# Impact of Work Zone Warning Light Configurations on Driver Behavior

Office of Maintenance

NOVEMBER 2013





*Your Destination...Our Priority*

# Table of Contents

# Introduction and Background

According to the FHWA Work Zone Mobility and Safety Program, there were 87,606 crashes in work zones nationwide in 2010, and there were 37,476 injuries—one work zone injury every 14 minutes.

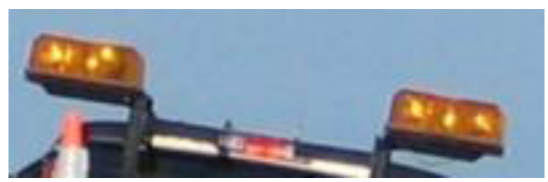
Worker safety can be improved by altering driver behavior, in particular lane choice and speed. Reduced speed will improve a driver's peripheral vision, from 80 degrees at 60 miles per hour to 120 degrees at 40 miles per hour. Slower travel speeds also give drivers more time to avoid obstacles or workers. Lane choice will naturally reduce the danger to workers, if drivers use the lane furthest from the work zone.

The Move Over Law (Minnesota Statute 169.18, Subdivision 11) recognizes the impact that lane choice has on worker safety by requiring drivers to move at least one lane away when passing a parked emergency vehicle, freeway service patrol vehicle, road maintenance vehicle, or construction vehicle with its warning lights activated. Despite this legal requirement, however, many drivers do not comply.

## Focus on Lighting to Change Driver Behavior

It can be difficult to capture a driver's attention so as to change behavior, since drivers do not always devote their full attention to the road, even in work zones. At high speeds, both motion and visual intensity are needed to gain notice.

MnDOT's standard warning lights on maintenance vehicles have traditionally been incandescent amber double rotators. These lights are not very bright or flashy and have not produced the desired impact on driver lane choice. In recent years, both LED lights and blue warning lights have emerged as potential options to improve effectiveness.



*Traditional double rotator warning lights.*

### LED Lights

An evaluation conducted by MnDOT's Maintenance Research Unit in 2009 and reported in Technical Memorandum No. 11-09-M-01, suggested that LED lights might make warning lights more effective. This evaluation showed that LED lights were far brighter than the incandescent double rotator at distances from 250 to 3000 feet.

LEDs may also make the most sense economically. Although their initial purchase costs are higher, LEDs may save money in the long run, due to:

- Potential safety improvements for workers (and the reduced workers compensation claims that ensue);
- Reduced energy usage, since LEDs require a low energy draw and can be left on when a vehicle is not running without draining the vehicle's battery;

- A reduction in the need for premature vehicle alternator replacement, which is also related to being able to run the lights without the vehicle running; and
- Reduced environmental footprint/emissions.

The potential advantages of LEDs have led both MnDOT staff and vendors to request their installation on plow trucks and other vehicles. The timing was right to evaluate the effectiveness of LEDs in the field.

### Blue Lights

Another lighting alternative to the double rotator is using blue warning lights in addition to the traditional amber lights. Blue lights are closely associated with emergency vehicles, making them more effective at attracting driver attention. The applications for which they are permitted are limited, however, to ensure that overuse does not blunt their impact.

Minnesota Statute 169.64, Subdivision 4 dictates where blue lights may and may not be used. Blue lights, in addition to amber lights, are permitted on high-exposure maintenance supervisor or superintendent vehicles that are frequently used to respond to unscheduled incidents on roadways or shoulders; a dedicated vehicle used for area-wide debris patrol only; Freeway Incident Response Safety Team (FIRST) vehicles; and snow removal equipment. No more than 50% of a light bar may be blue, and the blue lights must be mounted on the passenger side only.

Using blue lights, even in limited cases, had the potential to positively impact vehicle speed and lane choice. However, a formal evaluation in the field was needed to confirm expectations.

