4, the MUTCD, and SHS. ⇒ For flip disk matrix signs, the disk elements shall be coated on the display side with a highly reflective florescent yellow Mylar material, and on the back with a flat black to blend in with the flat black background. ● Flashing lights Provide a pair of hooded PARS 46 LED advance warning flashing lamps on each side of the top of the sign panel. These lamps shall be visible day or night at a distance of one mile with a flash rate of approximately 55 flashes per minute. The lamp lens should be at least 5-3/4 inches in diameter. Smaller diameter lens is permissible if they provide an equivalent or greater brightness indication and meet the legibility criteria above. The color of the light emitted shall be in accordance with the MUTCD. For solar powered units, the bulbs shall provide a 350-candlepower intensity for day use and an automatic reduction or dimming capacity for night use. The dimmed night operation shall provide adequate indication without excessive glare. ● Portable radar speed display unit ● Message display Provide a bright led, two-digit speed display on a flat black background with bright yellow led. ● Truck mounted changeable message sign: ● Temporary glare screen. ● Temporary traffic control signals. ● Work zone signs. Provide steel flanged u-channel or square tube steel meeting the mechanical requirements of astm a499. ● Temporary raised rumble strips. The temporary raised rumble strip may be either a removable polymer striping tape type or a molded engineered polymer material type. ● Automated flagger assistance devices (afad). ⇒ **S**top/slow automated flagger assistance devices ⇒ Red/yellow lens automated flagger assistance devices ● Temporary barrier.

	• Temporary crash cushion (redirected or gating). • Truck Mounted Attenuators and Trailer Mounted Attenuators: Equip truck mounted and trailer mounted attenuator units with lights and reflectors in compliance with applicable Florida motor vehicle laws, including turn signals, dual taillights, and brake lights. Ensure that lights are visible in both the raised and lowered positions if the unit is capable of being raised. Install either alternating black with yellow or white with orange sheeting on the rear of trailer mounted attenuators and truck mounted attenuators in both the operating and raised position. Use Type III (work zone) or Type IV sheeting consisting of 4- or 6-inch-wide stripes installed to form chevrons that point upward. All sheeting except black must be retroreflective.

B.3.2.k- Georgia

Marking	• Portable changeable message signs • Illuminated sign system • Traffic impact attenuator • Barricades • Cones • Drums

B.3.2.l- Hawaii

Marking	• Signs • Barricades • Traffic delineators • Lane closure • Advisory signs • Pavement marking tape

B.3.2.m- Idaho

Marking	• Temporary traffic control signs • Channelizing device. Provide weighted base tubular markers, surface-mounted tubular markers, vertical, panels, drums, barricades, or other channelizing devices. • Temporary pavement markings • Arrow boards. • Portable changeable message signs (pcms). • Temporary concrete barrier • Temporary crash cushion • Truck mounted attenuator. Provide a truck mounted attenuator attached to a shadow vehicle. Provide test level 2 or 3 truck-mounted attenuators when the highway's posted speed is less than 45 mph. Provide test-level 3 truck mounted attenuators when the highway posted speed is greater than or equal to 45 mph • Flagger equipment. Ensure flaggers wear high-visibility safety apparel and are provided a STOP/SLOW paddle. • Pilot car. Provide a vehicle with a PILOT CAR FOLLOW ME sign mounted on the rear of the pilot vehicle. Show the company name of the pilot car contractor on both sides of the vehicle. • Miscellaneous Temporary Traffic Control Item. Provide miscellaneous temporary traffic control items

B.3.2.n- Illinois

Marking	• Cones. Reflectorized cones are for nighttime operations but shall only be used when specified in the plan or when approved by the Engineer. • Barricades. • Vertical barricades • Vertical panels • Direction indicator barricades • Drums • Flexible delineators • Truck Mounted/Trailer Mounted Attenuators (TMA) • Arrow boards. Arrow boards are used to warn motorists of an upcoming lane closure. Arrow boards shall not be used to direct passing moves into lanes used by opposing traffic or to shift traffic without having a lane change. On roads with normal posted speeds of 45 mph and above, Type C units shall be used for all operations 24 hours or more in duration, and Type B units may be used for operations less than 24 hours in duration. On roads with normal posted speeds less than 45 mph, Type A, B, or C units may be used for all operations. • Portable changeable message signs. • Temporary rumble strips. • Detectable pedestrian channelizing barricade.

