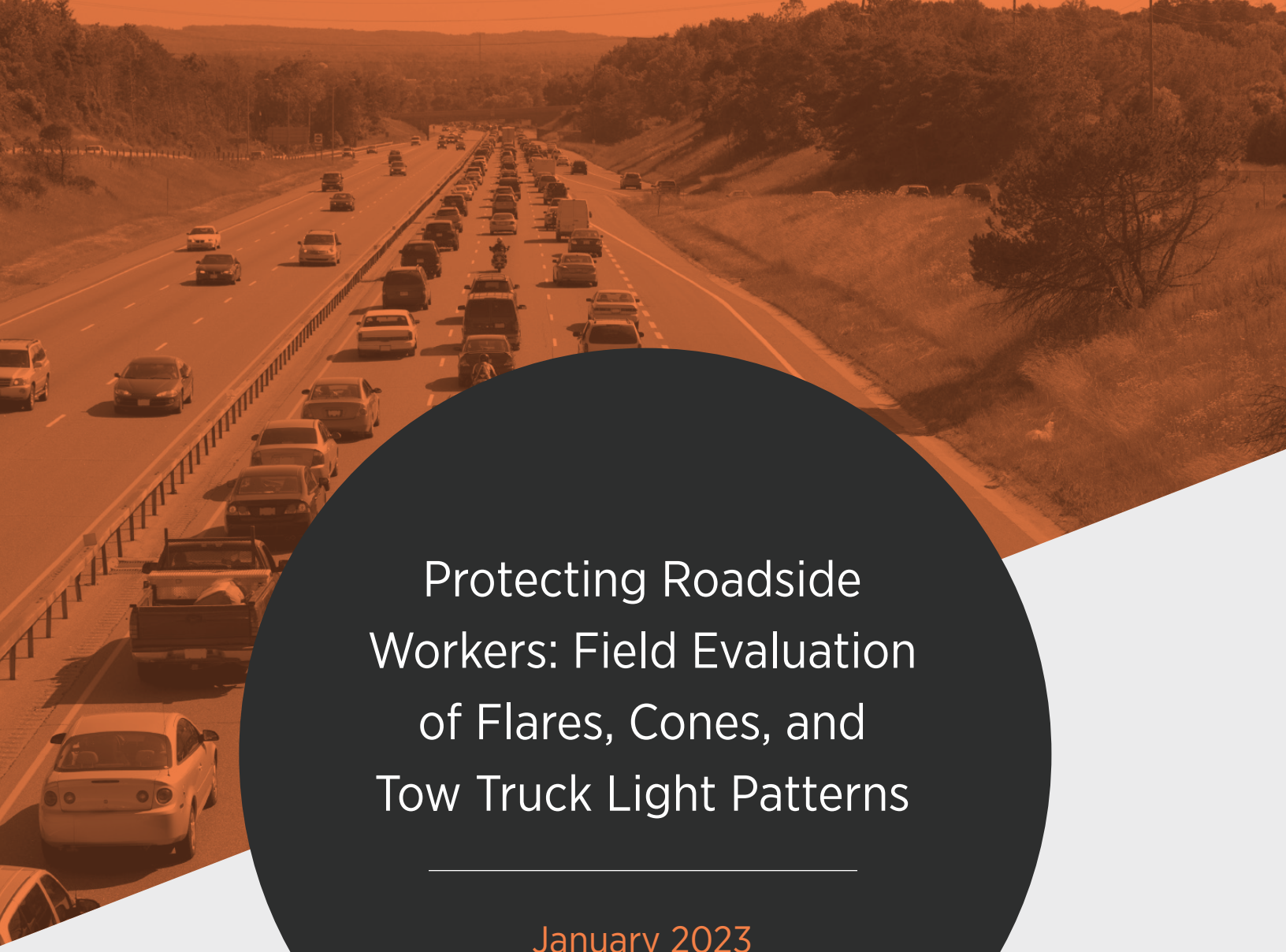

Protecting Roadside Workers: Field Evaluation of Flares, Cones, and Tow Truck Light Patterns

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AAA FTS
FOUNDATION FOR TRAFFIC SAFETY

Title

Protecting Roadside Workers: Field Evaluation of Flares, Cones, and Tow Truck Light Patterns

(January 2023)

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Foreword

Motor vehicle towing workers and other personnel working at roadside are at risk of being struck while performing their jobs, with higher rates of nonfatal and fatal injuries than workers in other industries. Thus, there is a need for additional research to identify and increase the use of countermeasures to improve the safety of towing, recovery, and other incident response personnel.

This technical report documents a study with three aims: evaluate the effectiveness of flares or cones in combination with two different tow truck light systems on the shoulder of a multilane highway; survey road service personnel regarding their experience with, and willingness to use flares and cones; and document available and potential countermeasures that could be deployed for protection at roadside. Information presented in this report should assist researchers and stakeholders in towing and recovery and other responder industries improve safety for these vulnerable workers.

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About the Sponsor

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Founded in 1947, the AAA Foundation for Traffic Safety in Washington, D.C., is a nonprofit, publicly supported charitable research and educational organization dedicated to saving lives by preventing traffic crashes and reducing injuries when crashes occur. Funding for this report was provided by voluntary contributions from AAA/CAA and their affiliated motor clubs, individual members, AAA-affiliated insurance companies, and other organizations or sources.

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List of Acronyms

AAAFTS	AAA Foundation for Traffic Safety
AI	Artificial Intelligence
ANOVA	Analysis of Variance
COTS	Commercial Off the Shelf
FMCSA	Federal Motor Carrier Safety Administration
fps	Frames Per Second
IR	Infrared
IRD	International Road Dynamics, Inc.
NIOSH	National Institute for Occupational Safety and Health
RSI	Roadside Service Information

Executive Summary

This study examines strategies for protecting towing and recovery and other incident response personnel working at roadside from being struck by passing motorists. The report consists of three parts, each reporting on the following separate but coordinated activities:

- **Evaluation of Flares and Cones in Combination with Two Different Light Patterns:** An on-road experiment tested the extent to which motorists passing a tow truck slowed down and moved over day and night in response to the deployment of flares or cones in combination with two different tow truck light systems: a Daytime light pattern representative of the emergency lighting currently in widespread use and a Nighttime light pattern designed to avoid masking road safety personnel working at the roadside at night. The results of the field test showed that all of the tested approaches were capable of improving motorist behavior at least under certain conditions, e.g., day, night.

  Lane Occupancy: At night, both the Daytime and Nighttime light patterns were associated with large and significant shifts from Lane 1 (closest to the roadside) into Lanes 2 or 3 in comparison to when the truck and client vehicle were not present. When flares were added to the truck displaying the Daytime light pattern at night, the occupancy of Lane 1 decreased significantly beyond the level achieved by the truck and Daytime lights alone. The addition of cones, however, produced only a very small additional reduction that did not reach statistical significance. When paired with the Nighttime light pattern at night, both flares and cones yielded a large and statistically reliable shift out of Lane 1 beyond what occurred with truck alone.

  Speed and Lateral Position: During the day, both flares and cones were associated with small increases in Lane 1 vehicle speeds, however only that for cones was statistically reliable. The lateral distance of the passing traffic did improve (increase) but did not reach significance for either the flares or cones. When flares and cones were added to the Daytime light pattern at night, both were associated with significant increases in Lane 1 speeds and decreases in lateral distance. In contrast, when added to the Nighttime light pattern, both cones and flares showed decreases in Lane 1 speed, although only the latter reached statistical reliability. Flares also resulted in a larger lateral distance of passing vehicles while cones yielded a small decrease in that measure, although neither of the changes reached statistical reliability.

- **Survey of Towing Industry Personnel:** An online survey of road service personnel assessed attitudes, knowledge, and experience with and willingness to use countermeasures such as flares and cones. Results of the survey suggest that overall industry personnel attitudes towards flares and cones are largely favorable and the majority use these countermeasures in a variety of situations. Making deployment easier and laws requiring use were indicated by respondents as motivators that would further increase use of flares and cones. Making cone retrieval easier and reducing expense of flares were also particularly popular motivators. In addition, respondents report being more likely to use flares and cones if research evidence

suggested that they were effective and even more so if a company policy were combined with such research evidence.

- **Review of Countermeasures:** A review identified and catalogued available and potential countermeasures that could be deployed on a tow truck technician, on the truck itself, on the site nearby, or in the motorist vehicle for protection when operating along the roadside. A total of 42 available and prospective countermeasures with potential to reduce the risk to roadside service and incident response personnel were identified. Some countermeasures were products that can be purchased currently and others were at various levels of technology-readiness ranging from nascent ideas to products under development. The most promising countermeasures, both in terms of altering passing motorist behavior and promoting widespread technician use, appear to be expensive, overly complex, and/or otherwise unattractive to the industry.

The three activities, when taken together, have implications for future efforts to improve the safety of roadside service and incident response personnel. The review of countermeasures identified many promising approaches, and concerns regarding the difficulty of deploying and retrieving the countermeasures were similar to concerns voiced in the survey with regard to use of flares and cones. This suggests that research and development focused on countermeasure deployment and retrieval systems could be productive. The survey also provided an encouraging note with respect to the use of flares and cones. Respondents indicated an increased willingness to use flares and cones if research indicated that they improved safety. The results of the on-road study provide compelling research evidence in that direction. The dissemination of these results to the operational as well as the research communities would therefore appear warranted.

Introduction

This report consists of three parts, each reporting on the following separate but coordinated activities:

- An on-road experiment to test the extent to which motorists passing a tow truck slowed down and moved over day and night in response to the deployment of flares or cones in combination with two different tow truck light systems;
- An online survey of road service personnel on their attitudes, knowledge, and experience with and willingness to use countermeasures such as flares and cones;
- A review of available and potential countermeasures that could be deployed on a tow truck technician, on the truck itself, on the site nearby, or in the motorist vehicle for protection when operating along the roadside.

The Appendices to the report present additional, detailed information to supplement the text.

Background

Between 2011 and 2016, The National Institute for Occupational Safety and Health (NIOSH) found that 191 motor vehicle towing workers (herein referred to as "road service technicians") were killed while conducting their functions on the roadway. Those crashes resulted in an annual rate of 42.9 deaths per 100,000 full-time equivalent towing workers. By comparison, the annual rate for all other industries is 2.9 per 100,000 full-time workers (Konda et al., 2018). When looking at nonfatal injuries during the same period, road service technicians had a rate of 204.2 injuries per 10,000 full-time workers, which is more than double the rate of 98.2 per 10,000 full-time workers for all industries (Chandler & Bunn, 2019). NIOSH states: "The findings from this study underscore the need for additional research and tailored prevention efforts" (NIOSH, 2019).

In response to this problem and similar dangers to other emergency workers such as police and firefighters, all 50 States have enacted "Slow Down and Move Over" laws (AAA Foundation for Traffic Safety, 2021). These laws require motorists overtaking a stopped emergency vehicle to reduce their speed and increase their passing distance to the emergency vehicle. A recent survey, however, showed that only about 77% of licensed drivers knew their state had such a law, and even fewer (about 73%) completely understood its requirements (AAA Foundation for Traffic Safety, 2021). When the same sample of drivers was asked how often they actually change lanes and/or slow down, almost 93% responded, "All times when I could have" (AAA Foundation for Traffic Safety, 2021). Data from actual measurements of lane changes and speed by, for example, Carrick et al. (2012) suggest these self-reports are gross over-estimates, a finding supported by data presented later in this report.

"Slow Down and Move Over" laws are but one strategy to protect roadside workers, it is reasonable to examine methods for increasing compliance with the laws as well as other ways to accomplish the same objective of getting drivers to leave a larger buffer zone between their vehicle and a road service worker. This was the basic theme of this research.

Study Approach

The study involved first identifying possible equipment, procedural, and regulatory countermeasures capable of yielding improved motorist behavior when passing a tow truck operating at the side of the road. Researchers then examined the most promising products or approaches in an on-road field test using lane changes as well as passing vehicle speed and lateral position in the inside lane as the main evaluation measures. The third step involved examining road service technician compliance with the specific (or at least the type of) countermeasures deemed effective. This approach was modified as the work progressed based on the results of the initial review.

The review of available countermeasures with the potential to get motorists to slow down and/or move over for a tow truck gave consideration to all technology readiness levels with the potential to prompt the desired motorist behavior. The search identified a variety of on-person, on-vehicle, and roadway-deployable countermeasure approaches that had demonstrated effectiveness or appeared to have potential to be effective. The analyses, however, indicated that none of the promising approaches considered sufficiently effective and capable of widespread, immediate deployment had sufficiently low cost and/or high convenience to be considered likely acceptable to the towing industry.

Given that the countermeasure review did not identify any readily implementable and acceptable approaches, the sponsor and researchers decided to field test two longstanding countermeasures, flares and cones, that are well-known and relatively inexpensive but not universally used. Also, since some new tow trucks were being equipped with a new light system designed to limit the possible masking of workers at night, these lights as well as the light system they were intended to supplant were also included in the on-road field test portion of the study.

The results of the field test showed that all of the tested approaches were capable of improving motorist behavior at least under certain conditions, e.g., day, night. Thus, an online survey of workers in the road service industry was carried out in order to examine their willingness to use cones and flares and whether their decisions to use these countermeasures could be influenced by promising research results.

The following sections present these three sub-studies in detail. The on-road study is presented first because its results formed the basis for the focus of the online survey, which is presented second. The review of available countermeasures closes the report and presents a useful cross-section of the current state-of-the-art of countermeasures applicable to the protection of roadside service and incident response personnel.

On-Road Study

The first study covered in this report involved an on-road experiment to measure the response of passing motorists to the presence of various combinations of stimuli placed on the shoulder at the side of the highway. The objective of the study was to see how various combinations of tow truck light configurations together with widely used site conspicuity enhancers (flares and retroreflective/fluorescent cones) affected compliance with a law that requires motorists to slow down and move over for an emergency vehicle. The following sections detail the approach and the results.

Evaluation Approach

The field study simulated the activities of a tow truck/wrecker and a "disabled" client vehicle by the side of a multi-lane, limited access highway. The truck and car in the simulated rescue were placed on the shoulder of a highway as far away from the fog line dividing the shoulder from the driving lane as possible for the safety of the research team. In each countermeasure condition, the hazard flashers of the car were always on and the truck emergency and running lights operated in one of two configurations.

The evaluation was structured around the reasonable assumptions that safety would be improved by the following:

- Fewer vehicles in the driving lane closest to the shoulder and therefore closest to the tow truck and client vehicle
- Lower speeds among the vehicles in the lane closest to the shoulder
- Cars farther from the fog line

The evaluation was therefore structured to measure the extent to which each tested condition changed these three parameters relative to appropriate baseline or comparison conditions.

Data Collection Site

Although road service workers and emergency personnel are at risk on all types of roadways, the scope of the study necessitated the selection of a single site for data collection. A limited access highway was selected for data collection for several reasons. First, the high speeds on these highways result in an elevated risk of a serious injury or fatality in the event of a crash. Second, the relatively high traffic volumes on a limited access highway provided a high sample acquisition rate that increased efficiency. Third, using a multi-lane highway provided motorists the freedom to comply with the move over law in any of its prescribed ways (see below). Finally, limited access highways often have stretches with wide shoulders or "breakdown lanes" so the tow truck, client vehicle, and researchers could be positioned reasonably far from the travel lanes.

Researchers and personnel from AAA Northeast collaborated to identify a site near the AAA facility from which the tow truck would be dispatched, convenient to the Dunlap offices, and exhibiting the desired physical characteristics. The site selected was on Route 25 northbound in Trumbull, CT (latitude 41.24799723649195, longitude

−73.19051779923193) as shown in Figure 1. The site was chosen because of the available wide shoulder and its ease of access. It was located approximately 0.9 mi north of Route 15 (The Merritt Parkway), a major highway through Connecticut running east/west at its intersection with Route 25.

Figure 1. Aerial view of Route 25 test site (adapted from Google Map Data ©2022).

As shown in Figure 1, Route 25 at the test site has three lanes in each direction separated by a wide grassy median. The roadway is slightly curved, but sight distance to the location at which the stimuli were placed was in excess of 1000 ft. The emergency lights on the tow truck were likely visible for an even greater distance. The speed limit is 55 mph.

The driving lane closest to the shoulder or breakdown lane is referred to as "Lane 1," the center lane is designated "Lane 2," and the lane closest to the center median is called "Lane 3."

Applicable Law

Connecticut, where the data collection was located, passed its "Slow Down and Move Over" law as Public Act 09-121, which was approved on June 9, 2009, and became effective October 1, 2009. The law requires the following:

> *Any operator of a motor vehicle on a highway when approaching one or more emergency vehicles that are stationary or traveling significantly below the posted speed limit and located on the shoulder, lane or breakdown lane of such highway shall (1) immediately reduce speed to a reasonable level below the posted speed limit, and (2) if traveling in the lane adjacent to the shoulder, lane or breakdown lane containing such emergency vehicle, move such motor vehicle over one lane, unless such movement would be unreasonable or unsafe.* (Connecticut General Statutes Chapter 248 Sec. 14-283b)

Within the law an "emergency vehicle" is defined as "any vehicle with activated flashing lights," and specifically includes a defined "wrecker" or tow truck.

Thus, if a wrecker with flashing lights were placed at the selected data collection site, a motorist would be able to comply with the law by slowing down and either changing lanes to the left (away from the shoulder) or, if this could not be accomplished safely, by moving as far left as safely possible within Lane 1.

Test Condition Selection

As discussed in the introduction to this report, the review of possible countermeasures that preceded this on-road test did not identify any innovative countermeasures considered sufficiently ready to test based on considerations of cost, complexity, acceptability, and technology readiness. AAA Foundation for Traffic Safety (AAAFTS) and the researchers therefore decided to test three "traditional" but not universally used approaches, all of which were designed to increase the conspicuity of the site containing the tow truck and client vehicle. Personal protective devices such as active (flashing LED lights) or passive (retroreflective and fluorescent) vests for road service workers were discounted for two main reasons. First, researchers were concerned about the safety of placing research staff near traffic, especially in baseline conditions without the enhancement of a high-visibility vest. Second, movements or changes in the position of a worker/researcher wearing a vest or other enhancement could alter its appearance to an oncoming motorist, thus making it difficult or impossible to ensure that motorists were exposed to the same stimulus.

AAA Northeast provided a brand-new flatbed style wrecker to serve as the test vehicle (see Figure 2). If a car needs to be transported somewhere for service, the entire rear bed tilts up so the vehicle can be winched onto the bed, which is then lowered and the vehicle secured. When the bed is elevated, it can partially obscure the emergency lights on the top of the cab. Thus, the bed remained down throughout the data collection so that the light bar would not be obscured.

Setup at the test site consisted of the wrecker parked at the far right of the shoulder with a 2020 silver Mercedes-Benz E350 sedan parked 6 ft (1.83 m) behind it with its hazard flashers operating both day and night. The setup is shown in Figure 3.

Figure 2. Wrecker used as the test truck.

Figure 3. Basic test site setup.

Flashing signals on emergency and highway service vehicles provide critical information to approaching vehicles to be vigilant for possible emergency workers and others in the roadway. Lighting technology has improved with the advent of LED, and the intensity has tended to increase. During daytime, the brightest flashes and highest intensities are likely

needed to compete with direct and ambient natural light. Under nighttime conditions with lower ambient light levels, however, bright flashes and high-intensity lighting have the potential to cause increased glare and oversaturation of flashes thereby actually masking service workers and stranded motorists rather than making them easier to detect. As a result, light systems have been developed by Whelen Engineering and others that automatically switch to light intensities and flash rates appropriate to the ambient situation. For example, using an ambient light sensor and inputs from the vehicle, the system can display bright, intense, random flashes during the day, and much slower, synchronized, lower-intensity flashes at night.

AAA Northeast and Whelen Engineering representatives worked together to develop the warning light package for new AAA trucks such as the one used in this study. The system employs the Whelen SmartLogic™ flasher that utilizes the vehicle and light sensor information to determine the flash rate and intensity of all the flashing lights on the truck automatically when the switch to activate the emergency lights is turned on.

Thus, the wrecker used in the test came equipped with a new light bar design that included automatically selected separate daytime- and nighttime-stationary light displays/patterns. In order to provide the flexibility to choose either light pattern at any time for the study's data collection, the manufacturer's representatives added a switch to bypass the photocell and switching logic, providing researchers with the ability to select either the day or night pattern at will.

The installed light bar's night pattern was designed to avoid masking road safety personnel while on or near the roadway, which could occur with the brighter daytime setting, which is representative of current (and widespread) industry standards. Both daytime and nighttime light patterns were deployed in different test conditions. The daylight lighting configuration was evaluated during both daylight and night data collection sessions, thus mimicking scenarios where a wrecker only had a single, fixed light pattern. The nighttime lighting configuration, which is only intended to be used when stationary in darkness (as selected by the photocell), was only tested under nighttime conditions. These two patterns are referred to in the remainder of this report as the "Daytime" and "Nighttime" light patterns.

A second test condition consisted of the deployment of a pattern of three standard roadway flares such as those the Federal Motor Carrier Safety Administration (FMCSA) requires tow trucks to carry. Older flares were difficult to light and included a spike to hold them upright. These spikes had to be retrieved after the flare burnt out to avoid leaving a road hazard behind. The current generation flares used during this test, however, left no spike or other dangerous residue when they burned out and therefore did not have to be retrieved. They also were easy to light using the cap covering the top of the flare. The specific flares used were the Auto Ignition models made by Orion Safety Products. They are the flares stocked and used by AAA Northeast. Researchers marked the locations for the flares, which were approximately 30 ft (9.14 m), 45 ft (13.72 m), and 64 ft (19.51 m) behind the car as shown in Figure 4. Figure 5 shows an overhead scaled diagram of the flare placement along with the positions of the wrecker, client vehicle, and sequence of calibration markings for measuring speed and lateral position (discussed below).

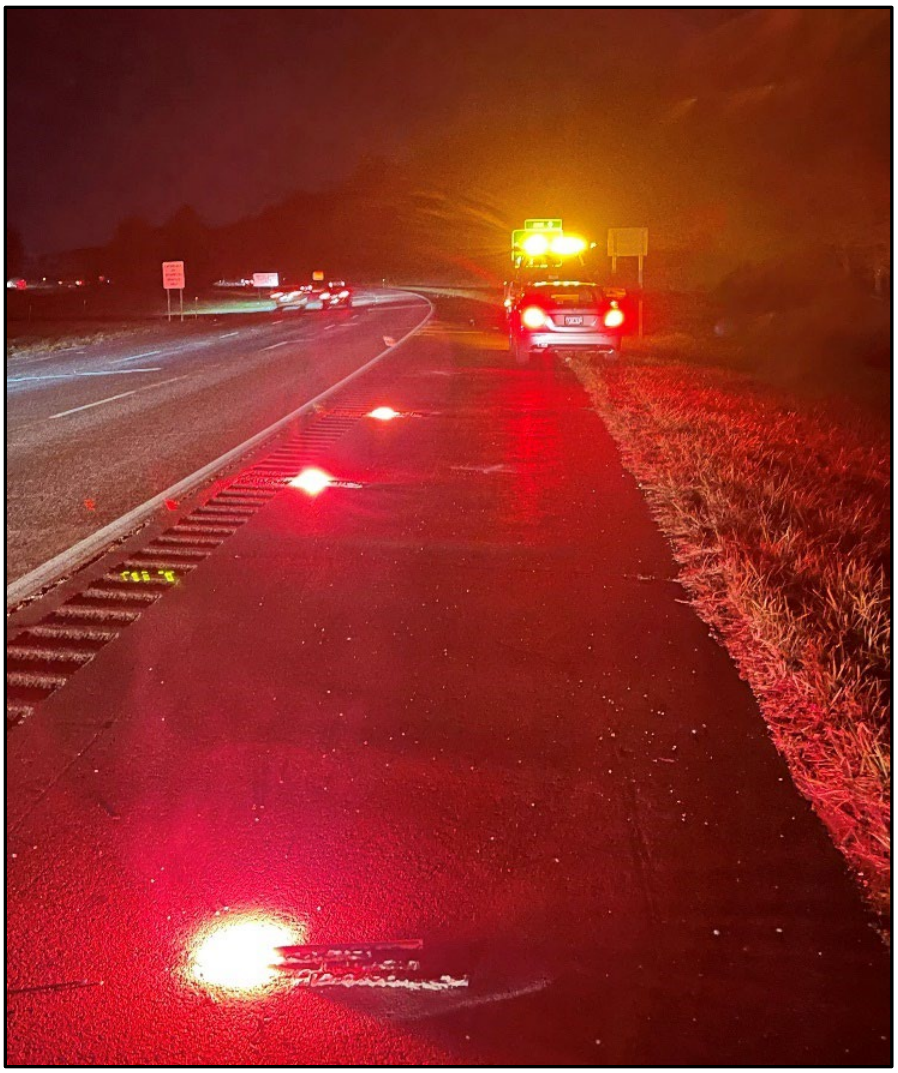

Figure 4. Flare pattern shown at night.