## Evaluate the Options in the Field

MnDOT staff were eager to determine which lighting alternatives made the most sense for replacing the double rotator configuration. Existing instrumentation on one of MnDOT's highways provided the perfect opportunity to evaluate the options. Using lane and speed data from a surveillance system aimed at preventing intersection crashes, MnDOT evaluated eight different lighting alternatives (including a variety of LED and blue light configurations) to determine the most effective lighting option for slowing down traffic and moving vehicles away from workers. This report describes the lighting configurations evaluated, the impacts of each on driver behavior, and the steps that MnDOT has taken to modify lighting policies as a result of the research findings.

## Study Approach

### Data Collection: Location and Equipment

The Comprehensive Intersection Collision Avoidance System (CICAS) is a surveillance system that uses sensors, computer processors, a communication network, and a geometric representation of the intersection to track the position, speed, and lane of travel of every vehicle that passes through the intersection. In other words, it facilitates real-time tracking of traffic.

*The CICAS detector as installed at Highway 52.*

CICAS is permanently installed at the intersection of Highway 52 and County Road 9 south of Cannon Falls in Goodhue County. CICAS and this intersection have been used for a series of prior research projects. The intersection has no traffic controls on Highway 52, and stop signs on County Road 9.

The data provided by CICAS was ideal for evaluating the impact of vehicle lighting on driver behavior. A patrol vehicle was parked at the intersection, and CICAS was mounted 400 meters upstream of the patrol vehicle to capture driver behavior. CICAS collected data about each vehicle that passed through the test area, including its speed and whether it was in the right or left lane. This information was collected at 50-meter intervals between the CICAS unit and the patrol vehicle, so driver behavior could be tracked as drivers approached the patrol vehicle.

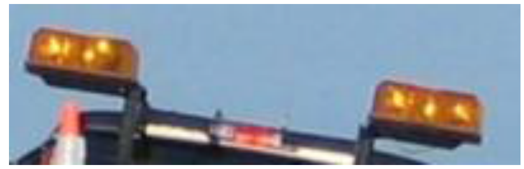
*The intersection of Highway 52 and County Road 9 where the study took place.*

Tests were conducted several times in 2011 and 2012. The results reported here represent average data across tests.

## Lighting Configurations Evaluated

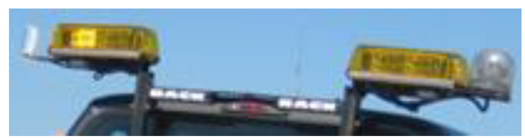
The seven lighting systems below were tested, along with a control vehicle (parked patrol vehicle with no warning lights at all). All tested lights except the double rotator were LED lights. All of the lights tested are approved under California Title 13.

**Double Rotator**
The standard incandescent amber double rotator used by MnDOT.



**LED Beacon**
A pair of amber lights, similar in appearance to the double rotator, but using LEDs instead of incandescent lights.

**Mini Bar**
A pair of small amber light bars mounted on each side of the vehicle.



**All Amber Bar**
A wide bar, extending nearly the full width of the patrol vehicle, that includes only amber lights.

**Amber Bar with Amber Lowers**
The same wide bar as the All Amber Bar configuration, with an additional amber light below the bar on both driver and passenger side.

**Amber Blue without Lowers**
A wide bar, similar to the All Amber Bar, but with a blue light on the passenger side.

**Amber Blue with Additional Amber Blue Lowers**
Similar to the Amber Bar with Amber Lowers, but the passenger-side light on the wide bar and the lower passenger-side light are blue instead of amber.

# Study Results

## Overview

Each of the lighting options reduced driver speeds, but by relatively small amounts. The Amber Blue without Lowers reduced speeds the most, by 5.8 miles per hour (9.1%) at the light 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%).

The light options had significantly greater impact on driver lane choices. In the test of the full-width Amber Blue with Additional Amber Blue Lowers, fully 99% of drivers used the left lane while passing the patrol vehicle. This was a significant improvement over the Double Rotator, 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.

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.

The table on the following page provides a summary of results for each lighting configuration. Detailed results for each option tested follow the table.