B.3.2.o- Indiana

Marking	• Temporary pavement marking tape. Temporary pavement marking tape shall be furnished in three colors and two types. It shall consist of a white or yellow reflecting film on a conformable backing which is a minimum of 4 in. wide and is designed for marking either asphalt or concrete pavements. Black temporary pavement marking tape shall consist of a matte film on a conformable backing which is designed for marking asphalt pavement. White and yellow temporary pavement marking tape shall be in accordance with ASTM D 4592. - Type I tape shall be selected from the Department's list of approved Temporary Pavement Marking Tape, Type I. Temporary pavement marking tape type I will be placed and maintained on the Department's approved list in accordance with ITM 806, Procedure H. - Type I tape furnished under this specification shall be covered by a type C certification in accordance with 916 • Temporary raised pavement marker • Construction warning lights. Construction warning lights shall be self-illuminated by means of an electric lamp behind the lens. Types A and C shall also be externally illuminated by reflex-reflective elements built into the lens to enable it to be seen by the light from the headlights of oncoming traffic. • Flashing arrow sign • Portable changeable message sign • Temporary worksite speed limit sign assembly • Tubular marker • Automated flagger assistance device • Detour route marker assembly • Road closure sign assembly • Barricades • Cones and tubular markers • Construction warning lights

B.3.2.p- Iowa

Marking	• Signs and devices. For Interstate and Primary projects, furnish diamond shaped warning signs that are 48 inches by 48 inches unless specified otherwise in the contract documents. • Portable dynamic message signs.

	● Channelizing devices. ⇒ Barricades. 1) A 2-foot minimum length barricade may be used when Type I or Type II Barricades are furnished as one of the options for channelizing devices in lieu of vertical panels, 42 inches, channelizers, cones, or drums. 2) Ensure Type III barricades have a minimum length of rail of 6 feet. When traffic is permitted in each direction around a Type III Barricade, ensure the Type III Barricade used has fully reflectorized faces on both sides of the rails. 3) Erect barricades in essentially a horizontal position perpendicular to the direction of approaching traffic. Ballast them so as not to cover any striped rail. ⇒ Cones, vertical panels, 42-inch channelizers, drums, and tubular markers. 1) Ensure cones, vertical panels, 42-inch channelizers, drums, and tubular markers meet the current requirements of the MUTCD, and Section 4188. 2) When used to separate two-way traffic, separate temporary no passing lines approximately 16 inches, with the marker to be installed between these lines. 3) Ensure tubular markers meet the following: a) A nominal 36-inch height. b) Diameter facing traffic at least 2 inches in width. c) Completely faced with reflectorized white and orange sheeting that is in two bands 4 inches wide with 6 inches between bands, with the top band no more than 2 inches from the top of the tubular marker. ● Temporary lane separator system. ● Temporary barrier rail. ● Lighting devices. Furnish lighting devices as required by the contract documents. Type A barricade warning lights will normally be required for nighttime installations. Type B warning lights will normally be required for 24-hour operation. ● Modular glare screen. ● Temporary crash cushions. ● Temporary traffic signals. ● Pilot cars. Ensure two signs are mounted on the vehicle to be clearly visible from both directions of traffic. Mount the signs so the bottoms are at least 1 foot above the top of the vehicle's roof. ● Flaggers When nighttime flagging is required, provide auxiliary lighting to illuminate the flagging stations according to the current Iowa DOT Flagger’s Handbook. Set up this lighting in such a manner to minimize glare to motorists. The cost of furnishing nighttime flagging stations is included in the lump sum price bid for Traffic Control. ● Monitoring with Incident Response.