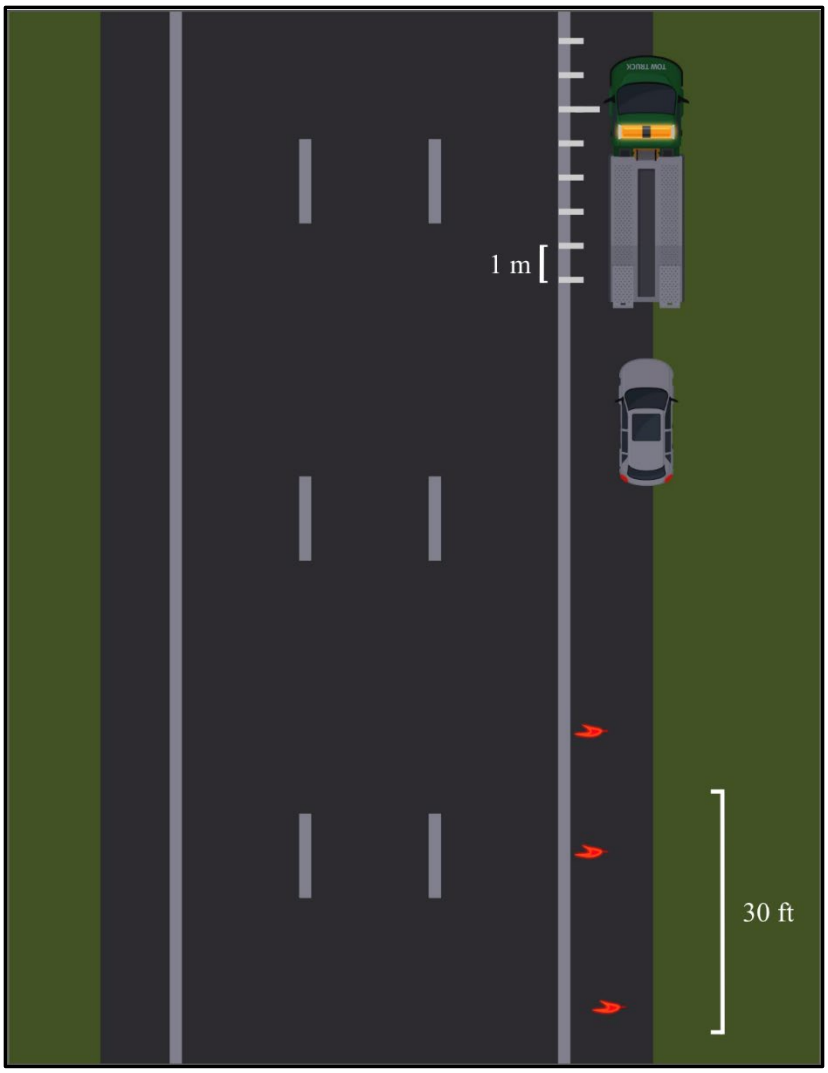

Figure 5. Overhead scaled diagram of flare placement.

The third test condition consisted of a pattern of three 28 in tall retroreflective and fluorescent cones at approximately 11 ft (3.35 m), 29 ft (8.84 m), and 43 ft (13.11 m) behind the client car as shown in the photograph in Figure 6. Figure 7 is an overhead scaled diagram of the cone placement. As is common, the test tow truck was equipped with a "cone rack" under the flatbed that was configured to carry three cones. The specific cones used were brand new and Wapco brand. As with the flares, they were AAA Northeast standard issue.

A final baseline condition consisted of the roadway with nothing added by the study team in both day and night in comparable traffic conditions. This permitted an assessment of the extent to which each of the conditions—daytime/nighttime truck lights, flares, or cones—produced a response compared to the stream of traffic unperturbed by the presence of any emergency equipment.

Figure 6. Cone pattern shown during the day.

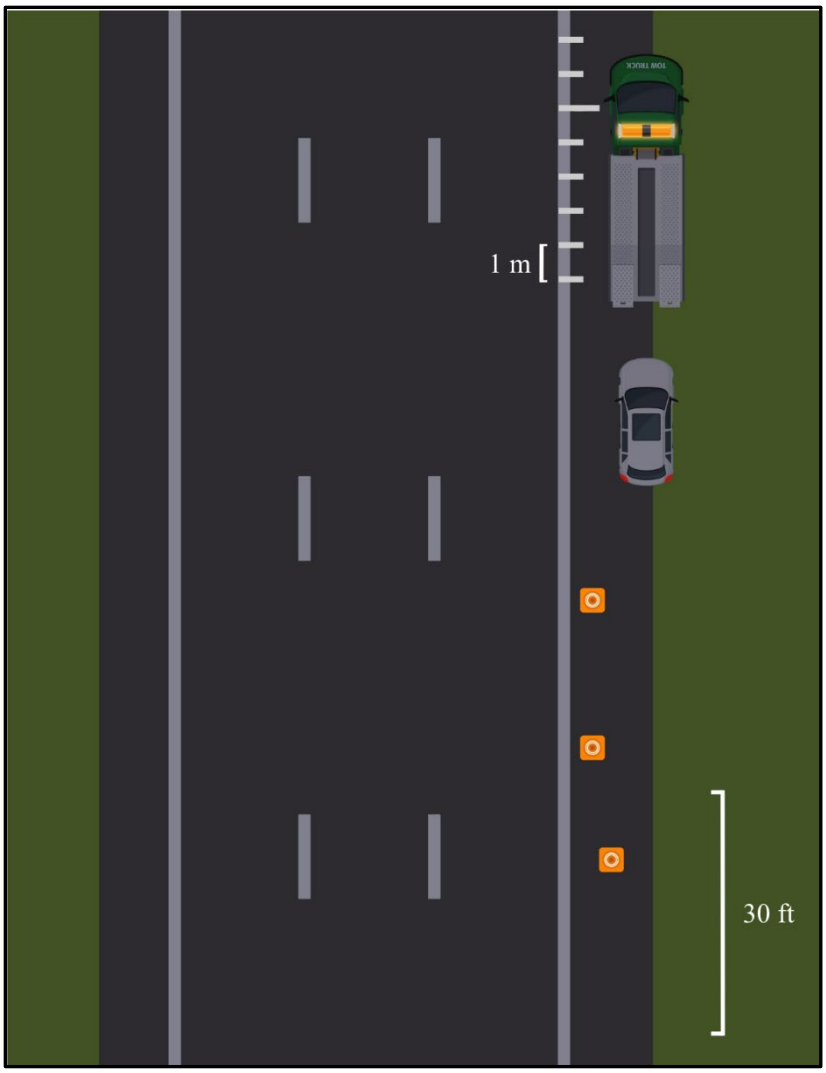

Figure 7. Overhead scaled diagram of cone placement.

Measures

As discussed above, the move over laws in general, and the Connecticut law specifically, require motorists approaching an emergency vehicle to slow down and move out of Lane 1. If that is not safe, motorists must slow down and give as wide a berth as possible to the emergency vehicle. To assess compliance with these requirements, researchers collected data to construct three measures—lane occupancy, Lane 1 speed, and Lane 1 lateral position.

Lane Occupancy. Lane occupancy is the number of cars in each lane as they passed the test tow truck and client car. Occupancy was measured by recording a continuous video of all three northbound lanes for each test condition using a rear-facing GoPro® Hero 5 camera attached to the left rear flatbed side rail of the tow truck as shown in Figure 8.

For the measurement of lane occupancy in baseline conditions (when no truck, car, or countermeasure was present), a camera was clamped to the stanchion of a road sign near where the truck was placed for the data collection. Figure 9 shows the sign stanchion that

was used and its proximity to the positions of the tow truck and car when they were on scene.

At the start of data collection for each condition, a researcher held a slate in front of the lane camera to indicate the date, time, and condition value. The camera then ran continuously until the end of the data collection period, denoted by the sampling of a minimum of 200 cars in Lane 1. In many conditions, the number of passing vehicles in Lane 1 was considerably more. Researchers sat in the client car and took periodic 10-minute counts of the traffic in Lane 1 to estimate when a sufficient sample had been acquired.

Data from all of the lane occupancy videos was later reduced by creating an entry in a spreadsheet for each condition indicating the lane position (Lane 1, 2, or 3) of each vehicle when they passed a point in the roadway at the rear of the client vehicle (or where that point would have been when neither the truck or client car were deployed).

Figure 8. Lane occupancy camera.

Figure 9. Camera position for lane occupancy camera without truck or client car deployed.

Speed and Lateral Position in Lane 1. Measurement of the speed of vehicles in Lane 1 and their lateral position within the lane required a complex approach. Conventional speed measurement techniques, such as roadside radar, could not be used because it would have been impossible to separate the radar returns from target vehicles in Lane 1 from other vehicles. Overhead radars that count traffic and measure speed in multiple lanes could not be used because there was neither an overpass nor a full-width overhead sign on which to attach a measurement unit. Roadway-mounted tubes were also precluded because the State of Connecticut would not approve their use on Route 25 and therefore would not have issued a permit for the data collection to take place. Deriving speed from frame-by-frame analysis of video data was also considered, but the data reduction task appeared daunting given the number of vehicles and their velocity.

Likewise, measurement of lateral position in Lane 1 presented a challenge without the option of putting tubes or other sensors on the roadway. The use of markings was considered for lateral position measurement from a video, but as with frame counting for speed, the resources required to reduce this data was excessive.

A literature search was initiated to find alternative techniques that were less labor intensive and capable of measuring speed and lateral position. Several promising approaches were identified that combined video with artificial intelligence (AI) analysis of the video. Given the need to capture data both day and night and at a high frame rate (frames per second—fps), a special camera and AI software capable of analyzing the lower quality images produced by night videography were required.

Ultimately, International Road Dynamics, Inc. (IRD), of Saskatchewan, Canada, was identified as a study partner because of the relative maturity of their AI system and their interest in assisting the development of a measurement technique for the study.

IRD implemented a road traffic video analysis process based on their AI and computer vision techniques to automatically estimate and gather vehicle data from video. Data included vehicle count, vehicle speed estimation, and relative vehicle lateral distance from the edge of the road (fog line). The process was applied to vehicles in Lane 1. IRD also helped in the selection of an infra-red (IR) camera and a set of three IR illuminators used to light the passing vehicles so they could be recorded by the camera without the drivers being aware of the illumination. The selected camera was a GoPro® Hero 7 modified by a third-party provider to respond to IR light.

The object detection component of IRD's software was used to locate objects of interest (i.e., vehicles) with coordinates defining a bounding box on the video frame image (see Figure 10). The Tracking component tracked a specific identified object of interest over multiple video frame images. Additional software implemented logic to determine the movement of the specific object from frame to frame.

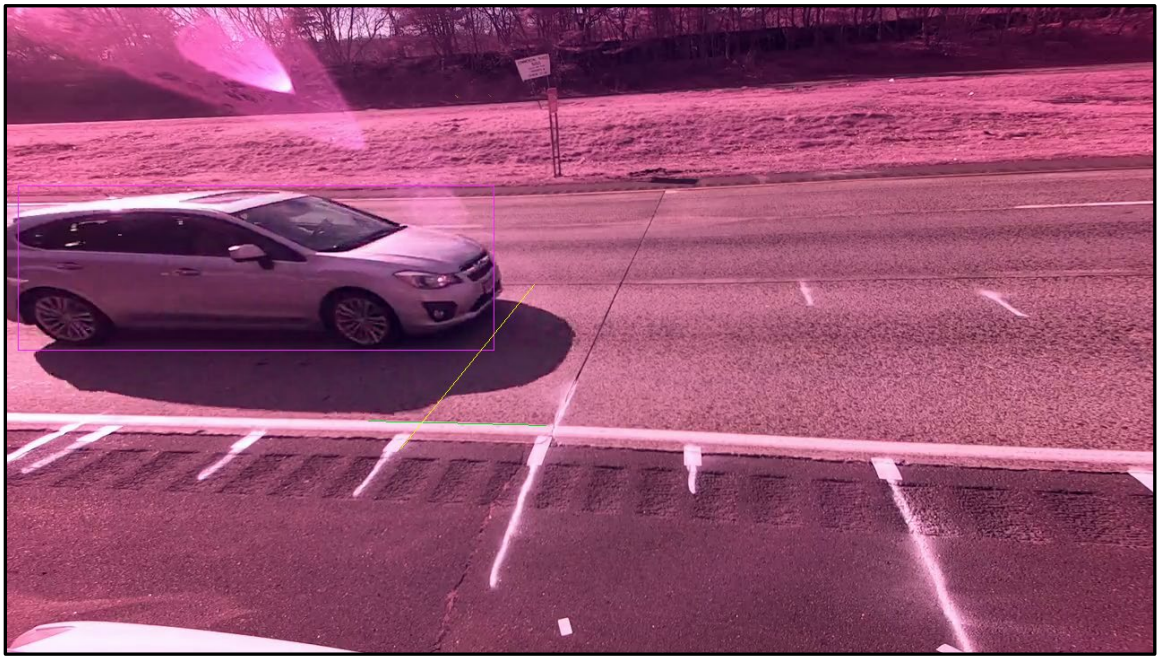

Figure 10. Daylight frame from Hero 7 IR camera showing bounding box and reference line.

Operationally, the IR camera was mounted on a 6 ft (1.83 m) long galvanized pole attached to the front bumper of the wrecker. The camera mount included a light shade to shield the camera from the flashing lights on top of the wrecker (see Figure 11). The camera was oriented parallel to the roadway surface and approximately perpendicular to the direction of travel. Ten marks a meter apart centered on the position of the camera were placed on the fog line of the roadway using bright, white tape supplemented by white spray paint as also shown in Figure 10. The AI system was trained to use these marks as a reference to estimate vehicle speed.

To calculate vehicle speed, the road markings were used to assist with identifying and calibrating start and end lines in the video frame image. Vehicle travel time was calculated by the number of frames of video it took the vehicle to travel from the start line to the end line based on the frame rate of the recorded video (120 fps). To account for vehicle

movement between video frames, interpolation calculations were performed at both the start and stop lines to obtain an adjusted fractional frame count for improved accuracy. The resulting vehicle speed was then calculated from the distance divided by the travel time. The calibration of the system was highly dependent on the position and field of view of the camera in relation to the reference marks on the roadway. Although the reference marks stayed in place throughout the several days of data collection, it was not possible to place the truck and camera into precisely the same position for each of the three data collection sessions. Thus, the calibration of the absolute values of speed were different across the three sessions; however, the relative difference in speed within a session was reliable.

Figure 11. IR camera and light shade mounted on front bumper of wrecker.

To estimate the lateral distance of each vehicle, the speed start line was used as a common reference line across the lane. The intersection point of the location where the bounding box crossed the reference line was then calculated. The distance of the intersection point from the lane edge reference (painted fog line) was calculated in pixels within the video image. A higher number of pixels indicates that the vehicle was farther away from the lane edge. As with the speed measurements, slight variations in camera position from session-to-session altered the calibration of the lateral position measurements and the ability to compare conditions across the three sessions. Comparisons within each of the three data collection sessions, however, were all accomplished with the same setup and, hence, the same calibration.

The resulting data collection and processing of speed and lateral position data included over nine hours of video captured at a resolution of 1920x1080, 120 fps, and with the "wide" field of view setting of the Hero 7 to maximize the number of visible reference lines.

Finally, given the positioning requirements, it was not possible to use this system to collect data on speed and lateral position on the roadway in the baseline condition with no truck present. This was not a problem with the lane occupancy camera, whose position was shown earlier in Figure 9, because its precise position was not critical as long as it clearly showed all three lanes at the point where the truck would have been parked.

Data Collection

The study collected data across four sessions on three days: December 14, 2021 (Sessions 1 and 2), December 16, 2021 (Session 3), and December 21, 2021 (Session 4), 2021. The weather was clear with excellent visibility for all of the data collection sessions.

Data was collected in each of the data collection sessions as follows:

- Session 1:
  - Daylight with no truck or countermeasures (unperturbed roadway)
  - Daylight with truck lights in Daytime light pattern
  - Daylight with truck lights in Daytime light pattern plus flares
  - Daylight with truck lights in Daytime light pattern plus cones
- Session 2:
  - Night with truck lights in Daytime light pattern plus flares
  - Night with truck lights in Daytime light pattern plus cones
- Session 3:
  - Night with truck lights in Daytime light pattern
  - Night with truck lights in Nighttime light pattern
  - Night with truck lights in Nighttime light pattern plus flares
  - Night with truck lights in Nighttime light pattern plus cones
- Session 4:
  - Night with no truck or countermeasures (unperturbed roadway).

Analyses

To determine whether vehicles moved out of Lane 1 in response to the application of each test condition, researchers performed chi-square tests on lane occupancy data. These tests compared the count of vehicles in Lane 1 to the count of vehicles in Lanes 2 and 3 combined in a 2 x 2 design. Additional analyses using one-way between-subjects ANOVAs compared speed and lateral distance of vehicles that remained in Lane 1. Researchers used the IBM SPSS Statistics 26.0 package for all analyses. It should be noted that the ANOVAs were only computed on data from the same data collection setups/camera positions. Thus, any differences in speed or lateral position reported can be considered true effects, free of any possible artifacts resulting from changes in camera position.

The primary focus of each analysis was whether there was a significant difference between the applicable reference condition and a countermeasure condition. The baseline condition (i.e., without the truck or client car present) was the reference for evaluating the

effectiveness of Daytime or Nighttime lights. When evaluating the added effect of flares of cones, these light conditions were the reference conditions. By approaching the analyses in this manner, the additive effect of truck light settings, as well as flares and cones, could be assessed. Since speed and lateral position data could not be collected for the baseline conditions, these measures are only referenced to the conditions with just the wrecker and one light pattern.

Evaluation Results

This section presents the results of the data analyses organized by each condition studied starting with the effect of just the truck and client car alone. When applicable, the results of all measures—lane occupancy, speed, and lateral position—are reported.

As discussed earlier, researchers applied chi-square tests to 2x2 contingency tables that compared the counts in Lane 1 and Lanes 2 and 3 combined under both a reference condition and a countermeasure condition. For simplicity, the tables in this section do not display all four cells of the 2 x 2 design; rather, they show only the counts for Lane 1 and the percentage they represent of the total counted vehicles. The counts and percentage of vehicles in the outside lanes can be calculated by subtracting the reported counts from the N in each condition and subtracting the reported percentage in each condition from 100. The chi-square or ANOVA values for each table are presented below the table itself.

Lane Occupancy Results

Effect of Truck and Client Car Alone. The initial analyses examined the lane occupancy data to determine if the presence of the wrecker with its Daytime light pattern reduced the proportion of cars in Lane 1, compared to daylight baseline conditions (i.e., without the truck or car on the shoulder). The Nighttime light pattern was not tested during the day because it was not intended for that use case. Table 1 shows that the presence of the truck displaying the Daytime light pattern was associated with a significant shift of vehicles (25%) from Lane 1 into Lanes 2 or 3.

Table 1. Truck with Daytime light pattern during the day

Condition	Count	%	% Difference from Daytime Baseline
Daytime Baseline (N = 3,103)	1192	38.4%	
Truck with Daytime Lights (N = 1,417)	409*	28.9%	−25%

*Significantly different from daytime baseline.
X^2 (1, N = 4,520) = 38.79, $p < .001$

Table 2 shows the effects of the truck with each of its light patterns at night. In this instance, the Daytime light pattern was tested at night because it is representative of the current, widely-used system. The data show that both light patterns were associated with large and significant lane shifts. The difference between the Daytime and Nighttime light patterns was also tested and was not significant, X^2 (1, N = 1,260) = 0.06, $p = .80$.

Table 2. Truck with Daytime and Nighttime light patterns at night

Condition	Count	%	% Difference from Nighttime Baseline
Nighttime Baseline (N = 1,558)	687	44.1%	
Truck with Daytime Lights (N = 693)	179*	25.8%	−41%
Truck with Nighttime Lights (N = 567)	150*	26.5%	−40%

*Significantly different from nighttime baseline.
Daytime light pattern — X^2 (1, N = 2,251) = 67.60, $p < .001$
Nighttime light pattern — X^2 (1, N = 2,125) = 54.18, $p < .001$

Effect of Truck Plus Flares or Cones During the Day. These analyses examined the effect of adding flares or cones to the truck with the Daytime light pattern during the day. As can be seen in Table 3, neither flares nor cones produced a significant change in the occupancy of Lane 1. In fact, both were associated with slight increases in the proportion of vehicles in Lane 1, but the change was not significant. The Nighttime light pattern was not examined during the day as it was not a designed for this use case.

Table 3. Truck with Daytime light pattern plus flares or cones during the day

Condition	Count	%	% Difference than Truck with Daytime Lights
Truck with Daytime Lights (N = 1,417)	409	28.9%	
With Flares (N = 1,016)	317	31.2%	+8%
With Cones (N = 1,206)	359	29.8%	+3%

Daytime lights vs. + flares — X^2 (1, N = 2,433) = 1.54, $p = .21$
Daytime lights vs. + cones — X^2 (1, N = 2,623) = 0.26, $p = .61$

Effect of Truck Plus Flares or Cones During the Night. Both the Daytime and Nighttime light patterns were relevant for night testing. The Daytime pattern was representative of the majority of wreckers in use, and the Nighttime pattern was intended to improve on the performance of the emergency lights by reducing their masking effect. Table 4 shows the results for the Daylight light pattern. When flares were added to the wrecker displaying the Daytime light pattern at night, the occupancy of Lane 1 decreased significantly beyond the level already achieved by the truck and Daytime lights alone. The addition of cones, however, produced only a very small additional reduction that did not reach statistical significance.

Table 4. Truck with Daytime light pattern plus flares or cones at night

Condition	Count	%	% Difference than Truck with Daytime Lights
Truck with Daytime Lights (N = 693)	179	25.8%	
With Flares (N = 1,034)	194*	18.8%	−27%
With Cones (N = 1,211)	275	22.7%	−12%

*Significantly different ($p < 0.05$) than truck with Daytime lights
Daytime lights vs. + flares — X^2 (1, N = 1,727) = 12.24, $p < .001$
Daytime lights vs. + cones — X^2 (1, N = 1,904) = 2.37, $p = .12$

Table 5 shows similar testing at night of the Nighttime light pattern. When paired with the Nighttime light pattern, both flares and cones yield a large and statistically reliable shift out of Lane 1 beyond what occurred with the truck alone. Recall from Table 2 that the

wrecker with either the Daytime and Nighttime light pattern produced large and essentially equivalent shifts out of Lane 1 by themselves. Thus, the cumulative positive effect of the Nighttime light pattern and the flares or cones is especially noteworthy.

Table 5. Truck with Nighttime light pattern plus flares or cones at night

Condition	Count	%	% Difference than Truck with Nighttime Lights
Truck with Nighttime Lights (N = 567)	150	26.5%	
With Flares (N = 903)	125*	13.8%	−48%
With Cones (N = 631)	109*	17.3%	−35%

*Significantly different ($p < 0.05$) than truck with Nighttime lights
Nighttime lights vs. + flares — X^2 (1, N = 1,470) = 36.43, $p < .001$
Nighttime lights vs. + cones — X^2 (1, N = 1,198) = 14.86, $p < .001$

Speed and Lateral Position Results

Measures of speed and lateral position in Lane 1 were available to compare the addition of flares or cones to the wrecker alone with the Daytime light pattern during the day and with either the Daytime or Nighttime light pattern at night. The results of the ANOVAs to examine these results are shown below in terms of miles per hour (mph) for speed and pixels (px) measured from the collected video for lateral position.

Effect of Truck Plus Flares or Cones During the Day. Table 6 presents the mean differences and ANOVA daytime results from the truck with the Daylight light pattern alone, the truck plus added flares, and the truck plus added cones. It can be seen from the table that both the flares and the cones were associated with small increases in passing vehicle speeds, which is not desirable. Only the increase for cones, however, was statistically reliable. The lateral distance of the passing traffic did improve (increase) but did not reach significance for either the flares or cones.

Table 6. Truck with Daytime light pattern speed and lateral position during the day

Measure	Lane 1 Speed	Lane 1 Distance from Fog Line
Flares	+0.66 mph	+2.53 px
Cones	+1.43 mph*	+2.87 px

*Significantly different ($p < 0.05$) than truck alone with Daytime lights
Speed: $F(2, 1121) = 4.97$, $p < .01$
Pixels: $F(2, 1125) = 1.63$, $p = .20$

Effect of Truck Plus Flares or Cones During the Night. Tables 7 and 8 present results for data collected at night with the Daytime and Nighttime light patterns, respectively. As seen in Table 7, the measures go significantly in the wrong direction when flares and cones are added to the Daytime light pattern at night. The changes were small, but the statistical reliability of all four measures is suggestive of a real phenomenon.

Table 7. Truck with Daytime light pattern speed and lateral position at night

Measure	Lane 1 Speed	Lane 1 Distance from Fog Line
Flares	+2.86mph*	−15.17px*
Cones	+6.84mph*	−16.64px*

*Significantly different ($p < 0.05$) than truck with Daytime lights
Speed: $F(2, 671) = 23.09$, $p < .001$
Pixels: $F(2, 671) = 46.59$, $p < .001$

With the Nighttime light pattern active on the truck, the results are quite different from those observed with the Daytime pattern. As shown in Table 8, both flares and cones show decreases in Lane 1 speed, although only the decrease with flares reached statistical reliability. Flares also resulted in a larger lateral distance of passing vehicles while cones actually yielded a small decrease in that measure. Neither of the lateral distance changes reached statistical reliability.

Table 8. Truck with Nighttime light pattern speed and lateral position at night

Measure	Lane 1 Speed	Lane 1 Distance from Fog Line
Flares	−4.25mph*	+2.34px
Cones	−2.58mph	−1.07px

*Significantly different ($p < 0.05$) than truck with Nighttime lights
Speed: $F(2,416) = 5.71$, $p < .01$
Pixels: $F(2,416) = 0.96$, $p = .38$

Evaluation Discussion

Several observations can be gleaned from the current results with potentially important benefits for road service operational safety. First, the emergency lights on the wrecker, regardless of whether displaying the Daytime or Nighttime patterns, appear effective in prompting motorists to move left out of Lane 1. The fact that the two light patterns performed essentially equivalently at night when no other countermeasures were present is important, especially when considering the addition of flares or cones. The demonstrated ability of the Nighttime light pattern to permit both flares and cones to provide an additional enhancement during hours of darkness appears to be a true net benefit. It also suggests that the design objective for the Nighttime light pattern of reducing the masking effect of overly bright emergency lights was apparently achieved without any negative side effects with respect to the evaluation measures examined.

Neither flares nor cones produced reductions in Lane 1 occupancy during the day. Thus, the results of this study do not support the promotion of their daytime use in situations such as were studied herein (limited access highway, 3 lanes in each direction with large median, 55 mph speed limit). The ability of flares to yield a significant reduction in Lane 1 occupancy at night with either light pattern suggests they may be a productive addition to the safety protocol for highway service workers. Likewise, the additional Lane 1 occupancy reductions produced by cones at night when paired with the Nighttime light pattern suggests that both countermeasures should be considered for night use. Clearly, use protocols prepared by industry specialists will be needed for the safe deployment and retrieval of cones and the deployment of flares, and the various on-road emergency service

providers will have to accept the benefits of the Nighttime light pattern and start converting their fleets to its use.

Caution is warranted when interpreting the speed and lateral position results, given several limitations of the data. First, measurements were only taken for motorists who did not respond to the site displays by changing lanes. Thus, the speed and lateral position measurement population was a group of drivers who saw the wrecker and could not (because of adjacent traffic) or chose not to comply with the law by moving over. Alternatively, those drivers could have been oblivious to the test site despite its high conspicuity. Second, only one speed measurement was taken. Hence, the measured drivers could, in fact, have slowed down from a higher speed in response to seeing the emergency lights far in advance and simply not have slowed further given the addition of flares or cones. Given the large lane change response of motorists, it is not unreasonable to assume that the measured speeds and lateral positions with the truck only are an improvement from the values when the truck and client car were absent from the road.