**Table 1. Summary of Lighting Impacts on Speed and Lane Choice**

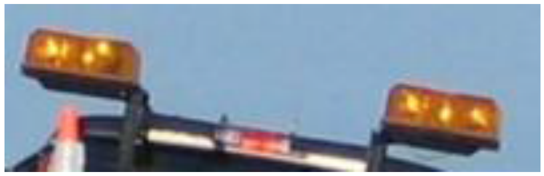
| | Impact on Speed | | Impact on Lane Choice | |
|---|---|---|---|---|
| Type of light | Overall average speed | Average speed at patrol vehicle | Percentage of vehicles in right lane 400 m from patrol vehicle | Percentage of vehicles in right lane at patrol vehicle |
| Control | 66.6 mph | 63.5 mph | 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 | 29% | 8% |
| Amber Blue with Additional Amber Blue Lowers | 64.2 mph | 60.1 mph | 11% | 1% |

## Detailed Findings by Lighting Configuration

Below is a description of the impacts on driver behavior for each of the lighting configurations evaluated. As with Table 1 above, the lighting options studied are presented in the order of least effective to most effective.

| Control – No Lights on Patrol Vehicle |
|---|
| **Speed reduction within 400 meters:** 3.1 mph<br>**Drivers in left lane (away from workers) at patrol vehicle:** 23% |
| As might be expected, the patrol vehicle with no lights had little impact on driver behavior. Less than one-quarter of drivers (23%) used the left lane while passing the patrol vehicle, a figure that was consistent throughout the test area and almost identical to the 22% of drivers who used the left lane 400 meters away. Speeds at the patrol vehicle averaged 63.5 miles per hour, slightly lower than the 66.6 miles per hour average speed throughout the test area. Apart from a slight slowdown in the last 50 meters, driver speeds were consistent throughout the test area. |

## Double Rotator



**Speed reduction within 400 meters:** 4.3 mph

**Drivers in left lane (away from workers) at patrol vehicle:** 52%

The Double Rotator configuration had a relatively small impact on driver speed and lane choice. At the patrol vehicle, slightly more than half (52%) of drivers used the left lane. There was a small amount of movement to the left lane as drivers approached the patrol vehicle, as only 31% of drivers used the left lane 400 meters from the patrol vehicle. The percentage of drivers in the left lane increased steadily, but slowly, as they approached the patrol vehicle. Speeds at the patrol vehicle averaged 62.7 miles per hour, compared to an average of 67 miles per hour throughout the test area; the decrease in speed occurred primarily in the last 50 meters before the patrol vehicle.

## LED Beacon

**Speed reduction within 400 meters:** 5.3 mph

**Drivers in left lane (away from workers) at patrol vehicle:** 46%

Apart from the control test, the LED Beacon option had the least impact on driver lane choice. Less than half (46%) of drivers used the left lane while passing the patrol vehicle. A relatively small number of drivers moved to the left as a result of the lights; one-quarter of drivers used the left lane 400 meters from the vehicle. For the most part, the drivers who did change lanes did so only in the last 200 meters before the patrol vehicle. Speeds at the patrol vehicle averaged 62.3 miles per hour, compared to a 67.6 miles per hour average throughout the test area; as with previous options, the drop in speed took place in the last 50 meters before the patrol vehicle.

## Mini Bar

**Speed reduction within 400 meters:** 3.9 mph

**Drivers in left lane (away from workers) at patrol vehicle:** 73%

The Mini Bar configuration was moderately effective at affecting driver behavior. Nearly three-quarters (73%) of drivers used the left lane while passing the patrol vehicles. This light was also somewhat more effective at encouraging drivers to move to the left lane earlier; nearly half (46%) of drivers were in the left lane at 400 meters from the patrol vehicle. Test results also showed that a noticeable number of drivers moved to the left lane at 200 meters from the patrol vehicle. Speeds at the patrol vehicle averaged 62.3 miles per hour, compared to a 66.2 miles per hour average throughout the test area; as with other tests, the speed drop took place in the last 50 meters of the test area.