B.3.2.q- Kentucky

Marking	• Lighting devices. Ensure lighting devices are visible every night between sunset and sunrise. • Arrow panels. Have available one portable flashing arrow in reserve. Place the reserve arrow in operation if one is damaged or if there is mechanical or electrical failure. • Temporary traffic signals. Use traffic signals for the control of traffic through presently signalized intersections. Use flaggers to expedite the flow of traffic, if directed by the Engineer or as specified in the Contract. • TMAs. Mount the attenuator on a support vehicle that is in close conformity to the one it was tested with for NCHRP compliance. Prevent shifting during impact. Furnish • Temporary barrier walls. • Cones or barricades • Temporary crash cushions. • Temporary pavement markings. Always maintain the following minimum retroreflectivity requirements: White: 175 mcd/lux/square meter Yellow: 150 mcd/lux/square meter Additionally, when temporary striping that is to remain in use for more than 120 days, provide striping with the following minimum initial retroreflectivity readings: White: 300 mcd/lux/square meter Yellow: 225 mcd/lux/square meter

B.3.2.r- Louisiana

Marking	• Temporary pavement markings: Color, width, and type of temporary pavement markings shall be in accordance with table 713-1 • Temporary signs and barricades. • Vertical panels. • Drums and super cones. • Traffic cones. • Portable changeable message signs. • Temporary precast concrete barriers. • Portable work zone traffic control devices.

B.3.2.s- Maine

Marking	• Flaggers • Signs • Flashing arrow board flashing arrow panels (fap) • Portable changeable message • Cones • Drums • Warning lights • Stop/slow paddles

B.3.2.t- Maryland

Marking	• Warning lights and devices • Temporary pavement markings (tpms) • Channelizing devices. • Temporary concrete traffic barrier (tcb) • Arrow panel • Temporary traffic signs (tts) • Temporary crash cushion sand-filled plastic barrels (sfpb) • Drums • Cones

	• Flagger • Protection vehicle (pv) (tma)

B.3.2.u- Michigan

Marking	• Temporary signs. • Channelizing devices • Lighted arrows • Type iii barricade • Temporary concrete barrier • Temporary pavement marking. • Temporary traffic signals. • Temporary portable traffic signal (pts) system. • Portable changeable message signs. • Warning lights.

B.3.2.v- Minnesota

Marking	• They mentioned different devices around the document such as Arrows, Cones, Drums.

B.3.2.w- Mississippi

Marking	• Pavement marking tape. • Construction signs. • Warning flashing arrow panels. • Barrier and delineators. • Channelization devices. • Traffic signals and flasher. • Portable traffic signs.

B.3.2.x- Missouri

Marking	• Channelizes and Tubular Markers • Signs. • Flag Assembly. • Warning Lights. • Flashing arrow panels • Trailer-mounted flashing arrow panels • Truck-mounted flashing arrow panels • Changeable message sign. • Message board. • Truck or trailer mounted attenuators.

B.3.2.y- Montana

Marking	• Signs and channelizing devices • Advance warning arrow panels • Warning lights • Flaggers • Pilot car • Signs and delineators

B.3.2.z- Nebraska

Marking	• Temporary signs • Barricades • Temporary Traffic Signals • Concrete Protection Barriers • Vertical Panels • Flashing Arrow Panels • Barricades • Portable sign supports. • Cones • Vertical panels • Plastic drums • Trailer-mounted devices

B.3.2.aa- Nevada

Marking	• Barricades • Drums • Cones • Vertical panels • Construction signs • Changeable message signs • Temporary impact attenuators • Portable beacons light system • Temporary pavement stripping tape

B.3.2.bb- New Hampshire

Marking	• Signs • Cone • Tubular markers • Flexible delineators • Plastic drums, • Portable changeable message sign (PCM) • Trailer mounted speed limit signs. • Portable concrete barrier

B.3.2.cc- New Jersey

Marking	• Temporary pavement markers • Temporary traffic signal system. • Flagger • Dynamic message system (DMS) • Traffic control truck with mounted crash cushions • portable variable message sign • flashing arrow board

B.3.2.dd- New Mexico

Marking	• Construction signing • Barricades and channelization devices • Barricades • Vertical panels • Traffic markers • Drums • Warning lights • Flexible high-performance reflective sheeting • Traffic cones

	• Sequential arrow displays. • Portable changeable message signs • Vehicular impact attenuator units and sand Barrel impact attenuator units

B.3.2.ee- New York

Marking	• Temporary pavement markings • Portable variable message signs (PVMS). • Truck mounted variable message signs (TMVMS). • Type III construction barricades. • Temporary concrete barrier. • Temporary glare screen • Temporary impact attenuator. • Temporary sand barrel arrays • Vehicle arresting barrier. • Temporary traffic signals.