A remaining unknown from this testing is the extent to which the deployed countermeasures increased the awareness of motorists of the existence of the road service site and prompted them to pay more attention to it. The totality of the results, including the absence of speed reductions in Lane 1, suggest that more drivers may have been attending to the site more intently even if they did not outwardly display this attention by altering their position and speed. If this is the case, the benefit of the Nighttime light pattern in revealing more detail of the contents of the site, as suggested by the lane occupancy response to cones at night with the Nighttime light pattern, is a further reason to consider use of the automatic Daytime and Nighttime light patterns.

Survey of Industry Personnel

A second objective of this project was to assess the extent to which current road service technicians are willing to use some of the countermeasures tested in the on-road study—cones and flares—and to identify factors that could potentially increase their use, such as research evidence, company policies, and legal or administrative requirements. The results of the online survey of towing and recovery industry personnel offer insight into to promoting these effective countermeasures.

Sample Recruitment

The target population for the survey was individuals 18+ years of age who are currently working in the towing and road service industry in any capacity, whether or not they are current road service technicians. Respondents were solicited through the AAA Roadside Service Information (RSI) website or via email invitations. The RSI site provides subscribers with key vehicle-specific service information regarding jump-starts, tire service (air and spare installations), fuel delivery, and all aspects of towing (e.g., attachment points, vehicle weights and dimensions, securing for transport recommendations). The subscribers consist primarily of towing providers or individuals in the roadside service industry and other emergency road service providers such as fire departments. Additionally, email solicitations were sent to over 200 providers in the AAA Federation.

Survey Implementation

The survey was created using SurveyMonkey. Once respondents clicked through to the survey, they were first provided with a brief welcome and consent statement. The survey then asked how long they had worked in the towing and road service industry in any capacity. If they selected the response "I don't work in the towing and road service industry," the survey was terminated. Otherwise, they proceeded into the questionnaire that covered the following topic areas:

- Classification items (e.g., age, sex, State, years in the industry, years as a technician, current job description)
- Overall view of the importance of the slow down and move over laws
- Overall view of the compliance of the motoring public with the slow down and move over laws
- Existence of a requirement for cones/flares in their jurisdiction or place of work
- Experience using cones/flares
- Current use of cones/flares
- Intended future use of cones/flares if supported by research evidence
- Intended future use of cones/flares if supported by research evidence, and required by a company policy
- Current availability of cones/flares on respondent's company's trucks and in current inventory
- Overall opinion of cones/flares as a safety countermeasure
- Training received on the use of cones/flares

Appendix A to this report contains the entire survey, including flow logic details. A respondent was free to skip any item they did not wish to answer. The survey took an average of 5 minutes to complete.

Survey Results

Sample Description

In total, 30 survey responses were received from the RSI website and 197 responses from the emails, resulting in a sample of 227 respondents; however, not all respondents answered all of the questions. Since the survey was intended for individuals currently working in the towing and road service industry, those who did not meet this criteria were excluded from the remainder of the analyses (from Table 9, 19 respondents [8.4% of the total sample] were excluded). The one individual who did not answer the tenure question, did answer subsequent questions and was retained. Thus, the resulting analysis sample had a maximum sample size of 208 respondents. These respondents were drawn from 38 states.

Table 9. How long have you worked in the towing and road service industry in any capacity?

Years in Industry (any capacity)	Count	%
Less than 2 years	10	4.4
2-5 years	17	7.5
6-9 years	19	8.4
10 or more years	161	70.9
I don't work in the towing and road service industry	19	8.4
No answer	1	0.4
Total	**227**	**100.0**

Of the 208 towing industry respondents, only 133 answered the question about their gender. The sample was predominantly male (73.7%), with 25 reporting female (18.8%), two respondents reporting their gender as non-binary (1.5%), and the remaining eight respondents (6.0%) selecting that they preferred not to answer.

The average age of the 121 respondents who provided an age was 51.96 years (*SD* = 12.50 years). The 91 reporting males were slightly older than the 23 reporting females, with a mean age of 52.81 years (*SD* = 12.34 years) for males compared to a mean of 49.26 years (*SD* = 13.48 years) for females. The two non-binary respondents averaged 56.50 years *(SD* = 13.44 years), and the five people who preferred not to indicate their gender but did report age averaged 47.00 years (*SD* = 10.89 years).

Of the 208 towing industry respondents, 202 reported the number of years as a roadside service technician. Table 10 shows the responses to the roadside service technician tenure question. As can be seen in Table 10, over half of the respondents (54.5%) had worked 10 or more years as a roadside service technician.

Table 10. During your career, how many years have you spent as a roadside service technician?

Years as Roadside Service Technician	Count	%
None	47	23.3
Less than 2	14	6.9
2-5 years	17	8.4
5-9 years	14	6.9
10 or more years	110	54.5
Total	**202**	**100.0**

Respondents were also asked to report their current primary job description. Of the 199 participants who responded, 144 (73.9%) were owners/management not currently involved in roadside service.

Slow Down and Move Over Laws

Participants were asked to rate how important it was to have laws that require motorists to slow down and move over for tow trucks and emergency vehicles. Of the 195 participants who responded, the vast majority (95.4%) indicated it was very important to have such laws in place. When asked how well motorists obey these laws and slow down and move over, most respondents (76.3% out of the 193 who responded) indicated either poor or very poor compliance on the part of motorists.

Traffic Cones

Cone Requirements and Roadside Service Technician Use. Participants were asked whether there was a state or local law, regulation, or company policy requiring cones to be carried on tow trucks. Of the 189 participants who responded, 37.6% reported "No," 40.2% reported "Yes," and 22.2% answered "Not Sure." The most common kind of requirement reported was a company policy with 55.8% (53 of 74) of participants who reported a cone requirement indicating it was a company policy.

Participants' reported cone usage differed according to the presence or absence of cone requirements. These results are summarized in Table 11, which excludes 42 participants who were unsure of the existence of a cone requirement. The majority of participants (59.3%) report using cones occasionally or frequently. Of respondents who report being subject to a cone requirement, 80% indicate they use cones occasionally or frequently. The equivalent percentage of occasional or frequent use for those who report no such requirement is 41.3%. Notably, only one person (1.6%) of those not subject to a requirement to use cones used them frequently compared to 26 participants (47.3%) of those covered by a requirement.

Table 11. *Which answer best describes your experience deploying cones as a tow technician or light service technician?*

			I've never used them	I used them in the past but don't anymore	I currently use them occasionally	I currently use them frequently	Total
Is there a state or local law, regulation, or company policy where you work that requires cones to be carried on a tow truck?	No	Count	31	6	25	1	63
		Row N %	49.2%	9.5%	39.7%	1.6%	100.0%
		Column N %	83.8%	54.5%	58.1%	3.7%	53.4%
	Yes	Count	6	5	18	26	55
		Row N %	10.9%	9.1%	32.7%	47.3%	100.0%
		Column N %	16.2%	45.5%	41.9%	96.3%	46.6%
	Total	Count	37	11	43	27	118
		Row N %	31.4%	9.3%	36.4%	22.9%	100.0%
		Column N %	100.0%	100.0%	100.0%	100.0%	100.0%

Participants were asked to report in which kinds of situations they used cones and were permitted to select as many of the listed situations as applied. Responses were spread fairly evenly across the different situations among the 85 participants reporting, with between 30 and 60 participants indicating each situation. The most frequent situations—indicated by more than two thirds of respondents—were on hilly or 2-lane roads, at night, in bad weather, when traffic is heavy or fast, when the client vehicle is partially off the road, and when on site more than a few minutes. Appendix A presents the response distribution.

Nearly half of the 85 respondents reported they typically deploy three cones at a time, while more than a quarter reported deploying more than three cones.

Motivators to Use Cones. The survey also explored several motivators of the use of cones, including research on the effectiveness of this countermeasure (e.g., if studies showed that they enhanced safety), a company policy requiring its use, and other factors. Table 12 summarizes the likelihood of respondents regularly using cones in response to research findings suggesting they are effective. Over half of respondents overall (56.9%) would probably or definitely use cones if research suggested they were effective. Further, 70.8% of respondents with less than 10 years of experience in the industry and 50.0% of those with 10 or more years of experience would probably or definitely use cones in response to positive research results.

Table 12. If research showed that cones moved many more vehicles out of the lane closest to the shoulder than a tow truck with flashing lights alone, would you use them regularly?

			Definitely would not	Probably would not	I'm not sure	Probably would	Definitely would	Total
Experience Level	>10 years	Count	0	2	5	5	12	24
		Row N %	0.0%	8.3%	20.8%	20.8%	50.0%	100.0%
		Column N %	0.0%	14.3%	33.3%	27.8%	52.2%	33.3%
	10+ years	Count	2	12	10	13	11	48
		Row N %	4.2%	25.0%	20.8%	27.1%	22.9%	100.0%
		Column N %	100.0%	85.7%	66.7%	72.2%	47.8%	66.7%
	Total	Count	2	14	15	18	23	72
		Row N %	2.8%	19.4%	20.8%	25.0%	31.9%	100.0%
		Column N %	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

This line of investigation was expanded upon with a question assessing the combined influence of research evidence of effectiveness and a company policy requiring cone use. Results are summarized below in Table 13. Note that the percentage of respondents who probably or definitely would use cones increased from 56.9% to 74.3% when company policy was added to research evidence. Those with less than 10 years of experience still were more likely to indicate they probably or definitely would use cones (87.0%) than those with more than 10 years of experience (68.1%).

Table 13. If research showed that cones moved many more vehicles out of the lane closest to the shoulder than a tow truck with flashing lights alone and your company required their use in appropriate situations, would you use them regularly?

			Definitely would not	Probably would not	I'm not sure	Probably would	Definitely would	Total
Experience Level	>10 years	Count	1	0	2	4	16	23
		Row N %	4.3%	0.0%	8.7%	17.4%	69.6%	100.0%
		Column N %	33.3%	0.0%	20.0%	25.0%	44.4%	32.9%
	10+ years	Count	2	5	8	12	20	47
		Row N %	4.3%	10.6%	17.0%	25.5%	42.6%	100.0%
		Column N %	66.7%	100.0%	80.0%	75.0%	55.6%	67.1%
	Total	Count	3	5	10	16	36	70
		Row N %	4.3%	7.1%	14.3%	22.9%	51.4%	100.0%
		Column N %	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Respondents were asked to indicate which factor(s) from a list of potential motivators would motivate them to use cones more frequently. Results of this item are summarized in Figure 12. The top three motivators were ease of deployment (37.5% of respondents), ease of retrieval (31.3% of respondents), and a law requiring use (28.1% of respondents).

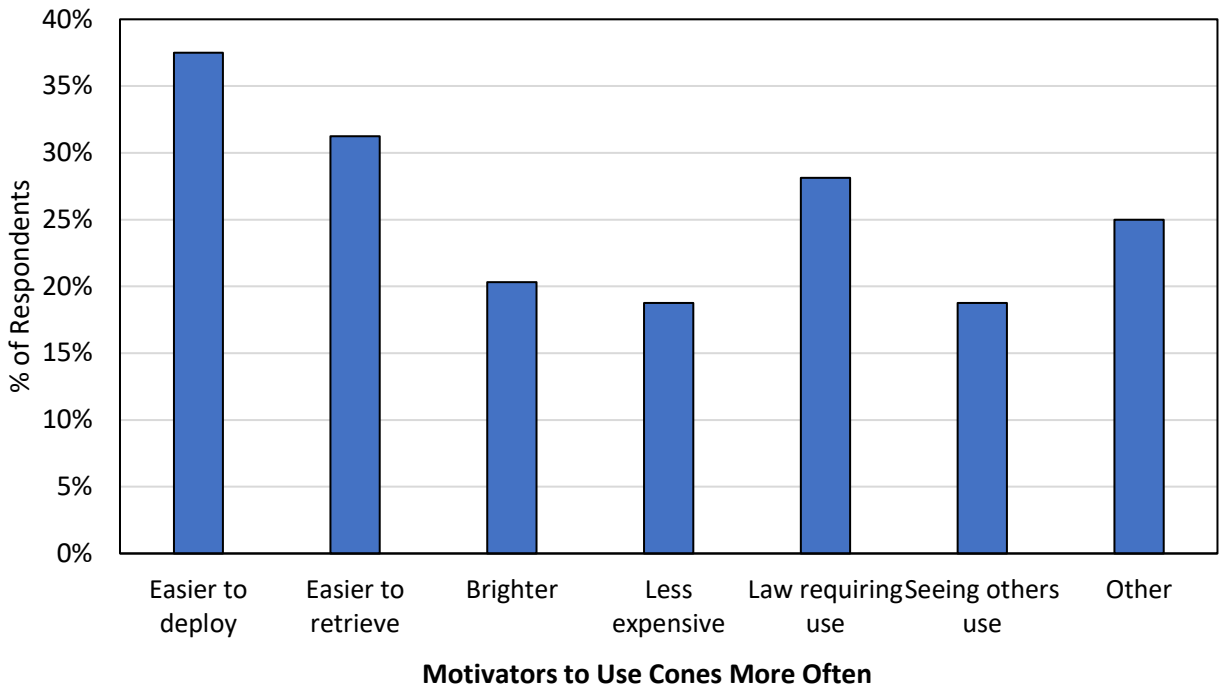

Figure 12. Which of the following would motivate you to use cones more often (check all that apply)? (N=64)

Sufficient Cones in Inventory and on Tow Truck. Respondents including management and non-service workers were asked about how often cone inventory at their garage was sufficient, and the most typical response of the 162 respondents was "Almost all the time" (43.2%), followed by "Most of the time" (24.7%). This pattern was not reflected, however, when the question involved how often at least 3 cones were on the actual tow truck. Of the 160 respondents to this question, the most common response was "Most of the time" (37.5%). The second most common was "Almost never" (24.4%).

Overall Opinion of Cones. When asked for their overall opinion on cones, most agreed that cones improve safety and very few of the 158 respondents (16.2%) indicated that using cones rarely or never helps in terms of safety.

Flares

Flare Requirements and Roadside Service Technician Use. Participants were asked about the FMCSA requirement to carry flares on tow trucks, and a large majority (86.3%) of the 159 participants who responded to this question indicated awareness of this requirement. Awareness of state or local law, regulation, or company policy requiring flares to be carried on tow trucks was affirmed by 21.8% of the 156 respondents to the question, with 44.2% not being aware and 34.0% not being sure. Similar to cones, the most common kind of requirement reported was a company policy with 31.8% of the 33 participants acknowledging such a requirement.

The next section of the survey focused on flare usage. Participants' reported usage differed according to the presence or absence of flare requirements. These results are summarized

below in Table 14, which excludes the 53 participants that were unsure of the existence of a flare requirement.

Table 14. Which answer best describes your experience deploying flares as a tow technician or light service technician?

			I've never used them	I used them in the past but don't anymore	I currently use them occasionally	I currently use them frequently	Total
Is there a state or local law, regulation, or company policy where you work that requires flares to be deployed on the roadway when a tow truck is stopped and giving assistance?	No	Count	25	12	18	3	58
		Row N %	43.1%	20.7%	31.0%	5.2%	100.0%
		Column N %	86.2%	70.6%	66.7%	27.3%	69.0%
	Yes	Count	4	5	9	8	26
		Row N %	15.4%	19.2%	34.6%	30.8%	100.0%
		Column N %	13.8%	29.4%	33.3%	72.7%	31.0%
	Total	Count	29	17	27	11	84
		Row N %	34.5%	20.2%	32.1%	13.1%	100.0%
		Column N %	100.0%	100.0%	100.0%	100.0%	100.0%

As evident from Table 14, slightly less than half of all participants reported using flares at least occasionally (45.2%). This was composed of 65.4% of respondents who reported a flare requirement imposed by their company or locality and 36.2% of respondents who reported no such requirement.

Similar to cones, participants were then asked to report in which kinds of situations they used flares. Responses were spread out less evenly across the different situations as compared to cone deployment among the 63 participants reporting, with between 10 and 48 participants indicating each situation. The most frequent situation—indicated by more than three in four respondents—was at night, while more than half indicated they had used flares on 2-lane roads, when traffic is heavy or fast, during dusk/dawn, in bad weather, and when on site more than a few minutes. Appendix A presents this response distribution.

The typical number of flares deployed was also investigated, and similar to cones, the most common response of the 64 respondents was 3 flares at a time (39.7%).

Motivators to Use Flares. The survey also explored several motivators of the use of flares, including research on the effectiveness of this countermeasure, a company policy requiring its use, and other factors. Table 15 summarizes the likelihood of respondents regularly using flares in response to research findings suggesting they are effective. As evident from Table 15, 45.5% of respondents would probably or definitely use flares if research suggested they were effective. This was composed of 63.2% of respondents with less than 10 years of experience and only 36.1% of those with 10 or more years of experience.

Table 15. If research showed that flares moved many more vehicles out of the lane closest to the shoulder than a tow truck with flashing lights alone, would you use them regularly?

			Definitely would not	Probably would not	I'm not sure	Probably would	Definitely would	Total
Experience Level	>10 years	Count	1	4	2	4	8	19
		Row N %	5.3%	21.1%	10.5%	21.1%	42.1%	100.0%
		Column N %	25.0%	30.8%	15.4%	28.6%	72.7%	34.5%
	10+ years	Count	3	9	11	10	3	36
		Row N %	8.3%	25.0%	30.6%	27.8%	8.3%	100.0%
		Column N %	75.0%	69.2%	84.6%	71.4%	27.3%	65.5%
	Total	Count	4	13	13	14	11	55
		Row N %	7.3%	23.6%	23.6%	25.5%	20.0%	100.0%
		Column N %	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

As with cones, this line of investigation was expanded upon with a question assessing the combined influence of research evidence of effectiveness and a company policy requiring flare use. Results are summarized in Table 16. Note that the percentage of respondents who probably or definitely would use flares increased from 45.5% to 66% when company policy was combined with research evidence. Those with less than 10 years of experience still were more likely to indicate they probably or definitely would use flares (73.7%) than those with more than 10 years of experience (61.7%). This pattern is similar to that found with the questions on research impact and company policy for cones.

Table 16. If research showed that flares moved many more vehicles out of the lane closest to the shoulder than a tow truck with flashing lights alone and your company required their use in appropriate situations, would you use them regularly?

			Definitely would not	Probably would not	I'm not sure	Probably would	Definitely would	Total
Experience Level	>10 years	Count	1	3	1	4	10	19
		Row N %	5.3%	15.8%	5.3%	21.1%	52.6%	100.0%
		Column N %	33.3%	37.5%	14.3%	33.3%	43.5%	35.8%
	10+ years	Count	2	5	6	8	13	34
		Row N %	5.9%	14.7%	17.6%	23.5%	38.2%	100.0%
		Column N %	66.7%	62.5%	85.7%	66.7%	56.5%	64.2%
	Total	Count	3	8	7	12	23	53
		Row N %	5.7%	15.1%	13.2%	22.6%	43.4%	100.0%
		Column N %	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Respondents were also asked to indicate which factor(s) from a list of potential motivators would motivate them to use flares more frequently (Figure 13). Similar to cones, ease of deployment (30.2% of respondents) and a law requiring use (30.2% of respondents) were two of the top three motivators for respondents to use flares more frequently. Unlike the case with cones, which are reusable, expense was the top motivator for flares with 35.8% of respondents selecting this factor.

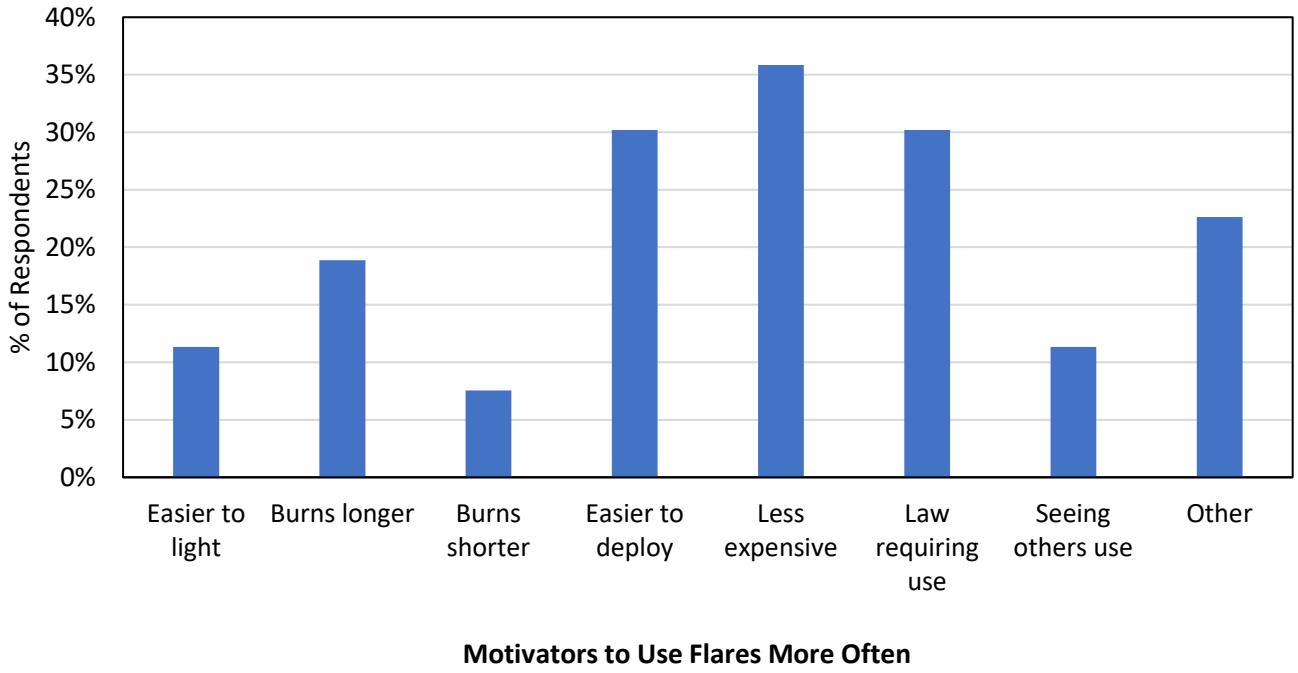

Figure 13. What would motivate you to use flares more often? (check all that apply) (N=53).

Sufficient Flares in Inventory and on Tow Truck. Sufficient standing inventory of flares was examined, and the most typical response of the 137 respondents was "Almost all the time" (40.1%), with the second most typical response being "Almost never" (21.9%). It appears inventory of flares is more often insufficient when compared to inventory of cones. In contrast with cone availability, the two most reported frequencies of having at least 6 flares on tow trucks were "Almost all the time" (30.6%) and "Almost never" (29.9%) among the 134 respondents.

Opinion on Flares. Most respondents agreed that, overall, flares improve safety. Only 7.0% of the 133 respondents indicated that using flares rarely or never helps make operations safer.

Training

The final sections of the survey focused on training. Just over half of respondents reported having taken training on the use of cones as a tow or light service technician, while less than one third reported they had taken training on the use of flares, with the vast majority from employers occurring on the job or during onboarding. Among those who had been trained on the use of cones or flares, around one third indicated their most recent training for each countermeasure was in the past year, while more than a quarter reported it had been more than five years since they had training on cones, and more than four in ten reported their last training on flares was similarly long ago. See Appendix A for the full distributions of responses.

Survey Discussion

A survey was conducted to collect attitudinal data from a sample of roadside service industry personnel regarding slow down and move over laws, as well as attitudinal and likely use data on cones and flares. Results of the survey suggest that overall industry personnel attitudes towards these countermeasures are largely favorable and the majority use countermeasures such as flares and cones in a variety of situations. Similar factors such as making deployment easier and laws requiring use were indicated by respondents as motivators for regularly using flares and cones. Making cone retrieval easier and reducing expense of flares were also particularly popular motivators. Critically, respondents report being likely to regularly use these countermeasures if research evidence suggested that they were effective and even more so if a company policy were combined with such research evidence. This particular finding suggests the importance of educating roadside service personnel of the results of the on-road study and implementing company policies that encourage or require the use of research-supported countermeasures that protect roadside service personnel. The fact that roadside service personnel with less experience are more favorable towards both cones and flares cannot be readily explained. Perhaps cumulative negative experiences have colored the opinions of longer-serving respondents. Another possibility is that more tenured staff have seen the supply problems reported for both cones and flares and do not believe they are "worth the hassle."

Overall, however, the survey results are encouraging that the widespread dissemination of the results of the on-road study together with management acknowledgement of the need to use cones and/or flares in the form of a rule or policy should increase their use and increase the protection of road service workers.

Countermeasure Review

Another objective of this project was to examine the state-of-the-art of countermeasures with potential to reduce the risk of crashes between roadside service technicians and incident response personnel and passing vehicles. This involved an assessment of the availability of the countermeasure, its technology readiness, its cost, and its amenability to valid research to determine its effectiveness. Countermeasures that could be applied to the worker (e.g., high visibility vests), the work vehicle (e.g., display boards), the work site (e.g., lighted cones), or the oncoming motorist's vehicle (e.g., a message warning of an upcoming incident site) were considered.

Review Approach

As a first step, the research team examined a number of sources that might address relevant countermeasures. Table 17 presents the types of sources that were examined.

Table 17. Types of Countermeasure Review Sources and their Content.

Type of Source	Content
Trade magazines, "newsstand magazines," and other non-scholarly publications	Novel countermeasures; new uses of "conventional" countermeasures
Pending or approved patents/small business innovative research (SBIR) results	Analytically assessed countermeasures including new approaches at a low technology readiness level
Pending or approved legislation	Proposed, recently passed, and novel legislation
Networking with local and international government representatives	Countermeasures unavailable from other sources
Networking with professional organizations	Countermeasures unavailable from other sources

Project staff queried patents, and pending or approved legislation, and networked with local/international government representatives and/or experts and contacts from professional organizations to seek additional promising approaches that have yet to be discussed in the literature.

A form was developed and used to document relevant information for each countermeasure identified through the sources in Table 17. Table 18 presents each category of information that was coded along with its operational definition. In addition to the information in Table 18, staff also made an overall assessment of the pros/cons of each countermeasure.