## All Amber Bar

**Speed reduction within 400 meters:** 3.1 mph

**Drivers in left lane (away from workers) at patrol vehicle:** 89%

The All Amber Bar light configuration was third most effective at affecting driver lane choice. Almost nine out of ten drivers (89%) chose the left lane for passing the patrol vehicle. More than half of drivers (53%) moved over before entering the test area and used the left lane at 400 meters from the patrol vehicle. There was also significant movement to the left lane throughout the test area, although much of this happened at the 200-meter point. Speeds at the patrol vehicle averaged 61.9 miles per hour, compared to a 65.0 miles per hour overall average. Drivers appeared to begin slowing 100 meters from the patrol vehicle, slightly earlier than for other configurations, although the amount of this slowdown is small enough that its significance is dubious.

| Amber Bar with Amber Lowers |
| --- |
|  |
| **Speed reduction within 400 meters:** 4.5 mph<br>**Drivers in left lane (away from workers) at patrol vehicle:** 87% |
| The Amber Bar with Amber Lowers was nearly as effective as the All Amber Bar at affecting lane choice. At the patrol vehicle, 87% of vehicles used the left lane, while slightly more than half were in the left lane 400 meters from the patrol vehicle. Again, drivers moved to the left fairly consistently throughout the test area, with a noticeable bump at the 200-meter point. Speeds averaged 59.6 miles per hour at the patrol vehicle, and 64.1 miles per hour overall; the speed drop took place primarily in the last 100 meters of the test area. |

| Amber Blue without Lowers |
| --- |
|  |
| **Speed reduction within 400 meters:** 5.8 mph<br>**Drivers in left lane (away from workers) at patrol vehicle:** 92% |
| The Amber Blue without Lowers configuration was the second most effective at impacting driver lane choice, both at the patrol vehicle and at a distance. More than nine out of ten drivers (92%) used the left lane at the patrol vehicle, and more than seven out of ten were in the left lane 400 meters away. Within the test area, vehicles moved to the left primarily at the 200-meter point. Speeds at the patrol vehicle averaged 57.8 miles per hour, compared to a 63.6 miles per hour overall average speed. The drop in speed took place in the final 50 meters of the test area. |

| Amber Blue with Additional Amber Blue Lowers |
| --- |
|  |
| **Speed reduction within 400 meters:** 4.1 mph<br>**Drivers in left lane (away from workers) at patrol vehicle:** 99% |
| The Amber Blue with Additional Amber Blue Lowers was most effective at affecting driver lane choice. Almost all drivers used the left lane throughout the test area: 99% of drivers were in the left lane when passing the patrol vehicle, and almost nine out of ten were already in the left lane at the start of the test area 400 meters away. Speeds at the patrol vehicle averaged 60.1 miles per hour, compared to an overall average of 64.2 miles per hour. The speed decrease took place in the final 100 meters before the patrol vehicle. |

## Conclusions and Next Steps

The study identified several warning light characteristics that increased the lighting rig's impact on inducing drivers to use the left-hand lane when passing a work zone on the right. The incorporation of blue lights into a warning light configuration, the use of full-width warning light bars, and the incorporation of additional lower lights were each effective at encouraging drivers to move to the left lane and away from a construction/work zone.