B.3.2.ff- North Carolina

Marking	• Work zone signs • Barricades • Cones • Channelizing devices • Drums • Flashing arrow boards • Portable changeable message signs • Temporary crash cushions • Attenuators (TMA) • Flagger

B.3.2.gg- North Dakota

Marking	• Flagging • Pilot car • Reflective sheeting. • Barricades • Delineator drums • Vertical panels • Traffic cones • Delineators • Portable precast concrete median barriers • Warning lights • Advance warning flashing or sequencing arrow panels.

B.3.2.hh- Ohio

Marking	• In addition, equip all project motor vehicles and trailers having a gross vehicle weight rating of 10,000 pounds or greater, in single or combination, with conspicuity tape. Also, delineate all NCHRP 350 Category IV equipment (arrow boards, portable changeable message signs, etc.) with conspicuity tape. Conspicuity Tape: Use red and white, Type G, H, or J retroreflective sheeting that complies with 730.19, 730.192, and 730.193. • Traffic control general ⇒ Cones ⇒ Drums ⇒ Portable sign supports. ⇒ Type 3 barricades ⇒ Portable changeable message signs ⇒ Arrow boards ⇒ Impact attenuators • Work zone marking sings. • Detour signing. • Flaggers • Work zone traffic signals. • Work zone pavement markings.

B.3.2.ii- Oklahoma

Marking	• Arrow display • Construction signs and barricades • Vertical panels • Warning lights • Cones • Drums • Flagger • Tube channelizes. • Truck Mounted Attenuators (TMA)

B.3.2.jj- Oregon

Marking	• Temporary signing • Temporary barricades, guardrail, barrier, attenuators fencing, and channelizing devices. • Temporary traffic delineation • Traffic signals • Flaggers • Temporary electrical signs ⇒ (a) sequential arrow signs ⇒ (b) portable changeable message signs

B.3.2.kk- Pennsylvania

Marking	• Temporary barrier • Temporary concrete barrier, structure mounted. • Temporary impact attenuating • Painting traffic lines and markings • Shadow vehicle—a truck equipped with a flashing or revolving yellow light and as specified in the publication. • Truck-mounted impact attenuator and/or arrow panel—installed on the shadow vehicle, as required. • Temporary traffic control signals • Flagger

B.3.2.ll- Rhode Island

Marking	• Temporary construction signs • Portable channelizing devices and barricades ⇒ PVC Plastic Pipe Barricade (MUTCD, Type III). ⇒ Plastic Pipe Barricade with Sandbag Base (MUTCD, Type III). ⇒ Polyethylene Drum Barricade. ⇒ Fluorescent Traffic Cones. • Advance warning arrow panel • Portable changeable message sign ⇒ The lamp matrix sign. ⇒ The disk matrix sign. • An anchored and unanchored precast concrete barrier for temporary traffic control ⇒ Anchored and unanchored barrier units. ⇒ Delineators. ⇒ High strength non-shrink grout. ⇒ Anchorage system. • Truck-mounted attenuator (TMA) with truck-mounted flashing arrow board (tmfab)

B.3.2.mm- South Carolina

Marking	• Work zone signs • Barricades • Cones • Channelizing devises (drums) • Portable changeable message signs • Temporary crash cushions • Attenuators • Flaggers • Portable concrete barrier

B.3.2.nn- South Dakota

Marking	Traffic and traffic control devices shall conform to and be maintained in accordance with the requirements of Section 984 and Part 6 of the MUTCD. Traffic control devices are categorized by their intended use and certification requirements. • Category I traffic control devices are lightweight devices which may be self-certified by the manufacturer including, but not limited to: cones, drums, and delineators. • Category II traffic control devices are other lightweight devices which must be certified by individual crash testing including, but not limited to portable signs and barricades. • Category III traffic control devices are fixed or other massive devices which must be certified by individual crash testing including, but not limited to; breakaway sign supports, concrete barriers, concrete barrier end protection, crash cushions, truck-mounted attenuators, and longitudinal barriers. • Category IV traffic control devices are trailer-mounted devices which are not required to be individually crash tested including, but not limited to portable changeable message signs, arrow boards, portable temporary traffic signals, and work area lighting. • Truck mounted attenuators • Flagging • Pilot car • Type 3 barricades • Traffic control signs • Flexible delineators • Temporary traffic control signal • Arrow board