Table 18. Countermeasure Idea Form Definitions

Information Category	Operational Definition
Domain	Transportation environment(s)—including roadway, marine, aviation, and railroad—from which the idea was derived
Description (including relevant internet links)	Narrative explanation and example of use
Level of evidence	Extent countermeasure has been evaluated and context of the evaluation (e.g., whether it was assessed in the roadside incident response domain).
Technology readiness	Maturity of countermeasure components (ranging from idea to commercial-off-the-shelf (COTS))
Development time still required	Extent of additional development time before towing company could test or use
Cost/time to deploy/install	Resources required to prepare for use (based on actual COTS prices or a staff estimate of the likely types and general magnitude of costs required)
Cost/time to maintain	Resources required in continued use (based on actual COTS prices/data or a staff estimate of the likely types and general magnitude of costs/activities required)
Lighting applicability	Applicability to daytime and/or nighttime use
Mode	Class in which countermeasure primarily functions (education, engineering, or enforcement)
Intention	Immediate goal(s) of use (e.g., increasing conspicuity of worker/work vehicle, slowing down or channeling traffic, preventing collision with worker/work vehicle)

Review Results

The results of the review identified a total of 42 countermeasures for which the details shown in Table 18 were recorded. Of these, 11 could be applied to the worker, 13 each to the work vehicle and work site, and 5 to the oncoming motorist's vehicle. Appendix B contains the complete documentation for these countermeasures.

The countermeasure descriptions were then reviewed by research and sponsor personnel to select ideas that appeared most appropriate for future research (i.e., to be tested in an on-road experiment). Of the 42 ideas, 13 were selected as potential research candidates. Researchers then assessed test feasibility under the current study and possible future test approaches and made a judgment concerning whether the research could be accomplished under pandemic conditions. The results of these assessments are presented in Appendix C.

Review Discussion

The countermeasure review revealed a number of countermeasures that could be applied to the worker, the work vehicle, the work site, or the oncoming motorist's vehicle to protect roadside service and incident response personnel. Some of these were commercial-off-the-shelf (COTS) products that can be purchased currently and others were at various technology readiness levels, ranging from nascent ideas to products under development. Overall, however, the review identified fewer countermeasures than expected, particularly those widely in use by the towing or analogous industries. Moreover, few of the countermeasures, regardless of technology readiness level, appeared to be attractive to the

industry. Simply, the most promising countermeasures from a behavioral change standpoint (both altering passing motorist behavior and promoting widespread technician use) appear to be expensive (e.g., initial cost, maintenance) and/or overly complex (e.g., involving more time for deployment or retrieval). It is for this reason that cones and flares were selected for the on-road test.

When searching for relevant countermeasures, variations of long-standing approaches that were examined in the companion studies, such as cones and flares, were frequently identified, suggesting an acknowledgment of the "legacy" of these approaches and an interest in their enhancement. This is consistent with the results of the companion survey study, which shows that the majority of service technicians currently use classic approaches, such as cones, or are aware that some of these approaches, such as flares, are required to be carried on a tow truck. Finally, the fact that most of the countermeasures that were identified were amenable to verification of effectiveness through research suggests future research involving these countermeasures could expand their acceptance and use. Again, this is consistent with the results of the companion survey study, which showed that many respondents would regularly use countermeasures such as cones and flares if research confirmed their effectiveness.

General Discussion

The three activities of which this study was composed, when taken together, have implications for future efforts to improve the safety of roadside service and incident response personnel. Although the initial countermeasure review activity did not result in countermeasures ready for testing against this study's objectives, it did reveal many promising approaches for potential application to the worker, the truck, or the site. Operational concerns with these ideas included the difficulty of deploying and retrieving the countermeasures. These are some of the same concerns voiced in the survey of industry personnel concerning the use of flares and cones. This suggests that research and development focused on countermeasure deployment and retrieval systems could be productive.

The survey also provided an encouraging note with respect to the use of flares and cones. Respondents indicated an increased willingness to use flares and cones if research indicated that they improve safety. The results of the on-road study provide compelling research evidence in that direction. The dissemination of these results to the operational as well as the research communities would therefore appear warranted.

The significant success of the Nighttime light pattern in the on-road study suggests that further research on its potential benefits in improving the conspicuity of roadside workers, emergency personnel, and high-value equipment would be valuable. Both naturalistic on-road studies such as the one presented here and more controlled studies with eye focus measures and follow-up debriefings of drivers would appear beneficial both for determining the best configuration of the roadside site and for refining the design of emergency light patterns.

New vehicle-based countermeasure ideas (for the tow truck or passing motorist vehicle) and the worker were not considered for testing in this study because of their cost, technology readiness, or complexity. Although that was a reasonable decision given the focus and scope of the current research, it should not be interpreted as a conclusion that these countermeasure approaches are without potential merit. The trend towards a safe system approach to highway safety suggests that many of the countermeasures considered and used for the current study are likely worth pursuing further as research resources become available.

Finally, the study was focused on compliance with the slow down and move over laws, but did not depend on the assumption that most drivers on the road are aware of its existence and requirements. Some of the pattern of behaviors observed could have been the result of drivers detecting and recognizing the work site and simply tracking it better even though they were unaware of their duty to slow down and move over.

Acknowledgements

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Appendix A: Compliance Survey Results by Item

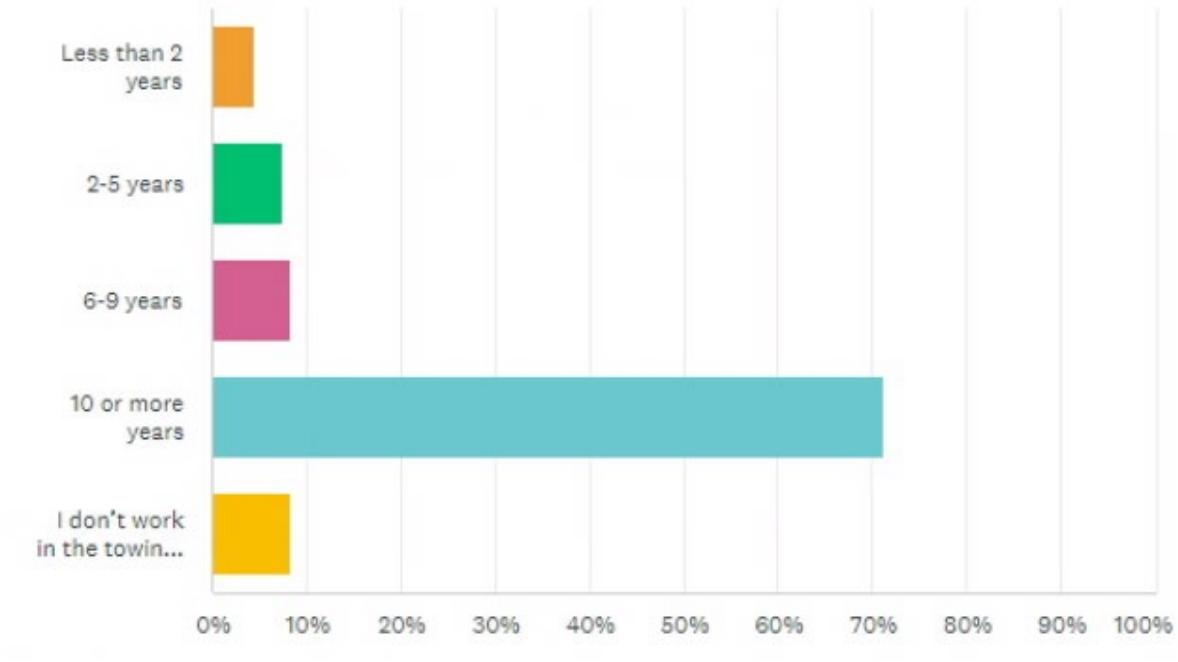
This Appendix presents the compliance survey item wording and results for each item in bar graph form.

Survey Items, Responses, and Summaries

Q1. How long have you worked in the towing and road service industry in any capacity?

- Less than 2 years
- 2-5 years
- 6-9 years
- 10 or more years
- I don't work in the towing and road service industry

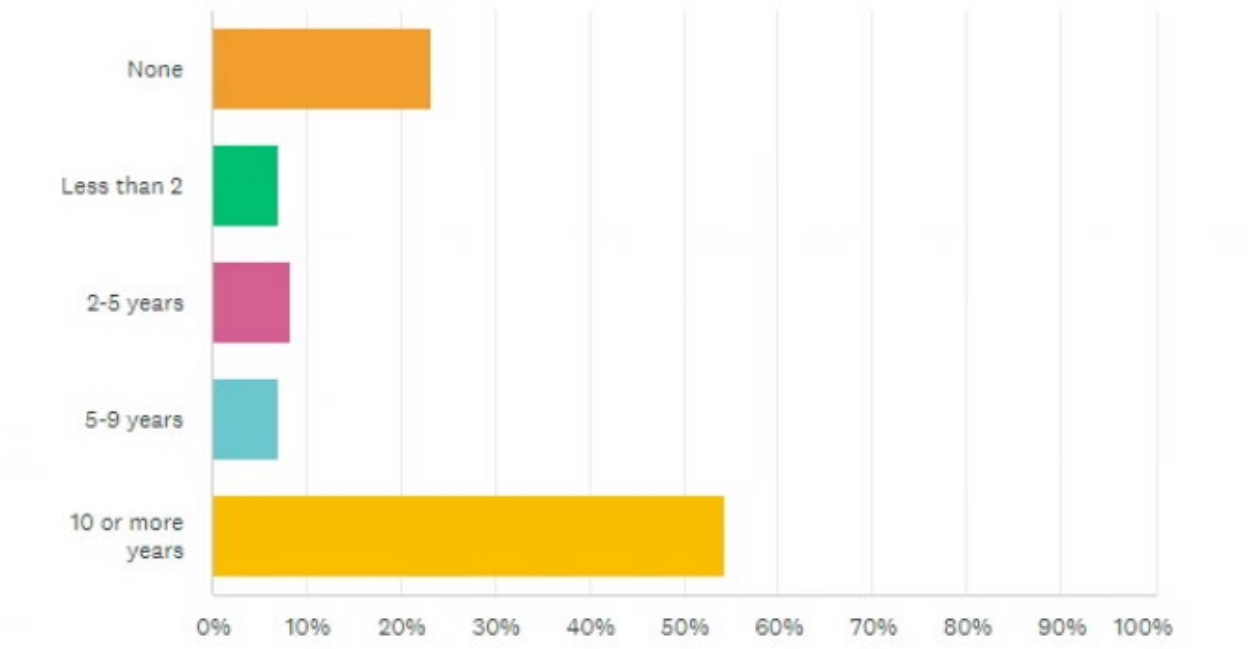
Number of responses = 226



Q2. During your career, how many years have you spent as a roadside service technician?

- None
- Less than 2
- 2-5 years
- 5-9 years
- 10 or more years

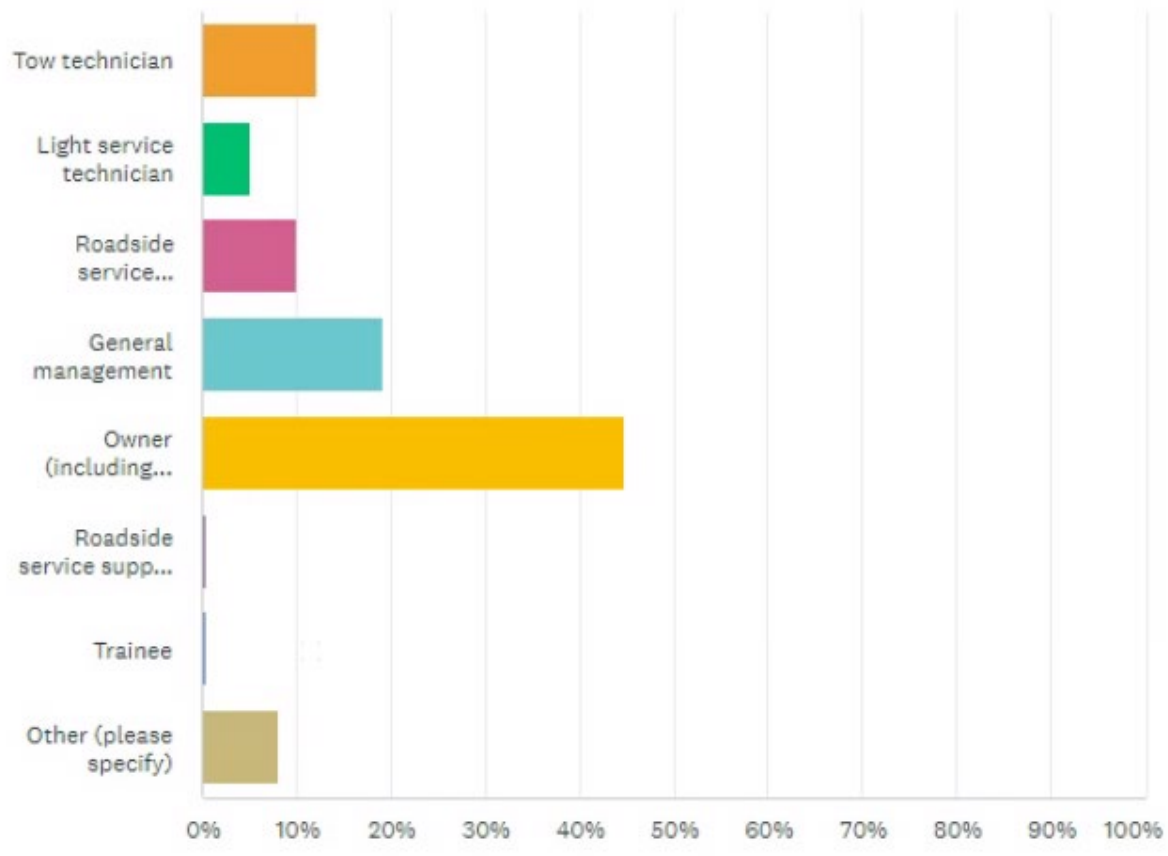
Number of responses = 202



Q3. What is your current primary job description?

- Tow technician
- Light service technician
- Roadside service management
- General management
- Owner (including owner-operator)
- Roadside service support (e.g., mechanic, parts manager)
- Trainee
- Other (please specify)

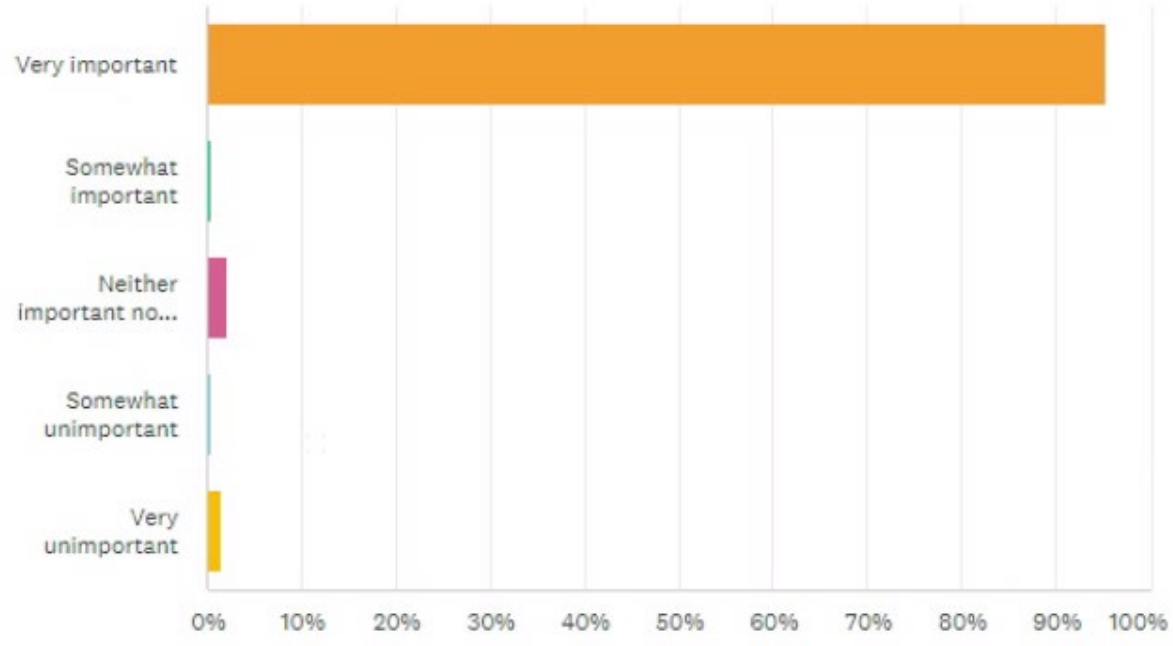
Number of responses = 199



Q4. How important is it to have laws that require motorists to slow down and move over for tow trucks and other emergency vehicles?

- Very important
- Somewhat important
- Neither important nor unimportant
- Somewhat unimportant
- Very unimportant

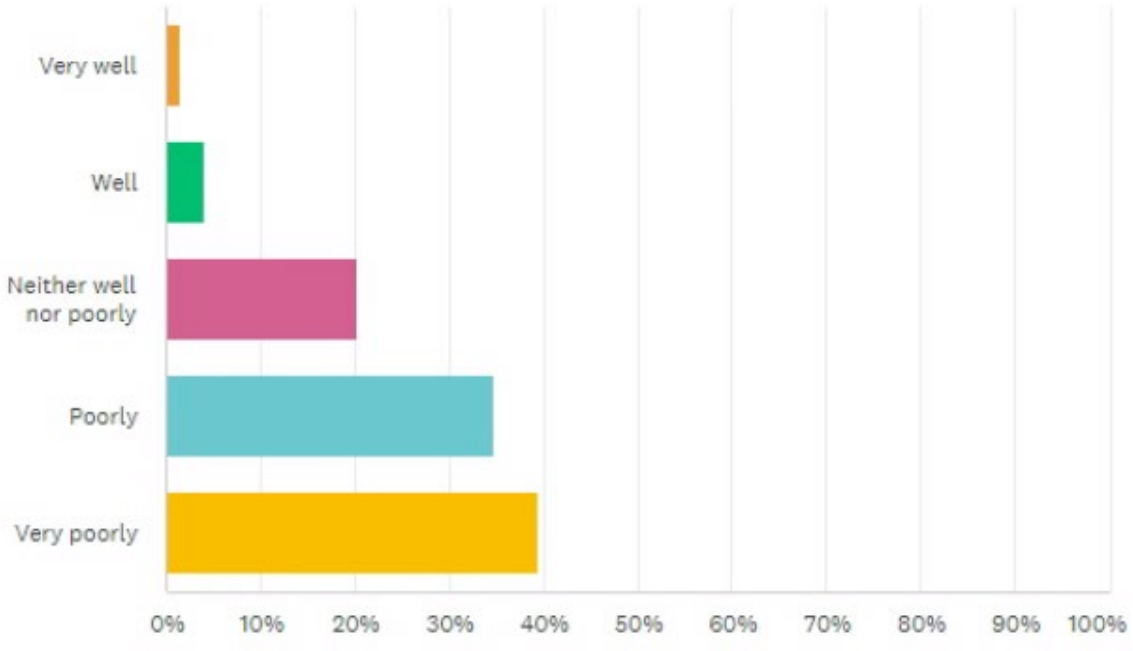
Number of responses = 195



Q5. How well do motorists obey the slow down and move over laws?

- Very well
- Well
- Neither well nor poorly
- Poorly
- Very poorly

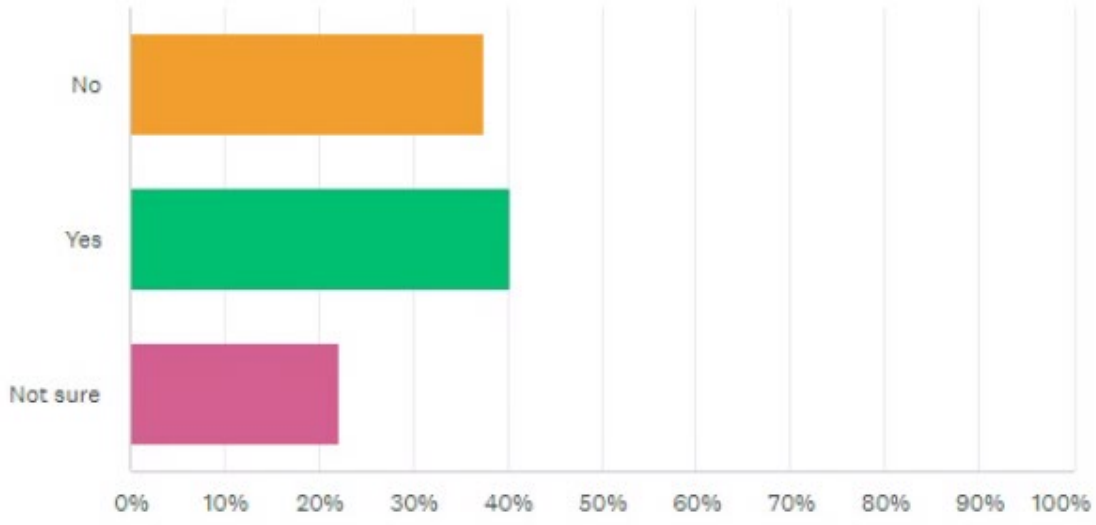
Number of responses = 193



Q6. Is there a state or local law, regulation, or company policy where you work that requires cones to be carried on a tow truck?

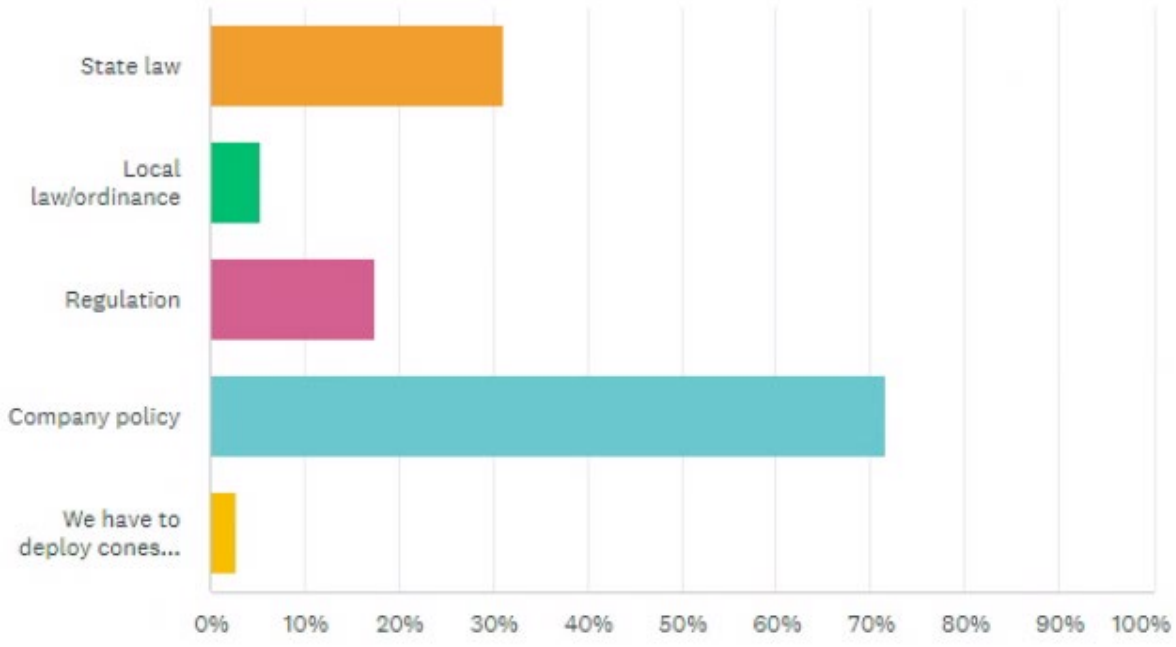
- No
- Yes
- Not sure

Number of responses = 189



Q7. What kind of cone requirement is it? (check all that apply) (N=74)

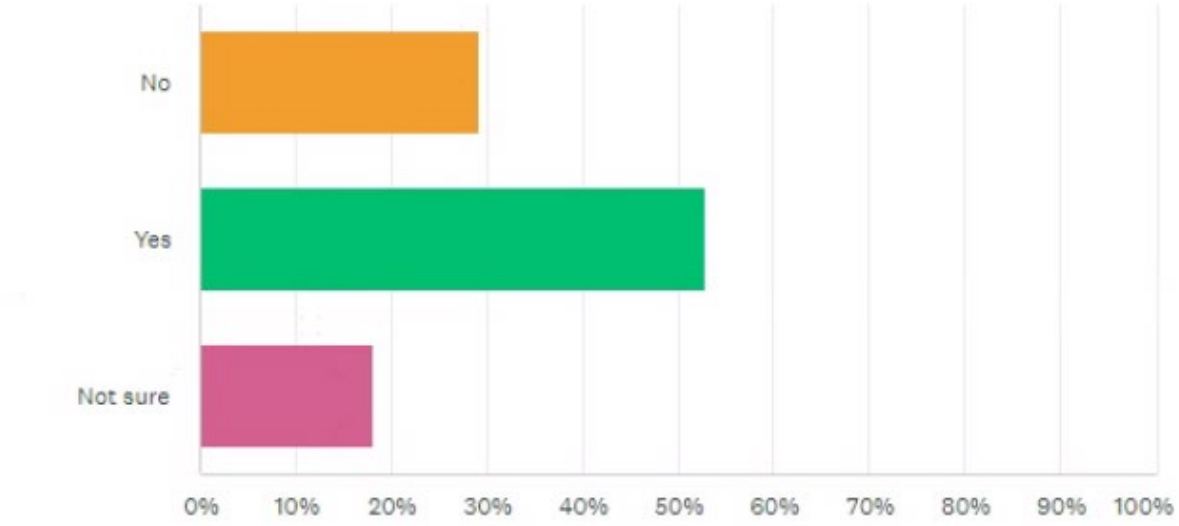
- State law (n=23)
- Local law/ordinance (n=4)
- Regulation (n=13)
- Company policy (n=53)
- We have to deploy cones, but I don't know why (n=2)



Q8. Is there a state or local law, regulation, or company policy where you work that requires cones to be deployed on the roadway when a tow truck is stopped and giving assistance?