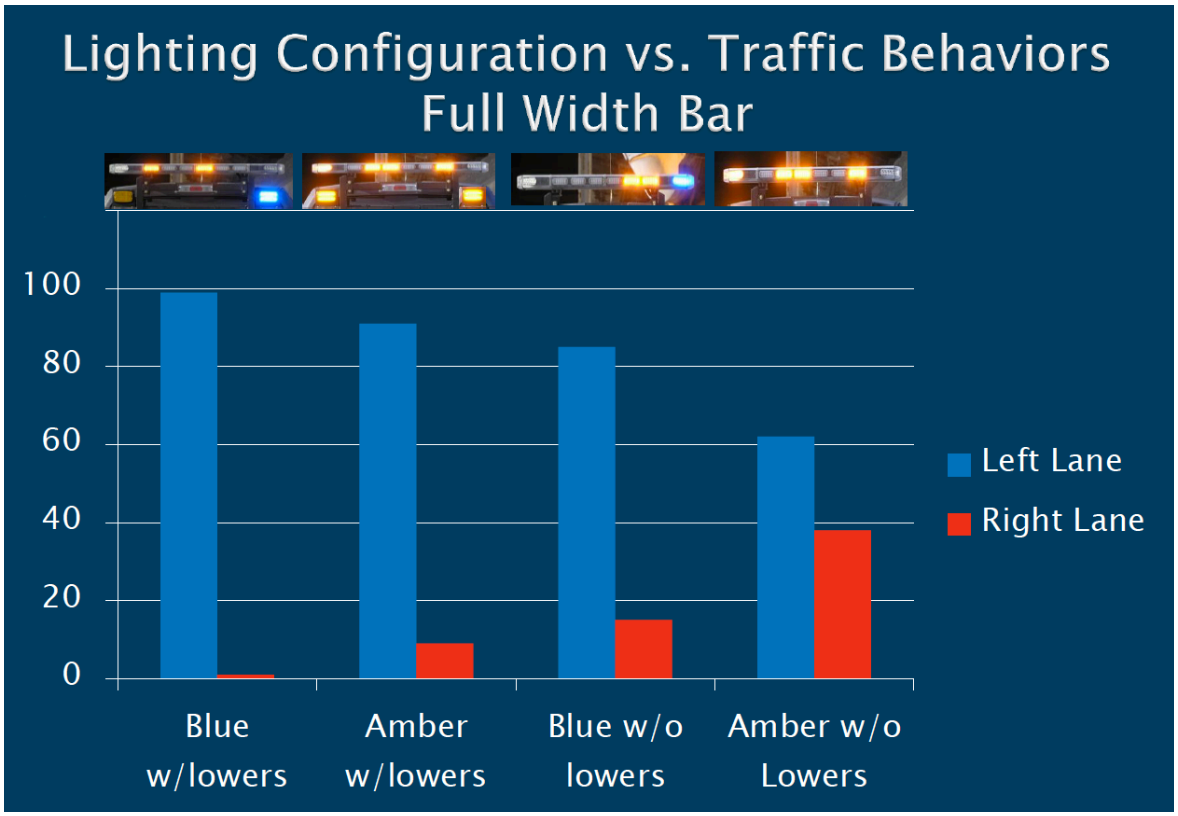
A combination of both blue lights and lower lights was most effective; 99% of drivers moved over to the left lane when this configuration was used. At least 87% of drivers used the left lane at the patrol vehicle for each of the lighting configurations that used a full-width warning light bar, which was significantly better than the traditional incandescent double rotator and the other options that were tested.

LED lights were significantly more effective than incandescent double rotator lights at altering driver behavior and creating a safer work environment for employees in the right of way. Depending on configuration, LED lights increased left-lane usage by 3% to 37%. Overall, 85% of drivers moved into the passing lane (away from the work zone) when LED warning lights were used, compared to 52% for the double rotators.

Blue lights are closely affiliated with emergency vehicles, which is likely why they are so effective at altering driver behavior. That also suggests that their usage should be limited so drivers do not become accustomed to seeing blue lights, which may reduce their impact.