	• Portable changeable message sign • Temporary pavement marking

B.3.2.oo- Tennessee

Marking	• Sign • Temporary pavement marking • Cones • Portable barriers • Portable impact attenuators • Vertical panels • Flexible drums • Flashing arrow boards • Changeable message signs • Flagger

B.3.2.pp- Texas

Marking	• Use of blue warning lights. Texas Transportation Code 547.105 authorizes the use of warning lights to promote safety and provides an effective means of gaining the traveling public's attention as they drive in areas where construction crews are present. In order to influence the public to move over when high risk construction activities are taking place, minimize the utilization of blue warning lights. These lights must be used only while performing work on or near the travel lanes or shoulder where the traveling public encounters construction crews that are not protected by a standard work zone set up such as a lane closure, shoulder closure, or one-way traffic control. Refrain from leaving the warning lights engaged while traveling from one work location to another or while parked on the right of way away from the pavement or a work zone. • Portable traffic barrier • Work zone pavement markings • Delineator and object marker assemblies

B.3.2.qq- Utah

Marking	• Pilot car • Flagger • Traffic control signing and devices ⇒ Signs ⇒ Channelizing devices ⇒ Precast concrete barrier • Arrow board • Traffic signals • Construction zone speed limit • Temporary portable rumble strips

B.3.2.rr- Vermont

Marking	• Temporary traffic control • Signals and flashing beacons. • Detours and temporary bridges • Reflectorized sheeting.

B.3.2.ss- Virginia

Marking	• Temporary (construction) signs • Flagger service • Pilot car

	• Electronic arrows • Waring lights • Channelizing devices • Traffic barrier • Impact attenuator • Traffic signals • Temporary construction pavement marking • Barricades • Truck mounted attenuator • Portable changeable message sign

B.3.2.tt- Washington

Marking	• Stop/slow paddles. • Construction signs • Sequential arrow signs • Portable changeable message signs • Barricades • Traffic safety drums • Traffic cones • Tubular markers • Warning lights and flashers • Truck-mounted attenuator • Portable temporary traffic control signal • Tall channelizing devices • Temporary pavement marking tape

B.3.2.uu- West Virginia

Marking	• Pilot truck and driver or shadow vehicle: • Temporary pavement markings and raised pavement markers • Signs • Barricades • Drums, cones • Channelize cones • Delineators • Flashers

B.3.2.vv- Wisconsin

Marking	• Drums • Warning lights • 42-inch cones • Barricades • Arrow boards • Portable changeable message signs • Flexible tubular markers • Signs

B.3.2.ww- Wyoming

Marking	• Channelizing devices, such as drums, cones, and tubular markers • Signs • Temporary pavement striping tape • Flags • Portable plastic water filled barrier. • Temporary concrete barrier and end terminal • Portable signs and mounts

B.4- Summary

Having the option to do construction work during nighttime, has its advantages and disadvantages, but surely certain standards should be followed to assure the safety of both workers and passing vehicles. Going through the DOT standard and/or provision we can say that all different states require illumination in general with some differences. Some states go into further details than just a generic adequate illumination during nighttime construction. Some states even require certain types of lighting for different phases during the project (See Table 41).