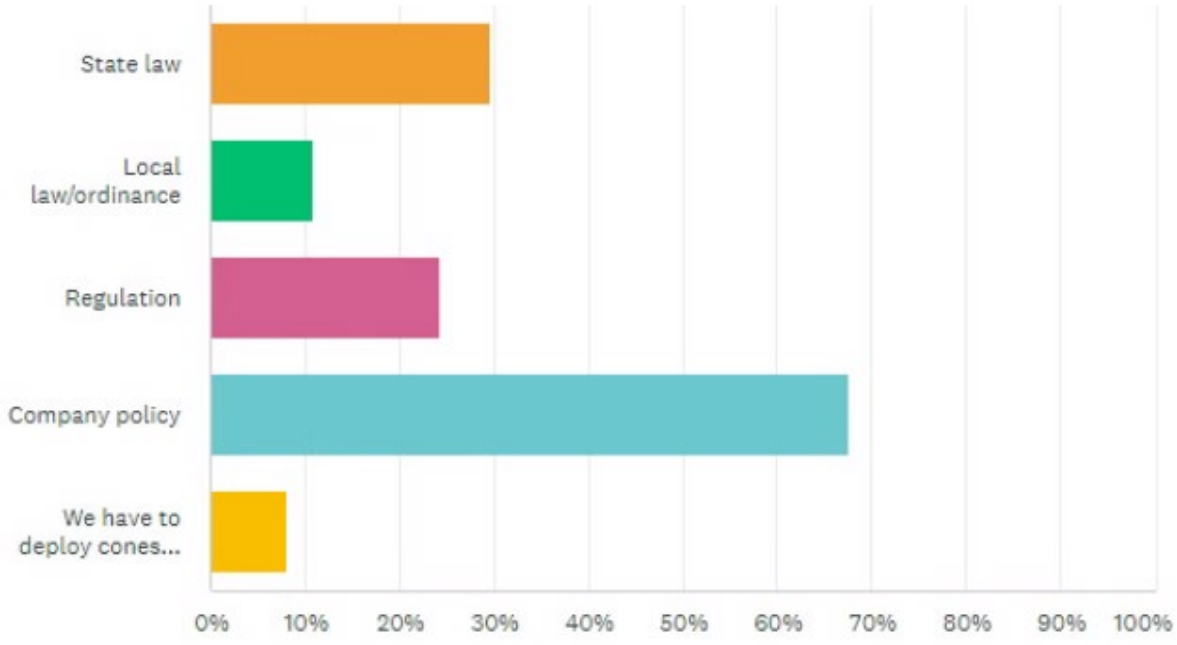
- No
- Yes
- Not sure

Number of responses = 72



Q9. What kind of cone requirement is it? (check all that apply) (N=37)

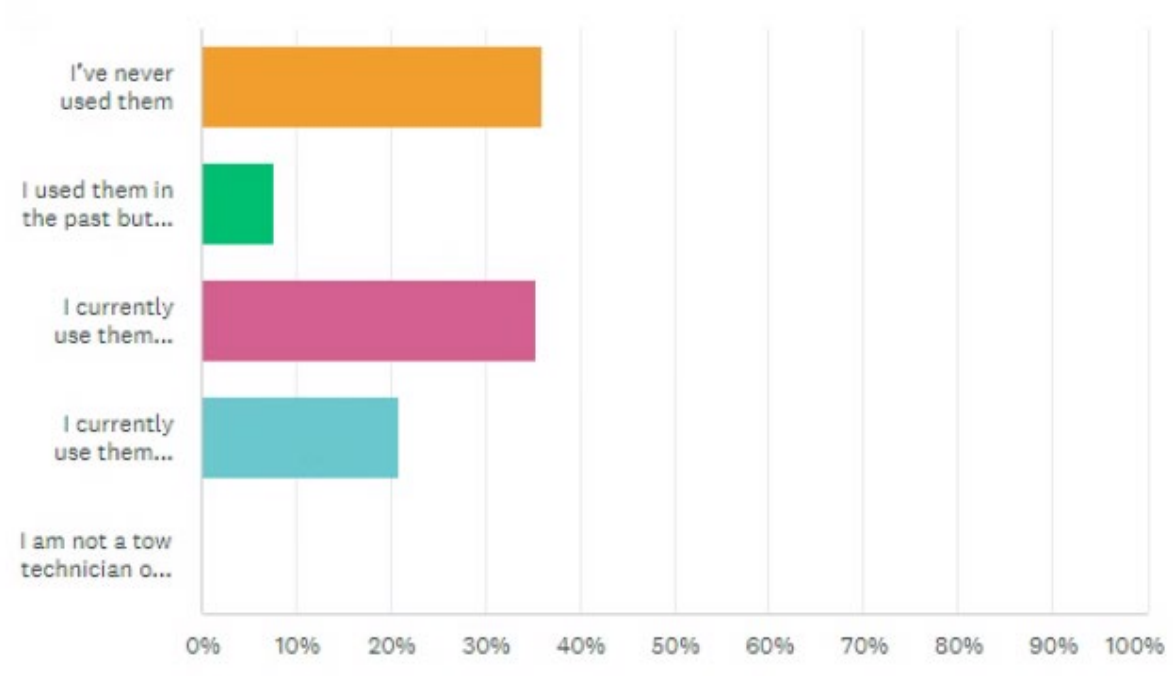
- State law (n=11)
- Local law/ordinance (n=4)
- Regulation (n=9)
- Company policy (n=25)
- We have to deploy cones, but I don't know why (n=3)



Q10. Which answer best describes your experience deploying cones as a tow technician or light service technician?

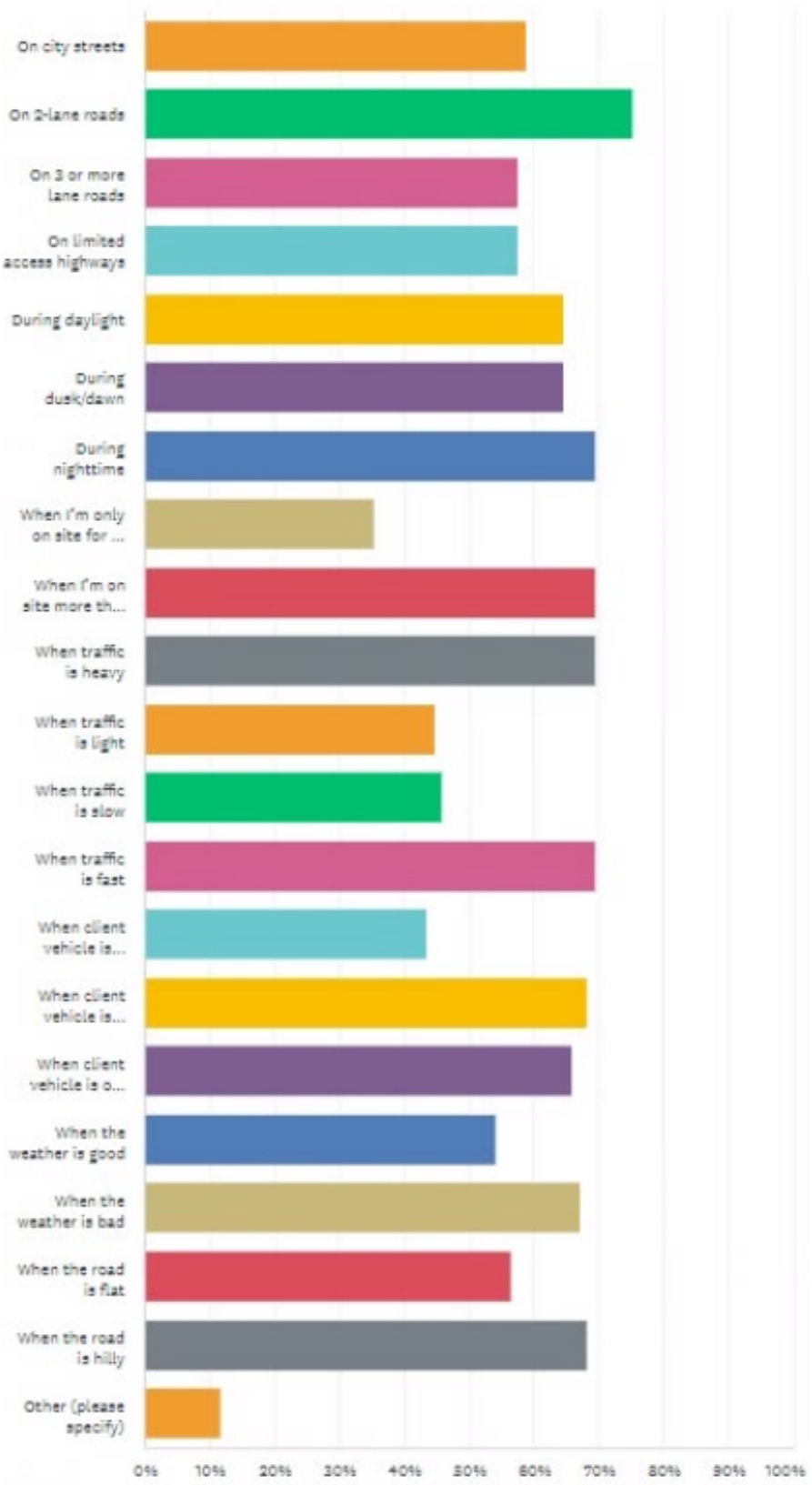
- I've never used them
- I used them in the past but don't anymore
- I currently use them occasionally
- I currently use them frequently
- I am not a tow technician or light service technician

Number of responses = 144



Q11. In which situations have you used cones? (check all that apply) (N=85)

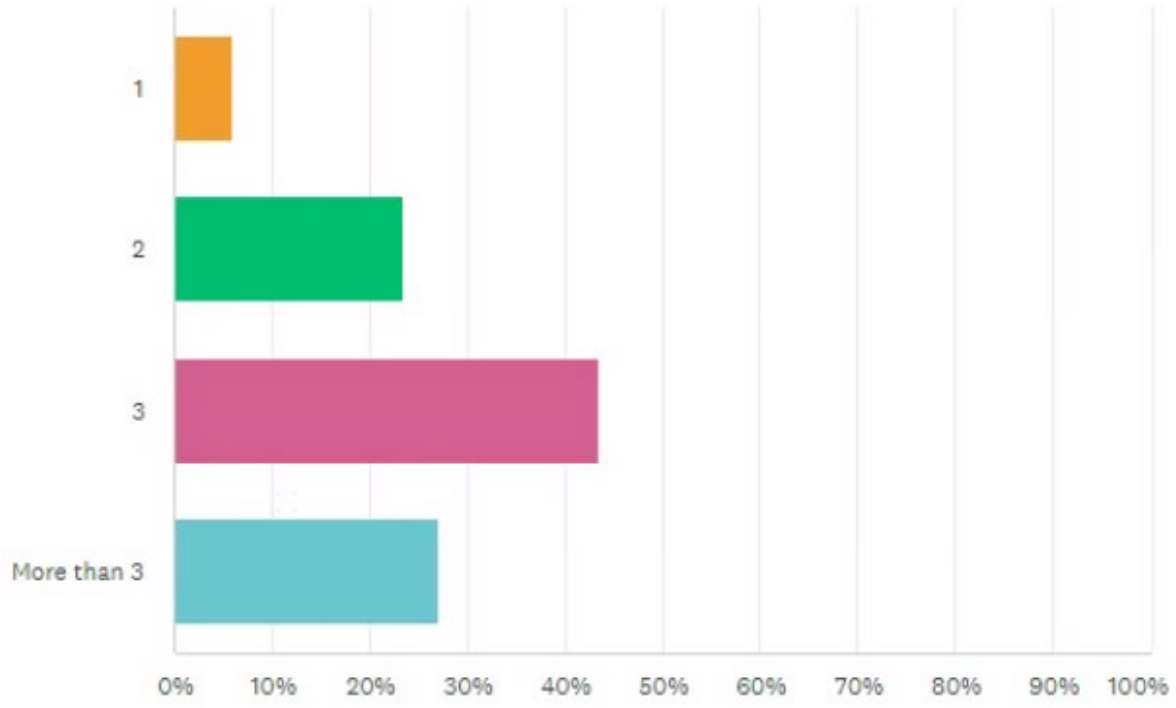
- On city streets (n=50)
- On 2-lane roads (n=64)
- On 3 or more lane roads (n=49)
- On limited access highways (n=49)
- During daylight (n=55)
- During dusk/dawn (n=55)
- During nighttime (n=59)
- When I'm only on site for a few minutes (n=30)
- When I'm on site more than a few minutes (n=59)
- When traffic is heavy (n=59)
- When traffic is light (n=38)
- When traffic is slow (n=39)
- When traffic is fast (n=59)
- When client vehicle is totally off the road (n=37)
- When client vehicle is partially off the road (n=58)
- When client vehicle is on the road (n=56)
- When the weather is good (n=46)
- When the weather is bad (n=57)
- When the road is flat (n=48)
- When the road is hilly (n=58)
- Other (please specify) (n=10)


On city streets
On 2-lane roads
On 3 or more lane roads
On limited access highways
During daylight
During dusk/dawn
During nighttime
When I'm only on site for ...
When I'm on site more th...
When traffic is heavy
When traffic is light
When traffic is slow
When traffic is fast
When client vehicle is...
When client vehicle is...
When client vehicle is o...
When the weather is good
When the weather is bad
When the road is flat
When the road is hilly
Other (please specify)
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%

Q12. When you have used cones, what is the typical number you deployed?

- 1
- 2
- 3
- More than 3

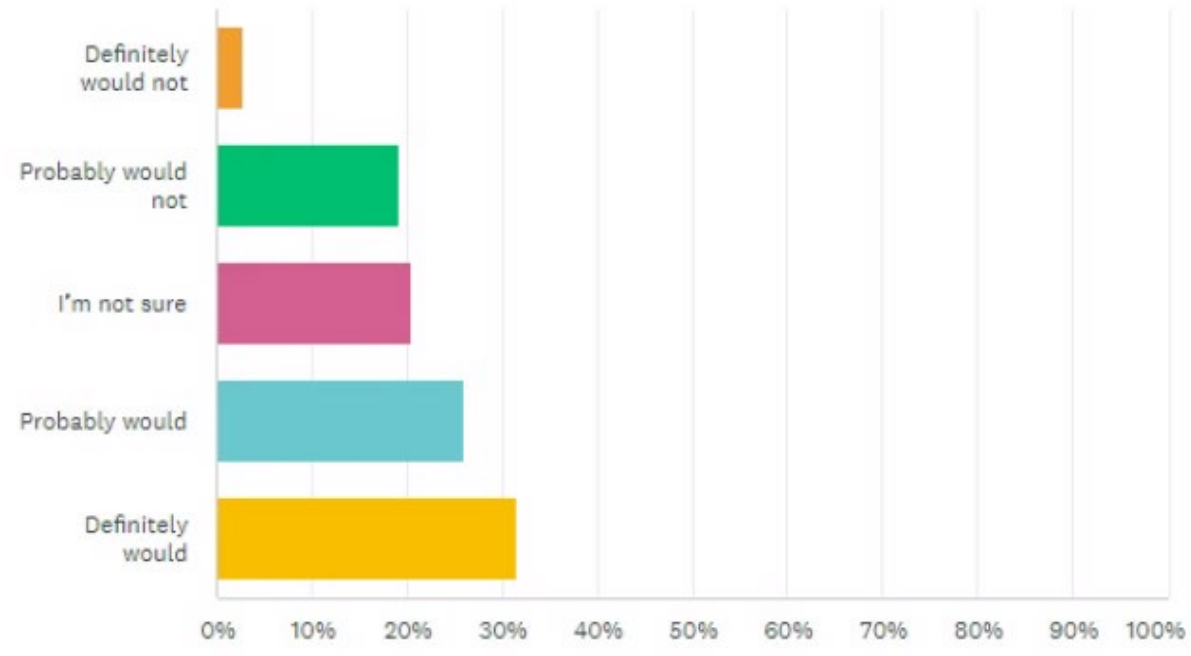
Number of responses = 85



Q13. If research showed that cones moved many more vehicles out of the lane closest to the shoulder than a tow truck with flashing lights alone, would you use them regularly?

- Definitely would not
- Probably would not
- I'm not sure
- Probably would
- Definitely would

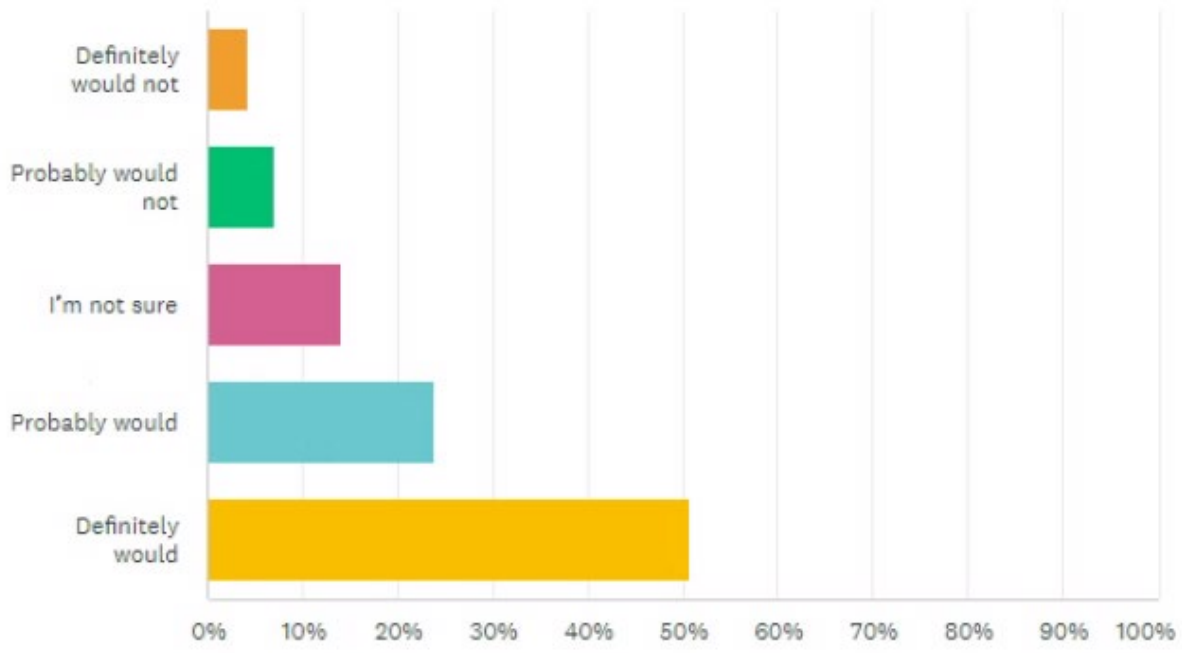
Number of responses = 73



Q14. If research showed that cones moved many more vehicles out of the lane closest to the shoulder than a tow truck with flashing lights alone and your company required their use in appropriate situations, would you use them regularly?

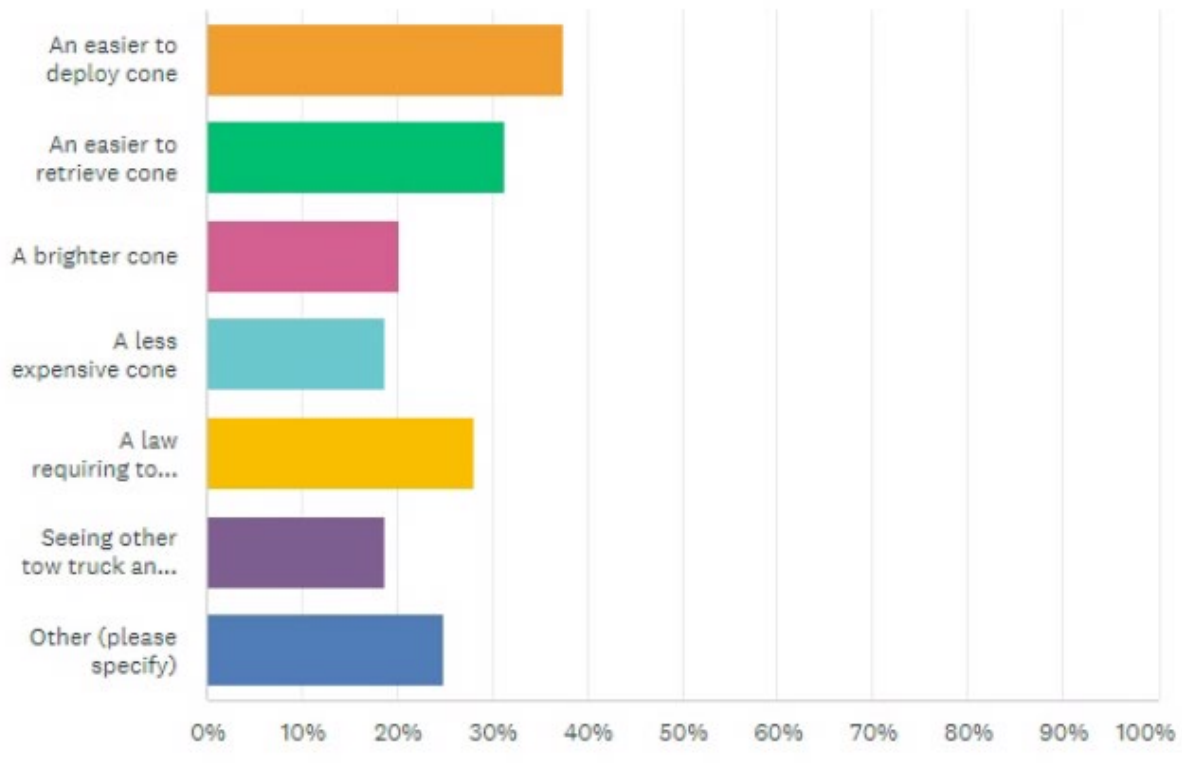
- Definitely would not
- Probably would not
- I'm not sure
- Probably would
- Definitely would

Number of responses = 71



Q15. Which of the following would motivate you to use cones more often? (check all that apply) (N=64)

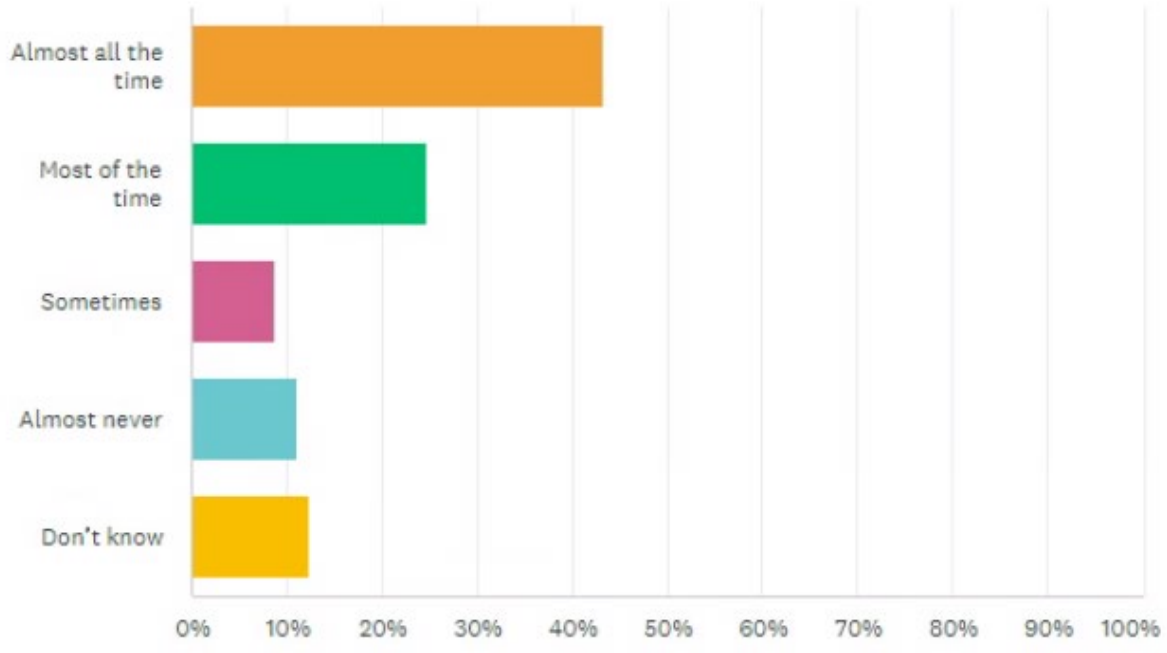
- An easier to deploy cone (n=24)
- An easier to retrieve cone (n=20)
- A brighter cone (n=13)
- A less expensive cone (n=12)
- A law requiring tow truck and light service technicians to use cones (n=18)
- Seeing other tow truck and light service technicians using cones (n=12)
- Other (please specify) (n=16)



Q16. How often are there sufficient cones in inventory at your tow truck garage when you need them?

- Almost all the time
- Most of the time
- Sometimes
- Almost never
- Don't know

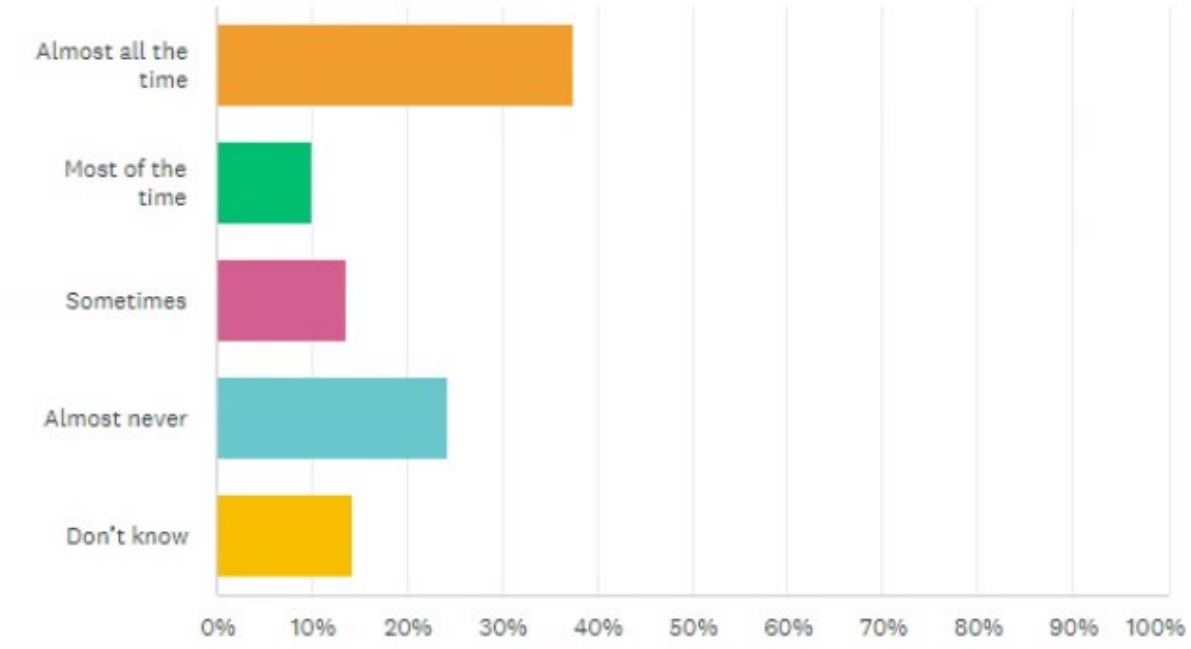
Number of responses = 162



Q17. How often are there at least 3 cones on your company's tow trucks?