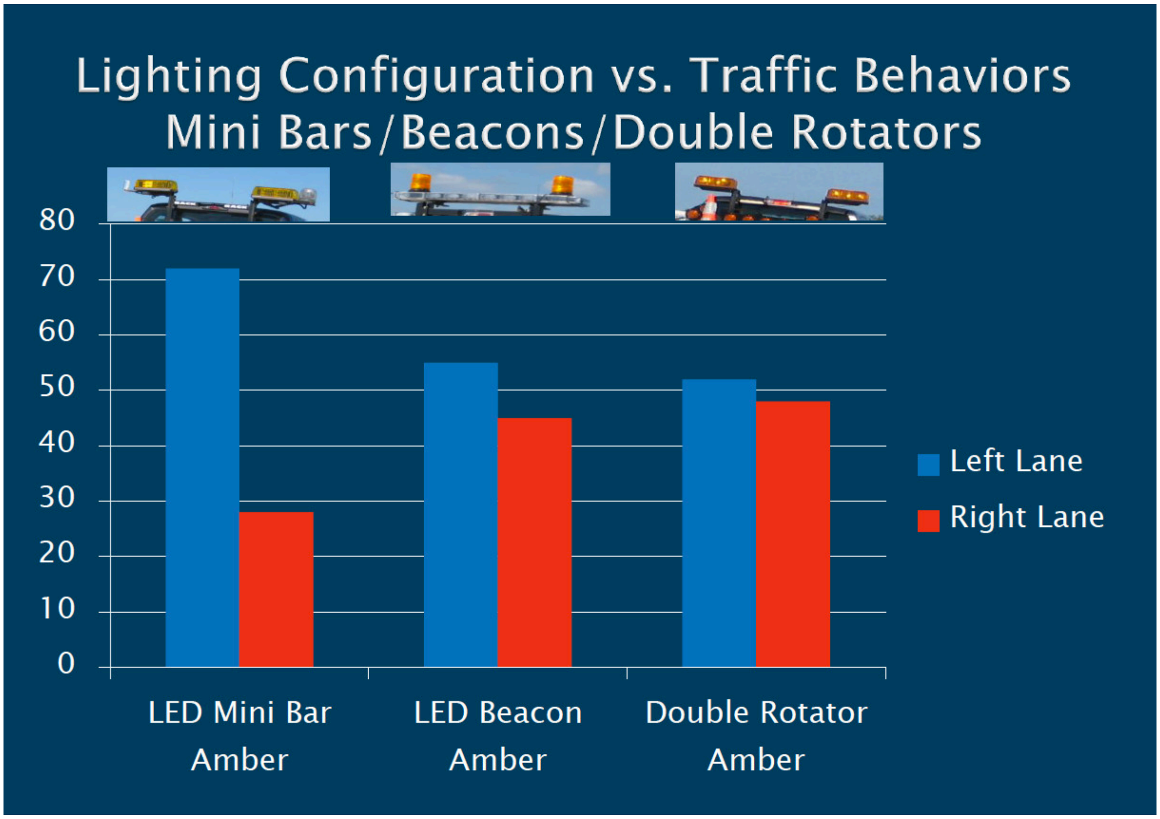
## Effectiveness of Full-Width Bar Lighting

The relative effectiveness of full-width bar configurations, with and without lower lights, at causing drivers to use the left lane when passing a parked vehicle, is illustrated in the graph below. Blue bars indicate the percentage of drivers using the left lane while passing the patrol vehicle.



## Effectiveness of Partial Bar Lighting

The next graph shows the relative effectiveness of the smaller light configurations, including the Mini Bar, LED Beacon, and Double Rotator. Again, the blue bars indicate the percentage of vehicles using the left lane when passing the patrol vehicle.




While several warning light configurations were noticeably effective at altering driver lane choice, they had less impact on driver speed. Each of the tested configurations, even the control vehicle with no warning lights, had a small impact on driver speeds ranging from 4.7% to 9.1%. None was greater than the 5.8 mile-per-hour speed reduction of the Amber Blue without Lowers, and none was lower than the 3.1 mile-per-hour speed reduction of the All Amber Bar.