Table 41. DOTs Standards and/or Provisions (by States) Illumination Requirement

State	Type of Work	Type of Lighting	Light as Indicated in the Standards	Light in Lux	Lighting Area
Alabama	All		An area light shall consist of a 250-watt mercury vapor light or equivalent	-	Mounted on a 12 foot {3.6 m} mast arm attached to a Class 7 wood pole of sufficient length to provide a 30 foot {9 m} luminaire mounting height above the elevation of the outside edge of paving
Alaska	Paving, milling, stripping, pavement marking removal, rumble strip installation	At least one Machine mounted balloon	At least 2000 watt		-
	Rolling, pavement sweeping	Sealed beam halogen 4 in the front and 4 in the back	55-watt		-
	Flagging	One balloon light	At least 2000-watt		Located within 30 feet from the flagger
	Truck crossing where haul vehicles cross or enter a road ….	At least one balloon light	At least 2000 watt		Located within 30 feet of the edge of the side street.
California	Pavement illumination	Include R/FL commercial-type flood lamp holder with protective covers. Lamp: PAR-38 quartz-halogen flood lamp	Lamp must be medium based 120 V(ac), 120 W, minimum		Mounting heights of fixtures must be between 12 and 16 feet above the roadway surface and must present an unobstructed light pattern on the pavement
	Portal illumination	PAR flood lamps mounted on the structure directly over each vertical support adjacent to the traveled way	Must be illuminated on the side facing traffic with 150 W, minimum		Each lamp must be supported approximately 16 feet above the pavement and approximately 6 feet in front of the portal face.

	Pedestrian walkway illumination	Flush mounted in the overhead protection shield and equipped with a damage-resistant, clear, polycarbonate diffuser lens.	Lamps must be standard incandescent 100 W, 120 V(ac).		Fixtures must be centered over the passageway at intervals of not more than 15 feet with the end fixtures not more than 7 feet inside the end of the pedestrian openings
Delaware	All	Portable light assembly unit, with a fully self-contained power source mounted to a trailer equipped to be towed by a full-sized pick-up truck and in full compliance with Title 21 Motor Vehicles of the Delaware Code	Includes four, 1000 Watt		-
Florida	All	Lighting may be accomplished using portable floodlights, standard equipment lights, existing streetlights, temporary streetlights, or other lighting methods approved by the Engineer.	Use lighting with 5 ft-cd minimum intensity	54 lux	
Hawaii	Roadway pavement illumination	Parabolic aluminized reflector (PAR) bulbs	100-watt		Lamps with medium base
	Pedestrian walkway illumination	Incandescent type parabolic aluminized reflector (PAR) bulbs	150-watt		Lamps with medium base
	Falsework portal face	Incandescent type parabolic aluminized reflector (PAR) bulbs	150-watt		Lamps with medium base
Idaho	Floodlights capable of illuminating flagger stations, work areas, and equipment crossings.	Floodlights	At least 5 foot-candles or greater.	54 lux	
Illinois	Stationary lighting: shall consist of roadway luminaires mounted on temporary poles or trailer mounted light towers at fixed locations.	Some lighting systems, such as balloon lights, may be adapted to both mobile and stationary applications.	Provide a minimum of 5 footcandles (54 lux) throughout the work area.	54 lux	Lighting systems with flood, spot, or stadium type luminaires shall be aimed downward at the work and rotated outward no greater than 30 degrees from nadir (straight down). Balloon lights shall be positioned at least 12 ft (3.6 m) above the roadway.

	Mobile lighting.	Luminaires attached to construction equipment or moveable carts	Provide a minimum of 5 footcandles (54 lux) throughout the work area.	54 lux	Lighting systems with flood, spot, or stadium type luminaires shall be aimed downward at the work and rotated outward no greater than 30 degrees from nadir (straight down). Balloon lights shall be positioned at least 12 ft (3.6 m) above the roadway.
Louisiana	All work areas of general construction operations, such as excavation and embankment; cleaning and sweeping; landscaping; planting and seeding.		A minimum of 5 foot-candles (54 lux)	54 lux	
	For areas on or around construction equipment such as that used for drainage installations, striping, base course construction, milling, asphalt paving operations, and concrete placement and removal.		10 foot-candles (108 lux)	108 lux	
	For tasks requiring a higher level of visual performance or for tasks with a higher level of difficulty. Such tasks include, pavement or structural crack filling, joint repair, joint cleaning, joint sealing, pavement patching and repairs, saw-cutting, installation of signal equipment or other electrical/mechanical equipment, and		20 foot-candles (215 lux)	215 lux	