- Almost all the time
- Most of the time
- Sometimes
- Almost never
- Don't know

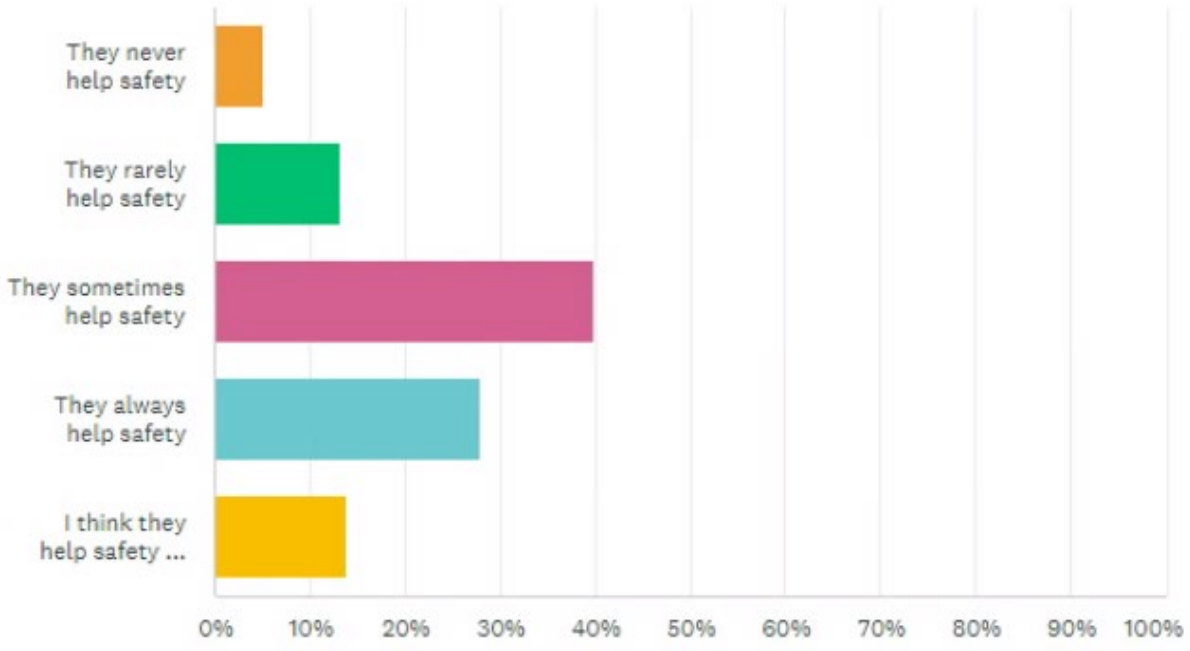
Number of responses = 160



Q18. Which statement best describes your overall opinion of cones for use by tow technicians and light service technicians?

- They never help safety
- They rarely help safety
- They sometimes help safety
- They always help safety
- I think they help safety in the right circumstances (please give examples)

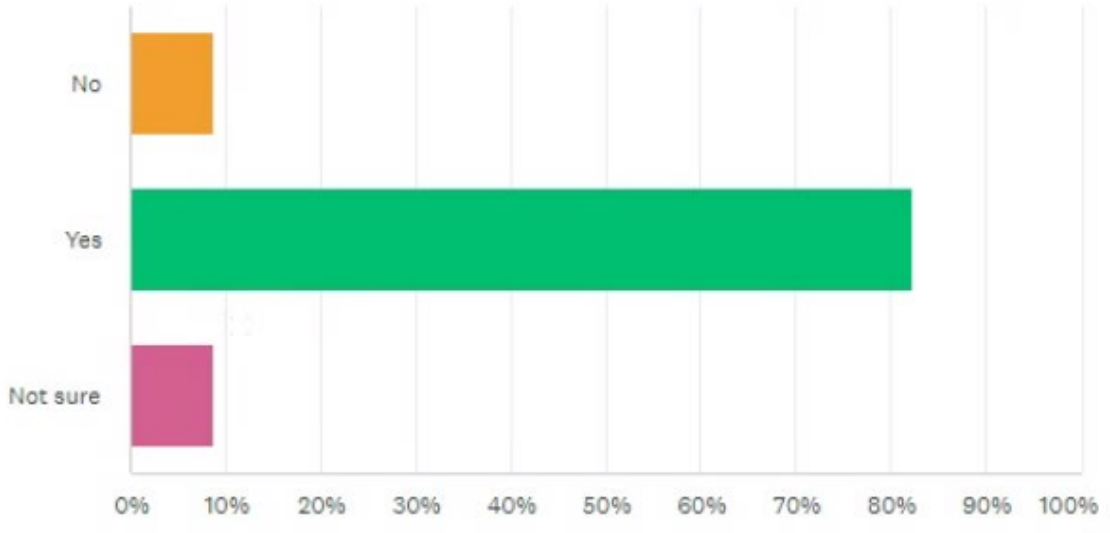
Number of responses = 158



Q19. Are you aware that the Federal Motor Carrier Safety Administration (FMCSA) requires flares and/or retroreflective triangles to be carried on a tow truck?

- No
- Yes
- Not sure

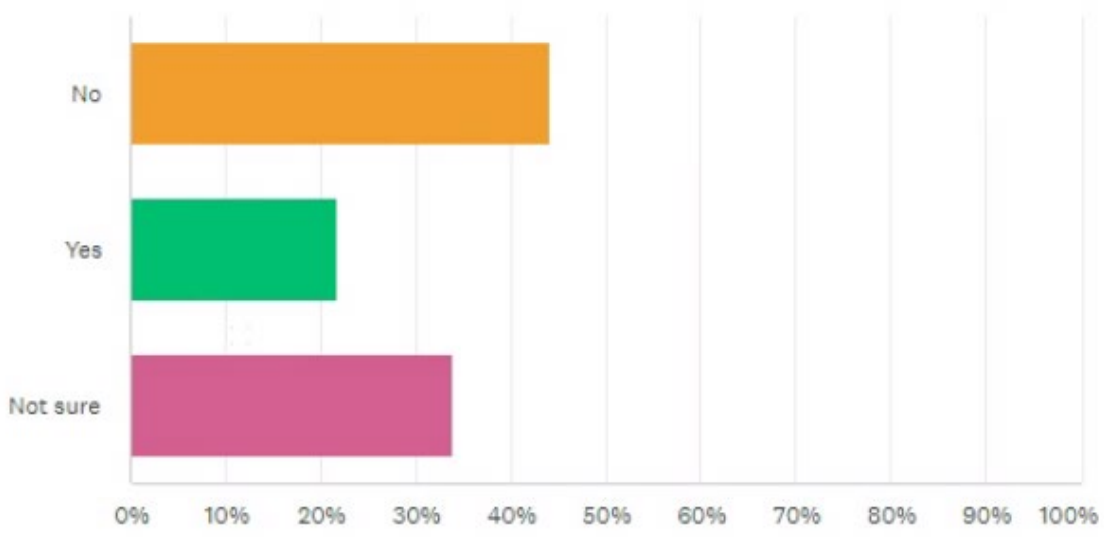
Number of responses = 159



Q20. Is there a state or local law, regulation, or company policy where you work that requires flares to be deployed on the roadway when a tow truck is stopped and giving assistance?

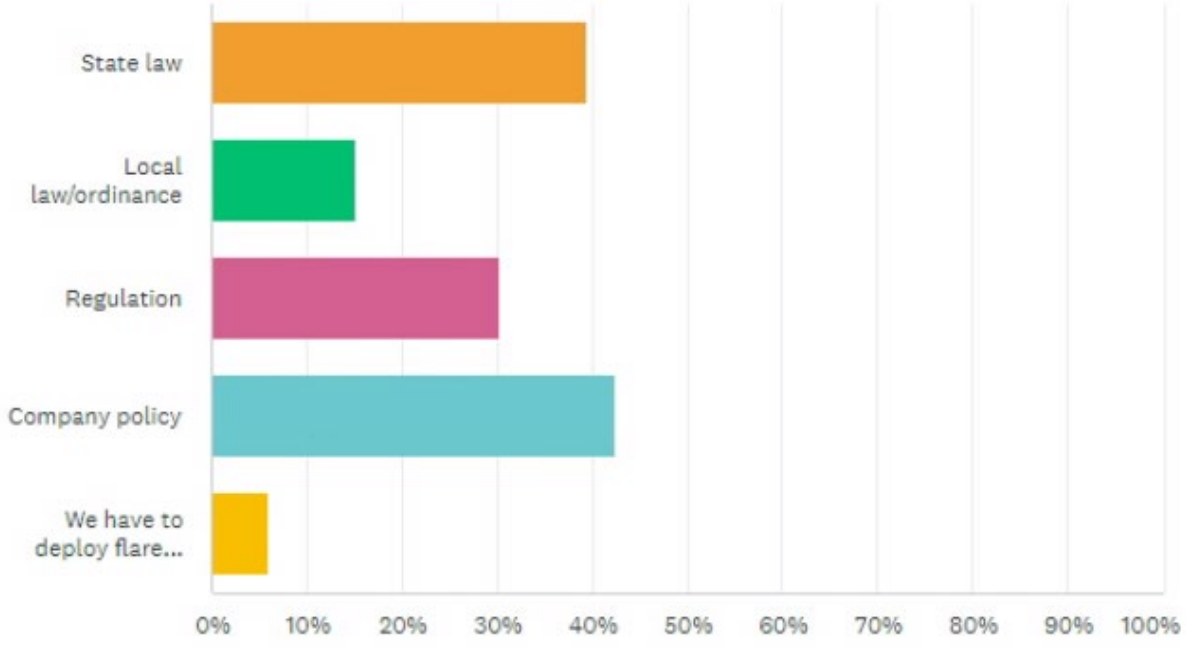
- No
- Yes
- Not sure

Number of responses = 156



Q21. What kind of flare requirement is it? (check all that apply) (N=33)

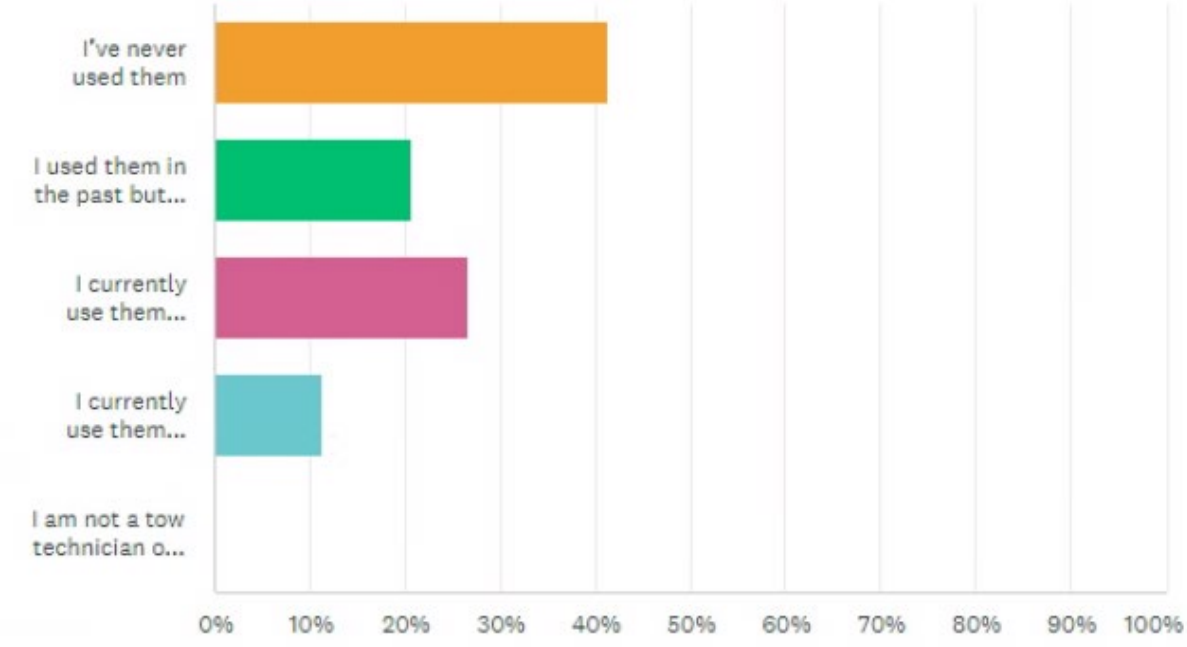
- State law (n= 13)
- Local law/ordinance (n=5)
- Regulation (n=10)
- Company policy (n=14)
- We have to deploy flares, but I don't know why (n=2)



Q22. Which answer best describes your experience deploying flares as a tow technician or light service technician?

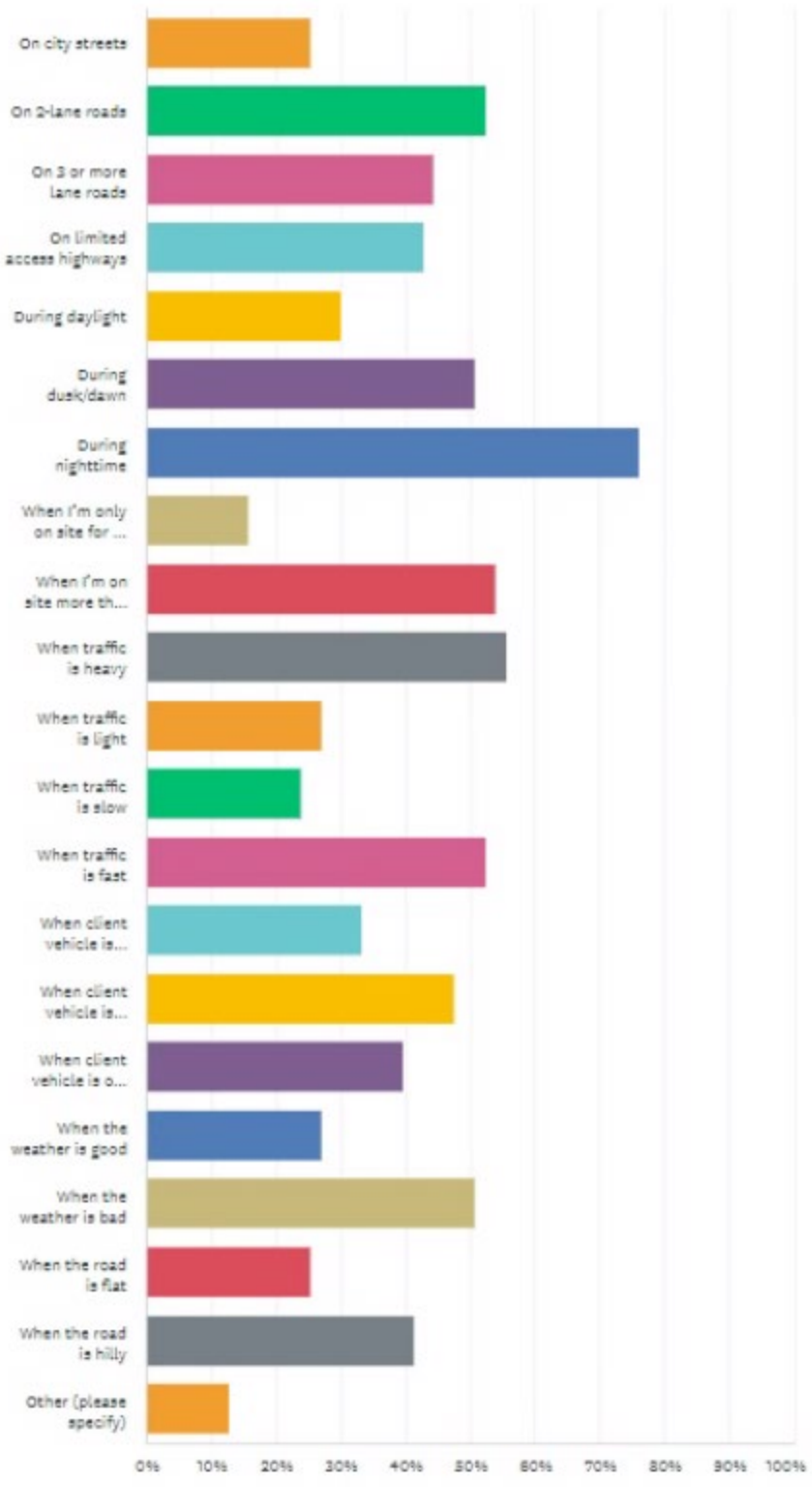
- I've never used them
- I used them in the past but don't anymore
- I currently use them occasionally
- I currently use them frequently
- I am not a tow technician or light service technician

Number of responses = 116



Q23. In which situations have you used flares? (check all that apply) (N=63)

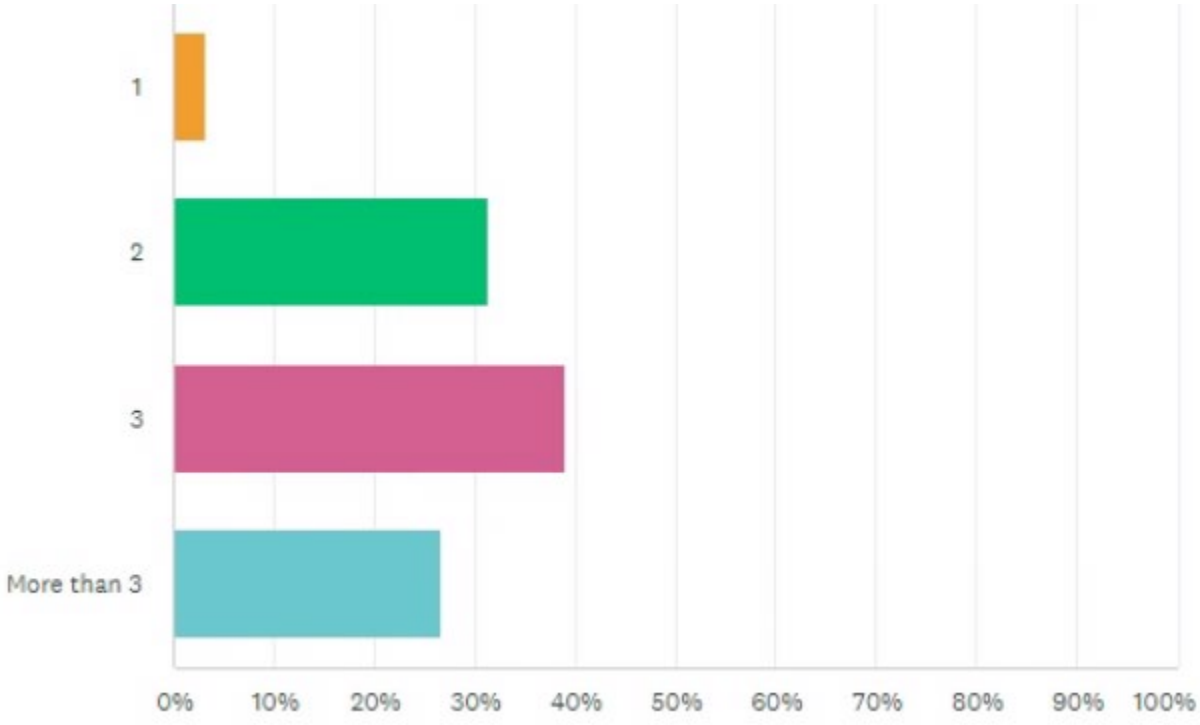
- On city streets (n= 16)
- On 2-lane roads (n=33)
- On 3 or more lane roads (n=28)
- On limited access highways (n=27)
- During daylight (n=19)
- During dusk/dawn (n=32)
- During nighttime (n=48)
- When I'm only on site for a few minutes (n=10)
- When I'm on site more than a few minutes (n=34)
- When traffic is heavy (n=35)
- When traffic is light (n=17)
- When traffic is slow (n=15)
- When traffic is fast (n=33)
- When client vehicle is totally off the road (n=21)
- When client vehicle is partially off the road (n=30)
- When client vehicle is on the road (n=25)
- When the weather is good (n=17)
- When the weather is bad (n=32)
- When the road is flat (n=16)
- When the road is hilly (n=26)
- Other (please specify) (n=8)


On city streets
On 2-lane roads
On 3 or more lane roads
On limited access highways
During daylight
During dusk/dawn
During nighttime
When I'm only on site for ...
When I'm on site more th...
When traffic is heavy
When traffic is light
When traffic is slow
When traffic is fast
When client vehicle is...
When client vehicle is...
When client vehicle is o...
When the weather is good
When the weather is bad
When the road is flat
When the road is hilly
Other (please specify)
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%

Q24. When you have used flares, what is the typical number you deployed?

- 1
- 2
- 3
- More than 3

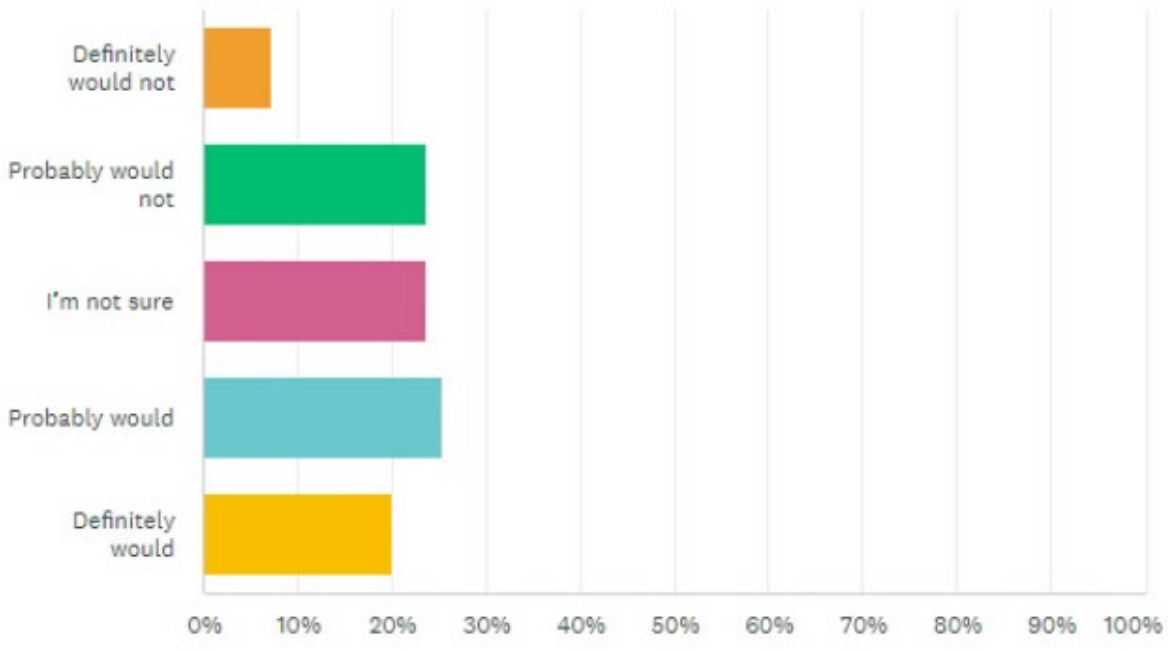
Number of responses = 64



Q25. If research showed that flares moved many more vehicles out of the lane closest to the shoulder than a tow truck with flashing lights alone, would you use them regularly?

- Definitely would not
- Probably would not
- I'm not sure
- Probably would
- Definitely would

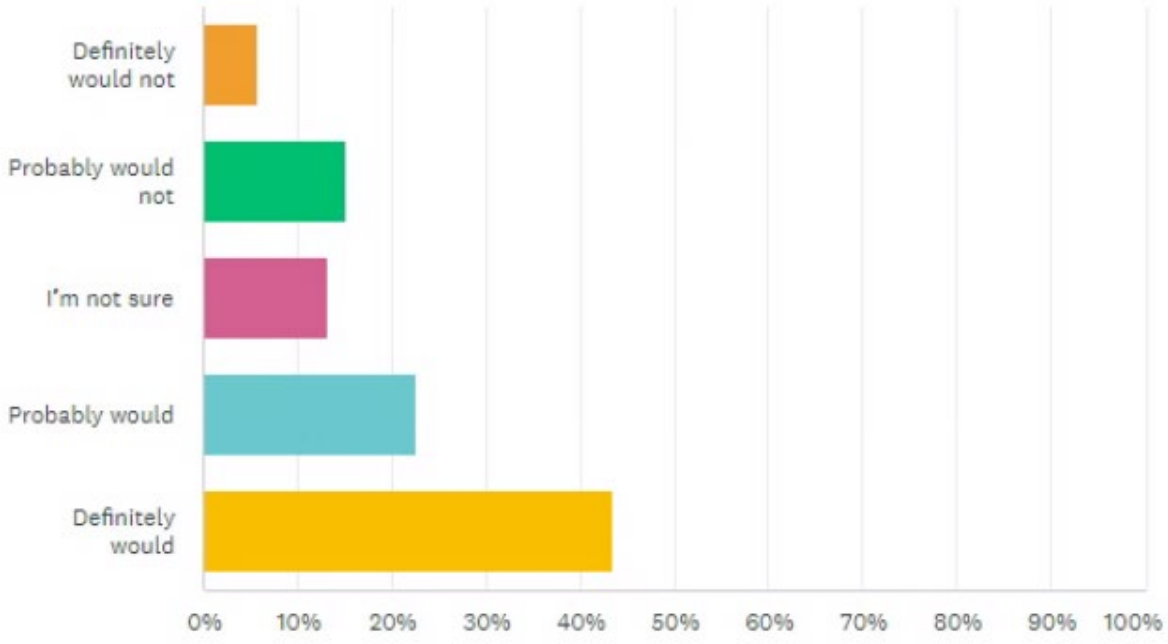
Number of responses = 55



Q26. If research showed that flares moved many more vehicles out of the lane closest to the shoulder than a tow truck with flashing lights alone and your company required their use in appropriate situations, would you use them regularly?