## Modifying MnDOT's Lighting Standards

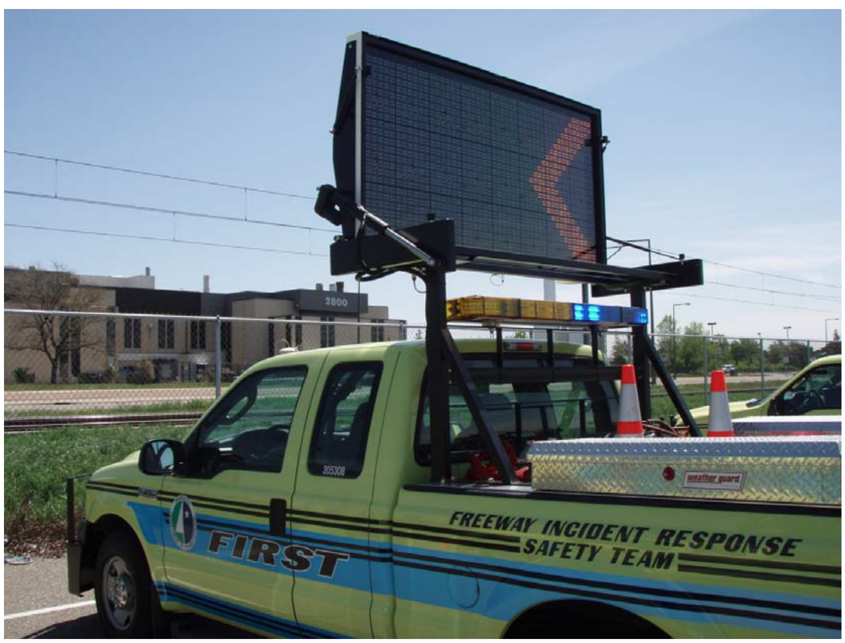
After analysis, this data was presented to MnDOT management with a recommendation to change MnDOT's standard for warning lights. MnDOT Technical Memorandum No. 11-09-M-01, Vehicle Warning Light Guidelines, updated and clarified MnDOT's warning light standards. These new standards include the following provisions:

- MnDOT's fleet of vehicles will phase out incandescent warning lights as their existing inventory is used up, and replace them with LED lights. (Portable lights can remain as their incandescent double rotator version.)
- Blue lights may be mounted on the passenger side only, in addition to amber lights, on maintenance supervisor or superintendent's vehicles that are often used to respond to unscheduled incidents on roadways or shoulders; dedicated vehicles used for area-wide debris patrols; Freeway Incident Response Safety Team (FIRST) vehicles; and snow removal equipment. (Blue lights were permitted on these vehicles by statute 169.64 before this memo was issued, but it was widely believed that blue lights were reserved for snow plows and state patrol vehicles, so that is how they were used.)
- No more than 50% of the light bar may be blue.
- Blue lights should not be overused.
- District Area Maintenance Engineers can provide guidance on the use of blue lights. Any variances must be reviewed and approved by the Maintenance Business Management Team.

MnDOT only approves LED warning lights that meet the California Code of Regulations, Title 13, Motor Vehicle Lighting Equipment Requirements, lab test, which addresses flash pattern, device durability, temperature requirements, lens configuration, color and photometric requirements, and overall light output. A list of approved vehicle lights (including both LED and non-LED) can be found under Vehicle Safety Lights on the Qualified Products List at http://www.dot.state.mn.us/products/index.html.

## Recommended Lighting Installations

*Maintenance Supervisor or Superintendent Vehicle/Area Wide Debris Patrol (Amber blue with amber blue lowers—less than 10% blue).*




*FIRST vehicle (50% blue).*

## References


FHWA Work Zone Mobility and Safety Program, "Facts and Statistics: Work Zone Injuries and Fatalities", http://www.ops.fhwa.dot.gov/wz/resources/facts_stats/injuries_fatalities.htm.

Minnesota Statute 169.18, Subdivision 11. Driving Rules/Move Over Law. https://www.revisor.leg.state.mn.us/statutes/?id=169.18.

Minnesota Statute 169.64, Subdivision 4. Prohibited Lights; Exceptions/Blue light. https://www.revisor.mn.gov/statutes/?id=169.64.

MnDOT Engineering Services Division, Technical Memorandum No. 11-09-M-01, Vehicle Warning Light Guidelines, Apr. 19, 2011. http://www.dot.state.mn.us/trafficeng/publ/pdf/11-09-M-01.pdf.

MnDOT Qualified Products List, http://www.dot.state.mn.us/products/index.html.

University of Minnesota Intelligent Vehicles Laboratory, Minnesota Research Intersection Testbed (Highway 52/County Road 9 intersection) homepage, http://www.idsweb.me.umn.edu/minnesota/.