	other tasks involving fine details or intricate parts and equipment.				
Maine	Mobile operations. (paver, roller, milling Machine, etc.)	For mobile-type operations, each piece of equipment Will carry indirect (i.e., balloon type) lights	At least 10 footcandles	108 lux	
	Fixed operations. (flaggers, curb, bridge, pipes, etc.)	Direct (i.e. Tower) lighting will be utilized	At least 10 footcandles	108 lux	
	Hybrid-type operations (guardrail, sweeping, in slope excavation, etc.),	Either direct or indirect lighting may be utilized.	At least 10 foot-candles	108 lux	
	Inspection operations	Either direct or indirect lighting may be utilized.	5 foot-candles	54 lux	
Maryland	General work zone	-	Providing a minimum illumination of 20 ft candles (20 fc)	215 lux	
Minnesota	Bridge slab placement and finishing		As a minimum of 50-foot candles	538 lux	
Mississippi	General work zone	Tower lights, Machine lights,	5 foot-candles	54 lux	
	Work around all construction equipment	Tower lights, Machine lights, balloon lighting	10 foot-candles	108 lux	
	Such as crack and pothole filling, joint sealing, critical connection, and maintenance	Tower lights, Machine lights,	20 foot-candles	215 lux	
Missouri		High pressure sodium	150-watt		Luminaires shall be mounted 30 feet above the pavement unless otherwise shown on the plans

Nevada	Pedestrian passageways	Lamp guard	660 w ,250 v		
	Portal faces of falsework	PAR reflector flood lamps	150-watt	74 lux	Support each approximately 5 m (16 ft) above the pavement ad approximately 1.8 m (6 ft) I front of the portal face
	Overhead lighting	PAR reflector flood lamps	25-watt	13 lux	Lamps spaced at 3.6m (12 ft) intervals and mounted between 2.4 m (8 ft) and 2.6 m (8.5 ft) above the pavement
	Roadway pavement between entrance and exit portals	PAR reflector flood lamps	150-watt	32 lux	Continues row of fixtures over center of each lane beneath the falsework structure of not more than 4.5 m(15ft)
New jersey	Embankment, excavation, landscaping, mechanical sweeping and cleaning, subgrade		5 foot-candles	54 lux	General lighting throughout area of operation
	Traffic control setup and removal		5 foot-candles	54 lux	Lighting on task
	Traffic director		5 foot-candles	54 lux	Lighting on task plus minimum of 50 feet ahead and 50 feet behind employee
	Milling, paving operation, roller operation		10 foot-candles	108 lux	Lighting on task and around equipment plus minimum of 25 feet ahead and 25 feet behind equipment plus 10 feet to each side of equipment
	Crack sealing, saw cutting ad sealing joints, electrical work, intelligent transportation system work		20 foot-candles	215 lux	Lighting on task
	All work not listed in table		10 foot-candles	108 lux	Lighting on task
New York	General construction including excavation, landscaping, cleaning…	Floodlights mounted on roller. Tower lights, construction equipment lights, equipment mounting.	5 foot-candles	54 lux	Minimum 400 ft ahead and 800 ft behind paving or milling machine, and it shall be extended as necessary.
	Flagging stations, asphalt paving, milling, and	Tower lights, construction equipment lights, equipment mounting.	10 foot-candles	108 lux	50 ft ahead and 100 ft behind a paving or milling machine

	concrete placement.				
	Pavement or structural crack filling, joint repair, pavement patching	Tower lights, construction equipment lights, equipment mounting.	20 foot-candles	215 lux	
North Carolina		Tower light	Greater than 20 foot-candles	215 lux	Consist of mercury vapor, metal halide, high pressure sodium or low-pressure sodium fixtures mounted on a tower approximately 30 feet in height. , have an output of 50,000 lumens minimum, have the combined outputs of all fixtures on each tower light does not exceed 460,000 lumens,
		Machine light - Balloon lights are an acceptable alternate luminaire for machine lights	Greater than 10 foot-candles	108 lux	Have mercury vapor, metal halide, high pressure sodium or low-pressure sodium conventional roadway enclosed fixtures mounted on supports attached to the construction machine at a height of approximately 13 feet. Use fixtures for machine lights which have light output between 22,000 and 50,000 lumens
Ohio	Zone around all operating machinery		At least 5 Foot-candles (55 lux) of lighting luminance the immediate vicinity of pavers, rollers, grinding equipment, material transfer vehicles, etc., and at least 1 Foot-candle (10 lux) at 25 feet (7.6 m) from this equipment.	54 lux	
			At least 5 Foot-candles (55 lux) of lighting luminance in the immediate vicinity of coring	54 lux	