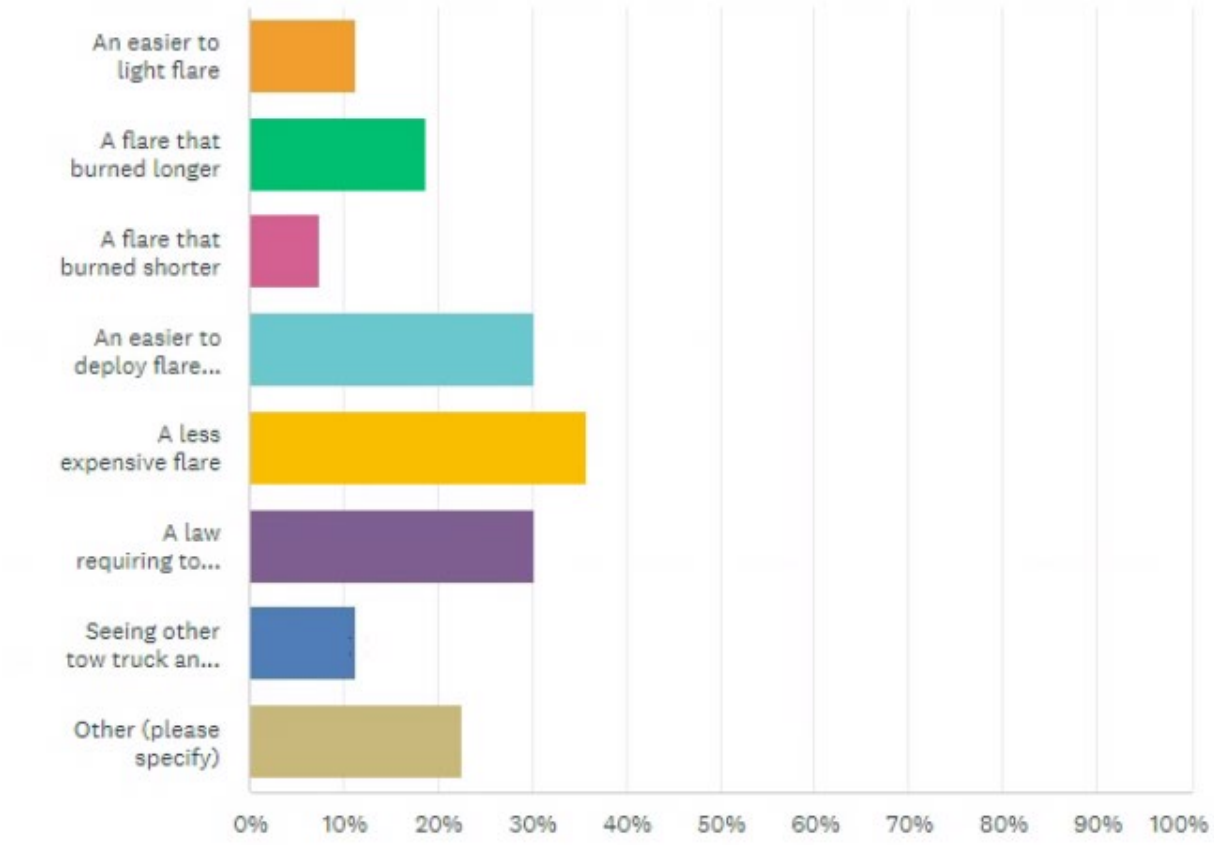
- Definitely would not
- Probably would not
- I'm not sure
- Probably would
- Definitely would

Number of responses = 53



Q27. What would motivate you to use flares more often? (check all that apply) (N=53)

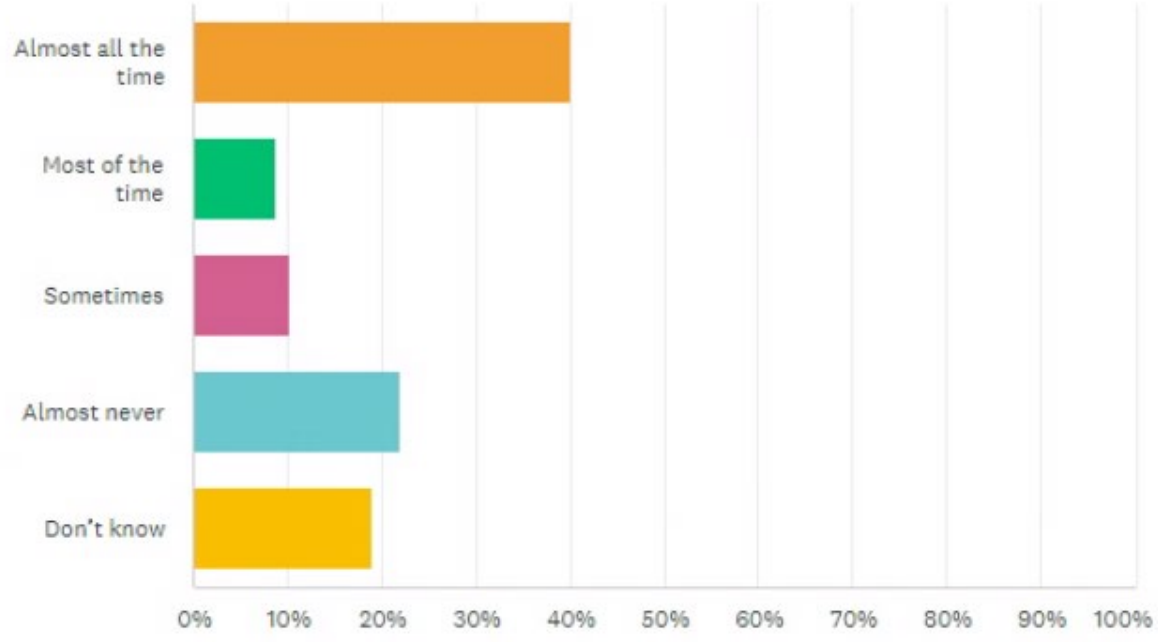
- An easier to light flare (n= 6)
- A flare that burned longer (n=10)
- A flare that burned shorter (n=4)
- An easier to deploy flare system (n=16)
- A less expensive flare (n=19)
- A law requiring tow truck and light service technicians to use flares (n=16)
- Seeing other tow truck and light service technicians using flares (n=6)
- Other (please specify) (n=12)



Q28. How often are there sufficient flares in inventory at your tow truck garage when you need them?

- Almost all the time
- Most of the time
- Sometimes
- Almost never
- Don’t know

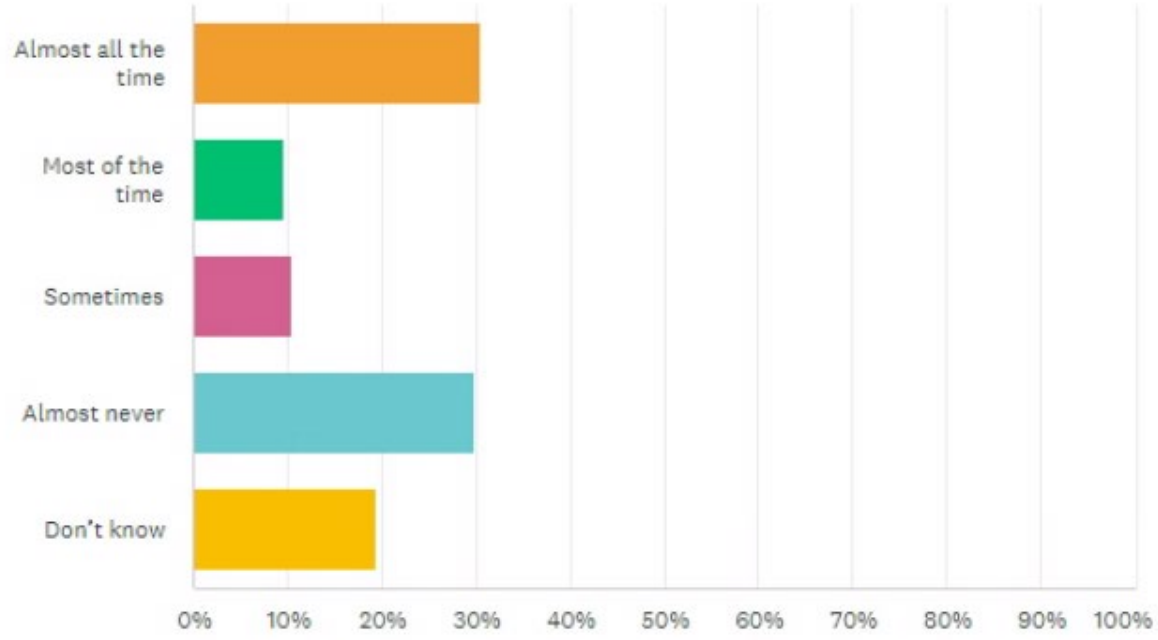
Number of responses = 137



Q29. How often are there at least 6 flares on your company's tow trucks?

- Almost all the time
- Most of the time
- Sometimes
- Almost never
- Don't know

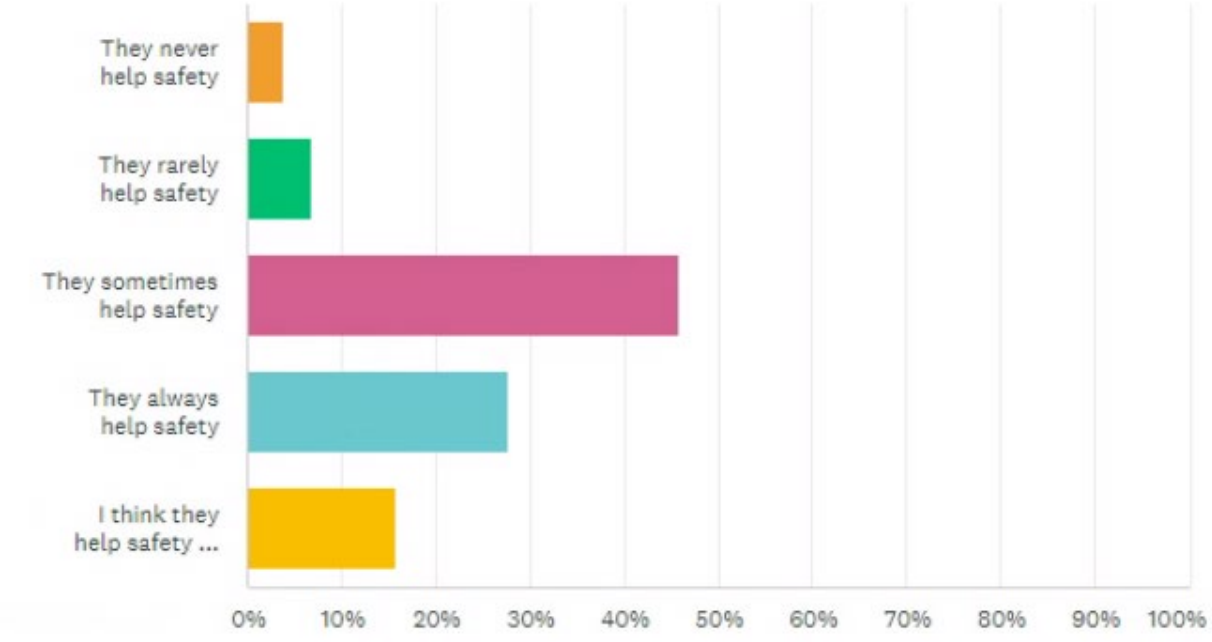
Number of responses = 134



Q30. Which statement best describes your overall opinion of flares for use by tow technicians and light service technicians?

- They never help safety
- They rarely help safety
- They sometimes help safety
- They always help safety
- I think they help safety in the right circumstances (please give examples)

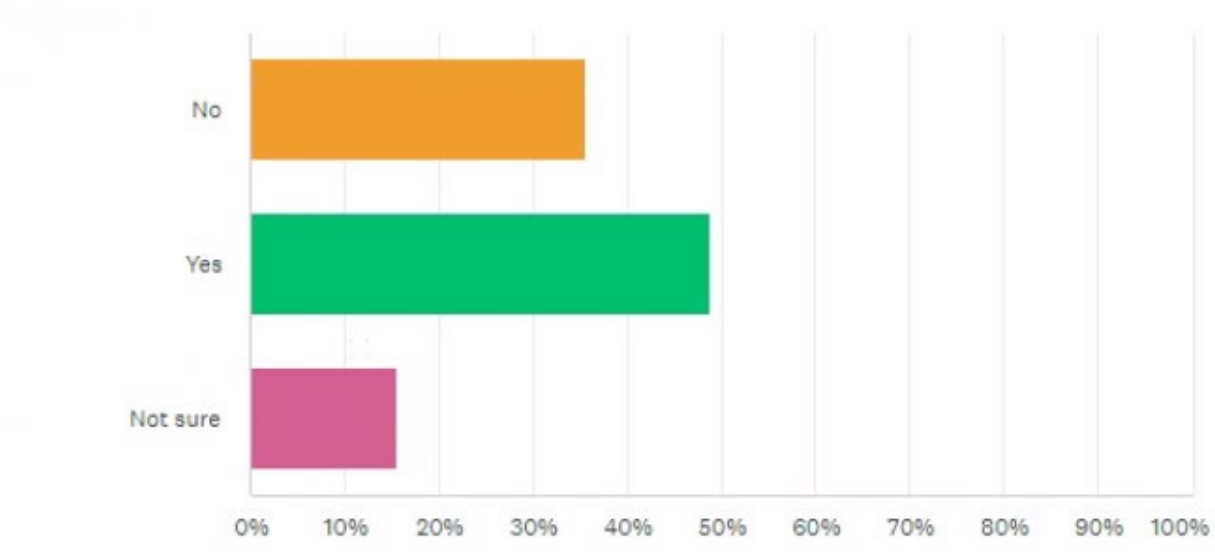
Number of responses = 133



Q31. Does your employer require any type of training on the use of cones by tow technicians or light service technicians?

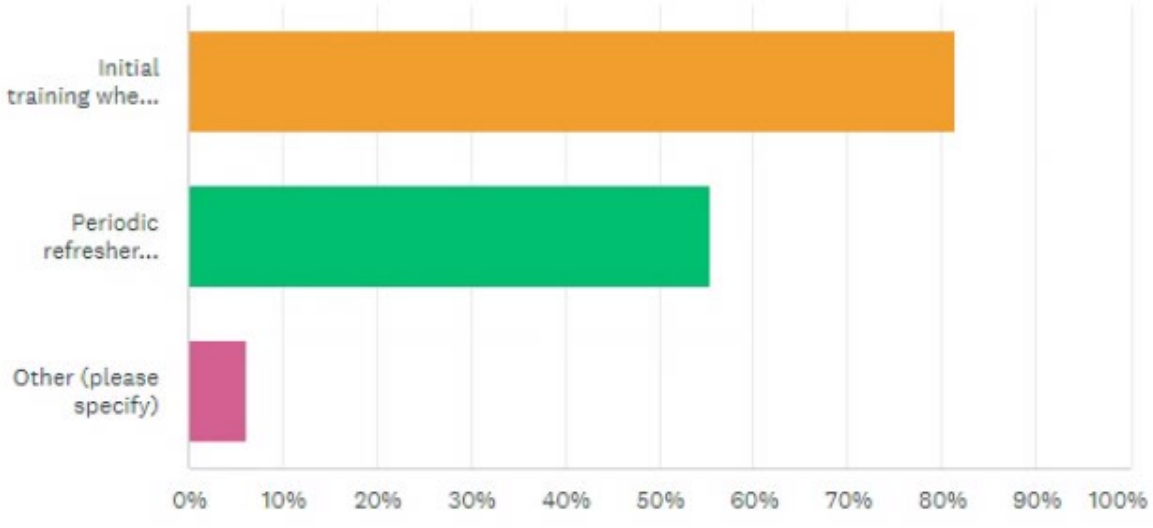
- No
- Yes
- Not sure

Number of responses = 92



Q32. Which of the following types of training on cones does your employer require tow technicians or light service technicians to take? (check all that apply) (N=65)

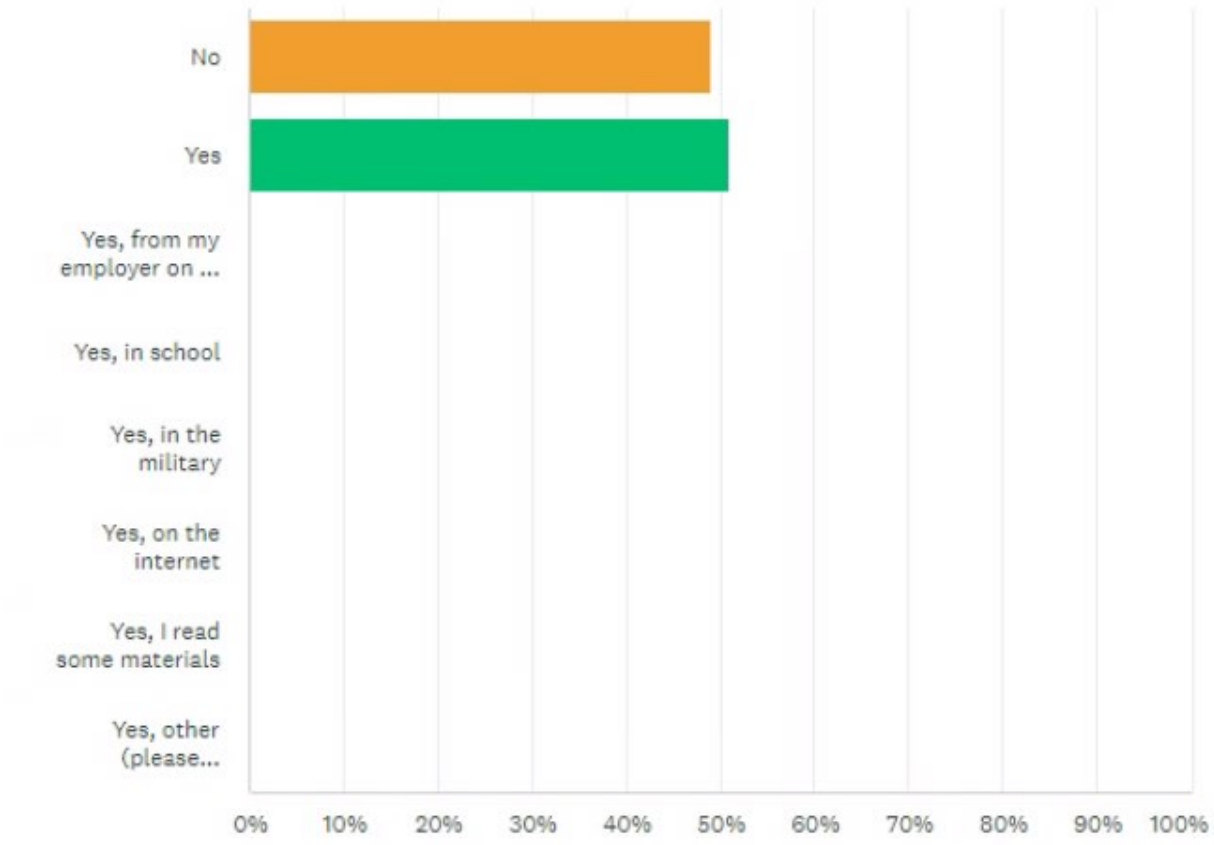
- Initial training when onboarding (n=53)
- Periodic refresher training (n=36)
- Other (please specify) (n=4)



Q33. Have you taken any training on the use of cones as a tow technician or light service technician?

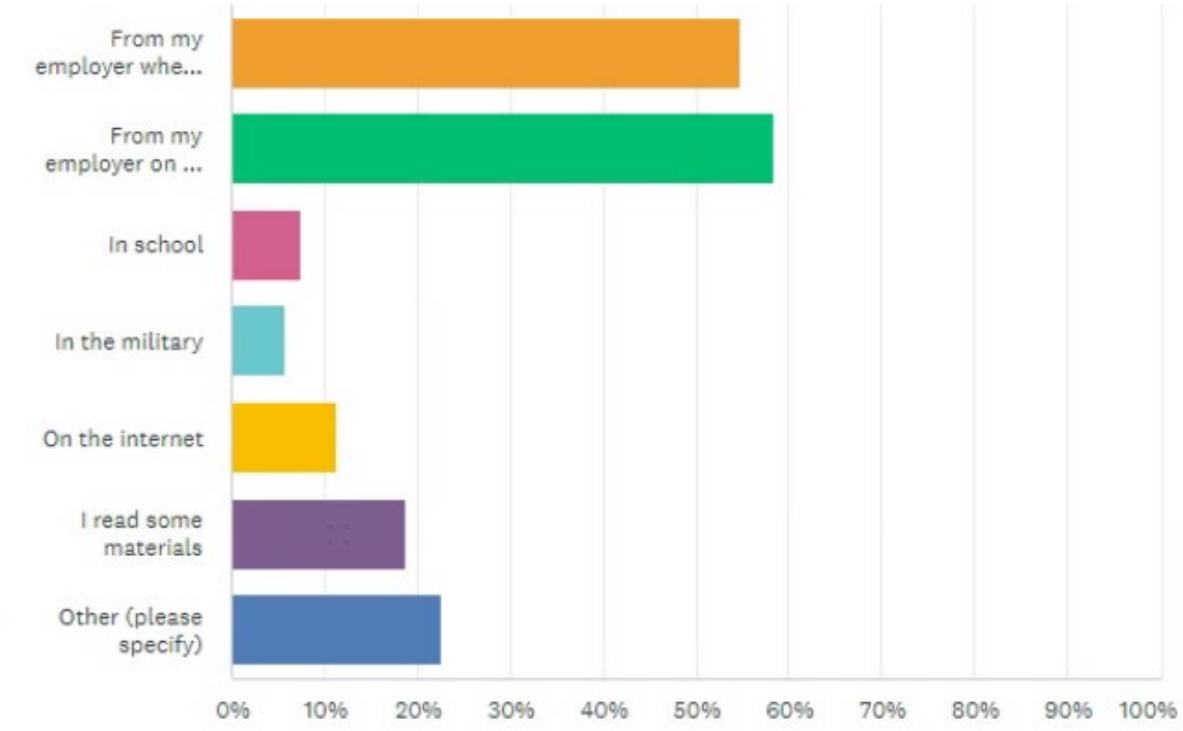
- No
- Yes

Number of responses = 104



Q34. What type of training was it? (check all that apply) (N=53)

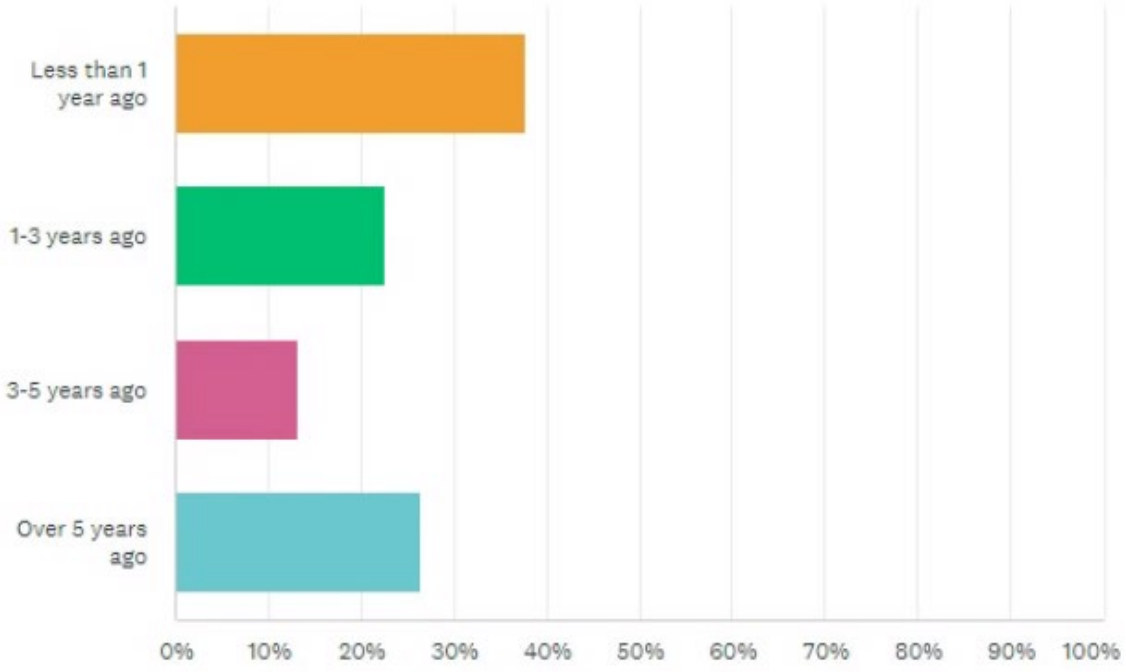
- From my employer when onboarding (n=29)
- From my employer on the job (n=31)
- In school (n=4)
- In the military (n=3)
- On the internet (n=6)
- I read some materials (n=10)
- Other (please specify) (n=12)



Q35. When was the last time you took any training that covered the use of cones?