			equipment and at least 1 Foot-candle (10 lux) at 10 feet (3 m).		
Oregon	Flagger station lighting	**Illumination Lamps** - All high-pressure sodium lamps shall conform to ANSI Standards. All lamps of the same size and type, on a single project, shall be from the same manufacturer's lot number. All lamp bases shall have a brass mogul base mounting with dating system. Lamps shall have an average minimum initial lumen rating (after 100 burning hours) and an average Minimum lamp life (based on 10 hours per start) as motioned			Illuminates the flagger so that the flagger is visible, and is discernable as a flagger, from a distance of 1,000 feet. Illuminates the flagger from above at a height of 18 feet ± 3 feet.
Pennsylvania	Inspection		Minimum illumination of 50-foot candles (538 lux	538 lux	
	Surface preparation and coating application, including working platforms, access, and entryways		20-foot candles (215 lux)	215 lux	
	In general work areas		10-foot candles (108 lux).	108 lux	
Rhode island	Lane drop	Floodlights shall be mounted on portable or fixed poles, tripods or staging in a location off the traveled way. Illumination of the lane drop areas shall be accomplished using 250-watt, 400-watt, 1,000- watt **metal halide** floodlights in any combination and any number necessary to achieve the foot candle levels and uniformity ratios specified above	The traveled way within the lane drops areas and all cones, barrels, or other physical barriers placed on the roadway for the purpose of channelizing or restricting vehicular traffic shall be illuminated to a minimum average of 2 footcandles.		Measured on both the horizontal and vertical planes 6 inches above the surface in question

	Roller	Floodlights should be mounted on steel bullhorn style brackets with 2-inch tenons and a 36-inch spread	250-watt		Floodlights should be mounted on steel bullhorn style brackets with 2-inch tenons and a 36-inch spread. Mounting height shall be a minimum of 8 inches above the top platform surface of the roller, provided the overall height from ground level does not exceed 15 feet
	Trucks	Floodlights, each truck shall have a minimum of three (1 wide beam and 2 narrow beams	250-watt		
	Pavers	Pavers shall Be equipped with a continuous twin lamp fluorescent bar consisting of enclosed 4-foot fluorescent fixtures mounted end to end across the full width of the screed area. Two auxiliary floodlights (narrow beam) shall be provided, one to illuminate guideline and one to illuminate the auger area. Care shall be taken in the placement of these floodlights to avoid aiming of the lights into the line of sight or into the mirrors of trucks which are backing into the auger/hopper area to unload bituminous concrete	A minimum of 10 footcandles must be provided at the screed area and in the area		In the area (minimum 15 feet) immediately behind the screed where manual raking operations are taking place.
South Carolina		Tower lights, tower lights which consist of mercury vapor, metal halide, high pressure sodium or low-pressure sodium fixtures mounted on a tower approximately 30 feet in height	Greater than 20 foot-candles	215 lux	
		Machin lights, use machine lights which have mercury vapor, metal halide, high	Greater than 10 foot-candles	108 lux	

		pressure sodium or low-pressure sodium conventional roadway enclosed fixtures mounted on supports attached to the construction machine at a height of approximately 13 feet.			
Tennessee	Paver, milling machine, material transfer devices	Balloon style lights or equivalent			
	Grader, roller, rumble strip machine, shoulder machine		One 4000-watt or two 2000-watt		
	Paint truck		One 400-watt		
	Guardrail driver, stationary operation		One 400 watt or non-glare 300-watt		
	Trial vehicle		One 4000-watt or two 2000-watt		
Vermont	Field offices		A minimum of 50 foot-candles	538 lux	

The safety of construction during nighttime can be measured by analyzing the number of accidents, but this way will include a lot of variables, therefore, we focused on the used method in lighting in different states. It is a fact that lighting during nighttime construction will increase the safety of workers and passing by vehicles. Some states went into details for each phase, the type and the method used for lighting, and some mentioned providing lighting in general. Most of them agreed on providing lighting 5 foot-candles for work areas of general construction operations, such as excavation and embankment; cleaning and sweeping; landscaping; planting, and seeding. 10-foot candles for work around all construction equipment, and 20-foot candles for surface preparation and coating application, including working platforms, access, and entryways.