- Less than 1 year ago
- 1-3 years ago
- 3-5 years ago
- Over 5 years ago

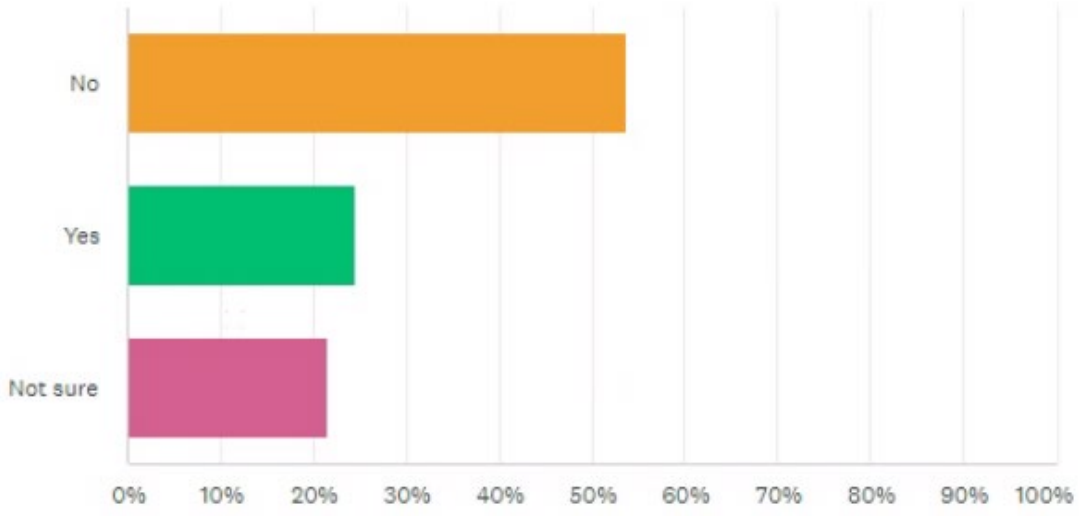
Number of responses = 53



Q36. Does your employer require any type of training on the use of flares by tow technicians or light service technicians?

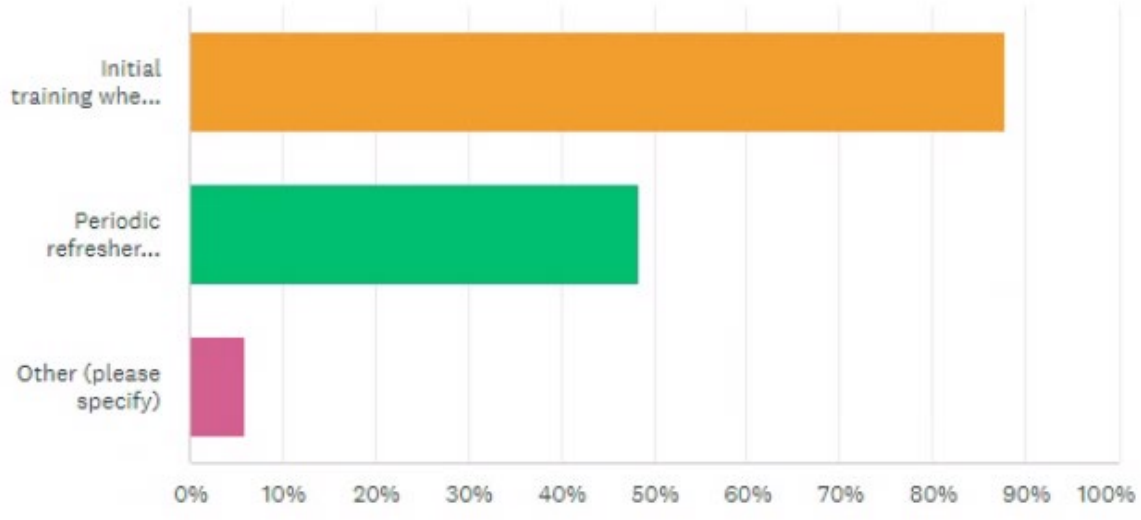
- No
- Yes
- Not sure

Number of responses = 134



Q37. Which of the following types of training on flares does your employer require tow technicians or light service technicians to take? (check all that apply) (N=33)

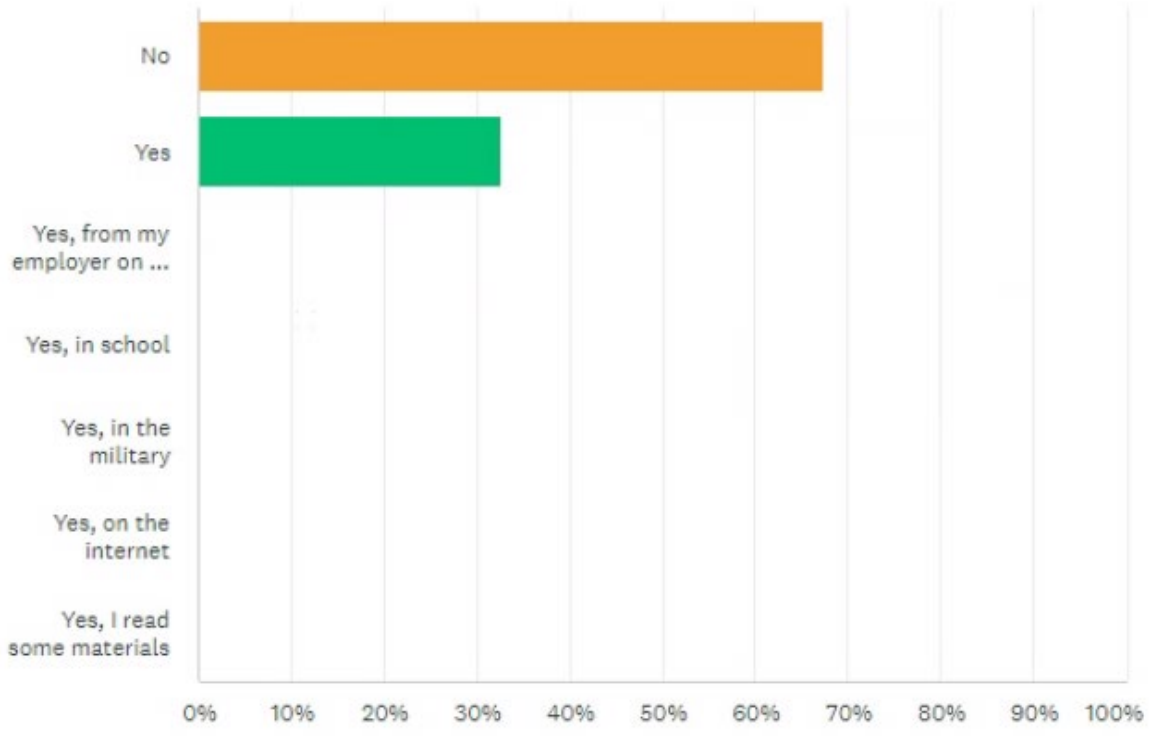
- Initial training when onboarding (n=29)
- Periodic refresher training (n=16)
- Other (please specify) (n=2)



Q38. Have you taken any training on the use of flares as a tow technician or light service technician?

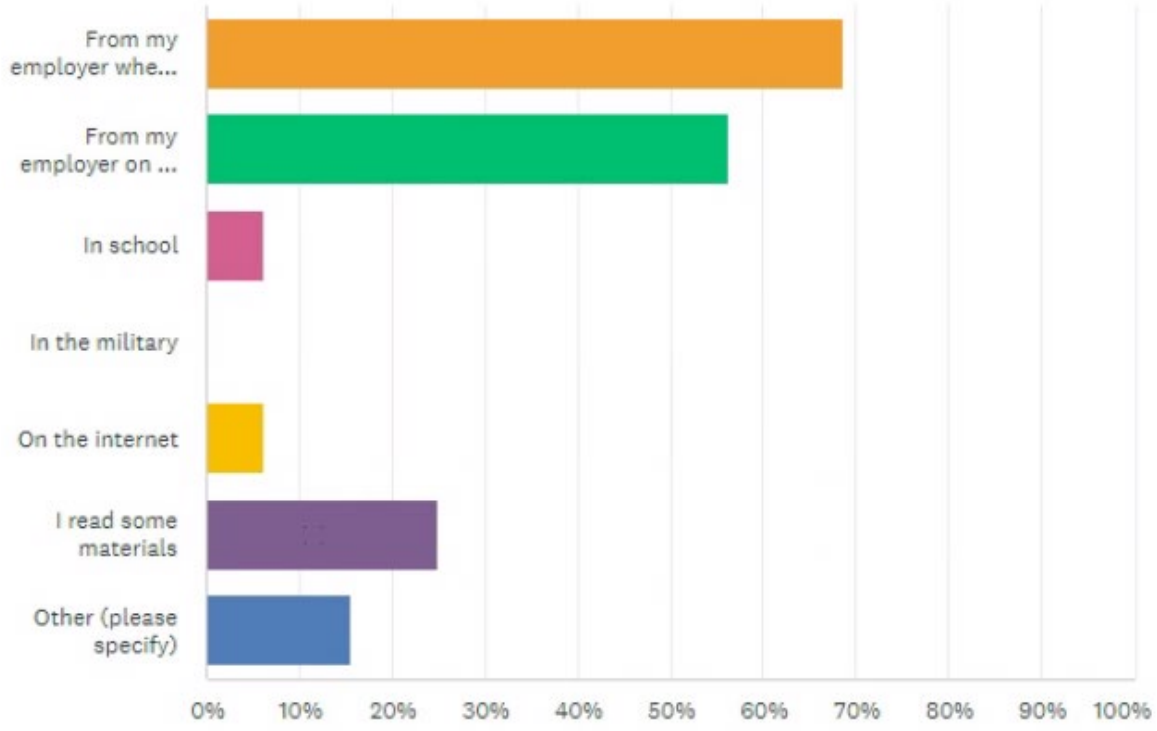
- No
- Yes

Number of responses = 101



Q39. What type of training was it? (check all that apply) (N=32)

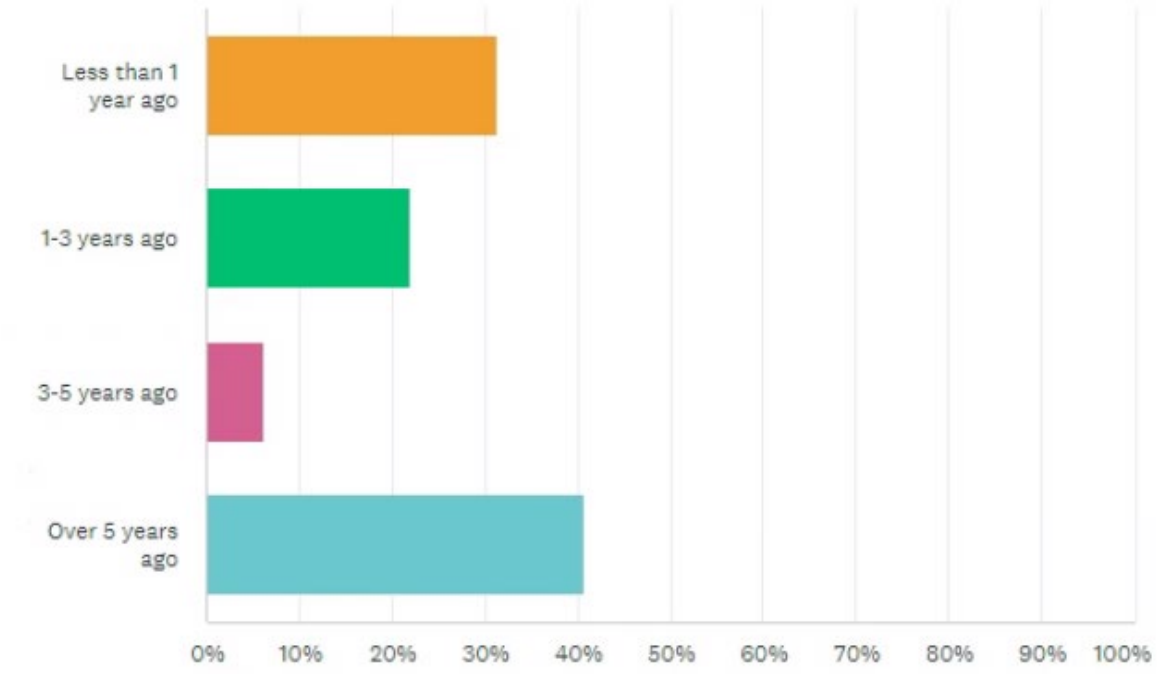
- From my employer when onboarding (n=22)
- From my employer on the job (n=18)
- In school (n=2)
- In the military (n=0)
- On the internet (n=2)
- I read some materials (n=8)
- Other (please specify) (n=5)



Q40. When was the last time you took any training that covered the use of flares?

- Less than 1 year ago
- 1-3 years ago
- 3-5 years ago
- Over 5 years ago

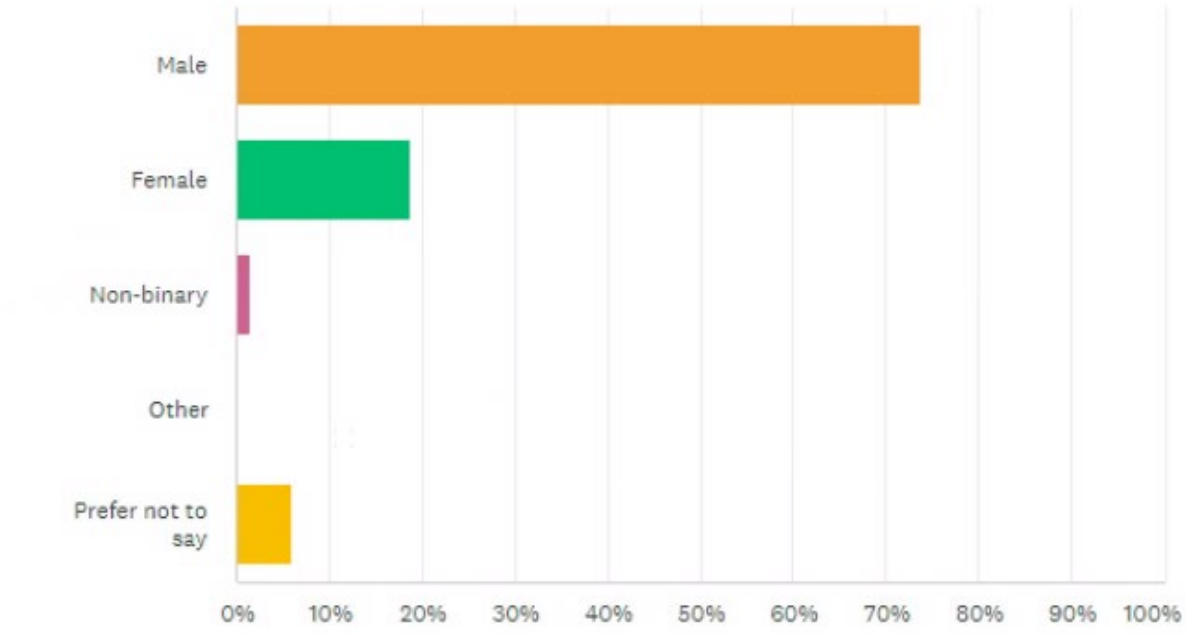
Number of responses = 32



Q41. What is your gender?

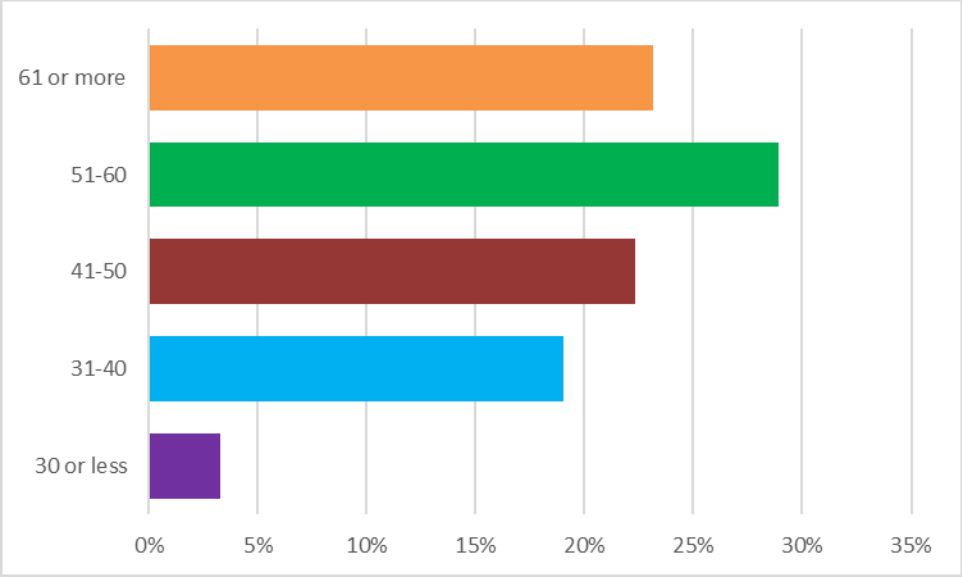
- Male
- Female
- Non-binary
- Other
- Prefer not to say

Number of responses = 133



Q42. What is your age?

Number of responses = 227



Appendix B: Countermeasure Idea Forms

This Appendix presents the 42 countermeasures identified during the review with the complete set of information generated for each. Countermeasures are identified by a letter prefix that indicates their type:

- W = Worker-based
- V = Vehicle-based
- S = Site-based
- M = Motorist-based (including both passing driver and vehicle)

Each countermeasure was also assigned a sequence number that simply indicates the order in which each countermeasure within a class was documented. Thus, S-04 was the fourth site-based countermeasure documented. No priority or evaluation result is to be inferred from the numbering sequence.

W - 01 AIRBAG SUIT

Domain (select all that apply)	☑ Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	Inflatable suit that a roadside worker wears for protection from injury from a striking motor vehicle. The proposed suit is similar to one initially designed for motorcycle racing (seen here)[1] but would require an early detection system that inflates the suit prior to impact with a motor vehicle.
Level of Evidence	☐ Specific Evaluation ☐ Analogous Evaluation ☐ Published Idea ☑ Project Generated
Technology Readiness	☑ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☐ Off the shelf
Development Still Required	☐ Extensive ☑ Moderate ☐ Limited ☐ None
Cost to Deploy/Install	☐ Known Cost ☑Estimated Cost ☐ Unknown >$1,000/suit
Cost to Maintain	☐ Known Cost ☐ Estimated Cost ☑Unknown
Time to Deploy/Install	☐ Known Time ☑Estimated Time ☐ Unknown 5-10 minutes
Time to Maintain	☐ Known Time ☐ Estimated Time ☑ Unknown
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☐ Slow down traffic ☐ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☑Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☑ **Engineering** ☐ Motorist ☑ Worker ☐ Management ☐ Work Vehicle ☐ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Designed to withstand substantial impacts; should limit injury even if not totally prevented
Cons	Expensive; technical challenges of detecting impending crash; may be uncomfortable and difficult to work in; may not reduce injuries due to first impact in roadside situation

[1] https://www.fc-moto.de/epages/fcm.sf/?channable=e78948.MjI0MjM3NTQ&ObjectPath=/Shops/10207048/Products/Spidi-T-2-Neck-DPS-Wind-Pro-Leather-Suit/SubProducts/Spidi-T-2-Neck-DPS-Wind-Pro-Leather-Suit-0002&Locale=en_US&gclid=CjwKCAiAyeTxBRBvEiwAuM8dnQ94xHYQCvzgy-Q-d9-VJARbGAnK2i8Y4ALRO5NOtipEPTj5pZTNMxoC7ZUQAvD_BwE

W - 02 WORKER VEST WARNING SYSTEM

Domain (select all that apply)	☑Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	Consists of an impact sensor and a transmitter unit. The impact sensor is designed to detect vehicles penetrating the perimeter of a zone (e.g., roadside incident area), and the transmitter receives the warning from the sensor. The transmitter can be placed in the pocket of a worker's vest. Patent can be seen here.[1]
Level of Evidence	☐ Specific Evaluation ☐ Analogous Evaluation ☑ Published Idea ☐ Project Generated
Technology Readiness	☑ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☐ Off the shelf
Development Still Required	☑ Extensive ☐ Moderate ☐ Limited ☐ None
Cost to Deploy/Install	☐ Known Cost ☑ Estimated Cost ☐ Unknown Moderate to High
Cost to Maintain	☐ Known Cost ☑ Estimated Cost ☐ Unknown Repair or replacement for wear-and-tear
Time to Deploy/Install	☐ Known Time ☑Estimated Time ☐ Unknown Low
Time to Maintain	☐ Known Time ☑Estimated Time ☐ Unknown Low
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☐ Slow down traffic ☐ Direct or channel traffic ☑ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☑ **Engineering** ☐ Motorist ☑ Worker ☐ Management ☐ Work Vehicle ☐ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Uses advanced sensor technology to warn service personnel; durable
Cons	Requires charging; users may not hear, feel, see warning; operating characteristics (e.g. false positive/negative rates) are unknown; likely needs periodic recalibration; wearer may not have enough time or knowledge to initiate proper evasive maneuvers; training would be required

[1] Souza, W. (2001). *U.S. Patent No. 6,288,651*. Washington, DC: U.S. Patent and Trademark Office.

W - 03 BASING WORKER PAY ON SAFETY COMPLIANCE

Domain (select all that apply)	☑ Roadway ☐ Marine ☑ Aviation ☐ Railroad
Description	Increase or reduce worker or emergency response personnel pay based on rate of compliance with safety standards.
Level of Evidence	☐ Specific Evaluation ☑ Analogous Evaluation ☐ Published Idea ☐ Project Generated Crash incidence fell for commercial truck drivers after a pay increase.[1]
Technology Readiness	☑ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☐ Off the shelf
Development Still Required	☐ Extensive ☑ Moderate ☐ Limited ☐ None Need good safety requirements, control procedures, and modified labor agreements
Cost to Deploy/Install	☐ Known Cost ☑ Estimated Cost ☐ Unknown Low – just need to develop protocol
Cost to Maintain	☐ Known Cost ☐ Estimated Cost ☑ Unknown Likely low just to maintain currency
Time to Deploy/Install	☐ Known Time ☑ Estimated Time ☐ Unknown Low
Time to Maintain	☐ Known Time ☐ Estimated Time ☑ Unknown Likely low depending on initiation of new safety rules
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☐ Slow down traffic ☐ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☑ Other Increase safety compliance among roadside workers
☐ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☐ Work Vehicle ☐ Traffic Control	
☑ **Enforcement** ☐ Motorist ☑ Worker ☐ Management	

Review

Pros	Low cost, no hardware
Cons	Difficult to develop valid metrics and agree with unions; needs to be validated in the emergency worker context

[1] Rodriguez, D. A., Targa, F., & Belzer, M. H. (2006). Pay incentives and truck driver safety: a case study. *ILR Review*, *59*(2), 205-225.

W - 04 ELECTROLUMINESCENT MATERIALS ON WORKER VESTS

Domain (select all that apply)	☑Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	Electroluminescent (EL) materials are bendable materials that emit light when powered and enhance pedestrian conspicuity in situations where retroreflective materials have limited utility. EL are relatively insensitive to variations in viewing angle. Commercial vests that use EL are available. Some also have good retro-reflective qualities, as can be seen here.[1]
Level of Evidence	☐ Specific Evaluation ☑ Analogous Evaluation ☐ Published Idea ☐ Project Generated Pedestrian garments that included both EL material along with retroreflective materials yielded longer response distances at night than the retroreflective material alone.[2]
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf
Development Still Required	☐ Extensive ☐ Moderate ☑ Limited ☐ None Charging apparatus or battery replacement criteria and use procedures need to be developed
Cost to Deploy/Install	☑ Known Cost ☐ Estimated Cost ☐ Unknown $8.95 for tape or $34.95 for panels
Cost to Maintain	☐Known Cost ☐ Estimated Cost ☑Unknown Periodic replacement required based on service conditions and end of life criteria
Time to Deploy/Install	☐Known Time ☑ Estimated Time ☐ Unknown Low
Time to Maintain	☐Known Time ☐ Estimated Time ☑ Unknown Depends on environmental conditions (e.g., dirt, rain) and worker care
Lighting Applicability	☐ Daytime ☑ Nighttime ☐ Both Can include daytime if substrate is fluorescent

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☑ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☐ Slow down traffic ☐ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☑**Engineering** ☐ Motorist ☑Worker ☐ Management ☐ Work Vehicle ☐ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Consistent luminance of EL materials may be particularly useful for workers on the shoulder of a road; shown to be effective; easy to use
Cons	Works on batteries which would need recharging or replacement; might be compromised by vehicle fluids and road grime; possibly not sufficiently rugged as is for the use environment

[1] https://www.youtube.com/watch?v=Ic5_9djZ_rk

[2] Fekety, D. K., Edewaard, D. E., Stafford Sewall, A. A., & Tyrrell, R. A. (2016). Electroluminescent materials can further enhance the nighttime conspicuity of pedestrians wearing retroreflective materials. *Human Factors*, *58*(7), 976-985.

W - 05 WEARABLE SAFETY LIGHT

Domain (select all that apply)	☑ Roadway ☑ Marine ☐Aviation ☐ Railroad
Description	Wearable safety lights consists of shoulder mounted lights, as can be seen here.[1] Lights attach magnetically to a point on the top of a worker's shoulder and project light to the front and back. Steady burn or flashing lights can be deployed.
Level of Evidence	☐ Specific Evaluation ☑ Analogous Evaluation ☐ Published Idea ☐ Project Generated Wearable safety lights appear to increase the visibility of construction zone workers.[2] Also, crash incidence rate was 19% lower for bicyclists with permanent lighting equipment compared to bicyclists without it.[3]
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf Several different configurations available for varied use cases
Development Still Required	☐ Extensive ☐ Moderate ☑ Limited ☐ None Exact configuration and procedures have to be defined
Cost to Deploy/Install	☑Known cost ☐ Estimated Cost ☐ Unknown $100
Cost to Maintain	☑ Known Cost ☐ Estimated Cost ☐ Unknown Recharging and possible periodic repair or replacement for wear-and-tear
Time to Deploy/Install	☑ Known Time ☐ Estimated Time ☐ Unknown Once installed, just switch them on
Time to Maintain	☑Known Time ☐ Estimated Time ☐ Unknown Possible periodic repair or replacement
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☑Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☐ Slow down traffic ☐ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☑ **Engineering** ☐ Motorist ☑ Worker ☐ Management ☐ Work Vehicle ☐ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Available in a variety of colors and flashing patterns. The front light can illuminate work area while the rear light alerts drivers. Battery life relatively good. Already in use in highway, marine and recreational environments
Cons	Might interfere with job performance (e.g., get in the way as worker completes service)

[1] https://www.guardianangeldevices.com/

[2] Nnaji, C., Jafarnejad, A., & Gambatese, J. (2020). Effects of Wearable Light Systems on Safety of Highway Construction Workers. *Practice Periodical on Structural Design and Construction*, *25*(2), 04020003.

[3]Madsen, J. C. O., Andersen, T., & Lahrmann, H. S. (2013). Safety effects of permanent running lights for bicycles: A controlled experiment. *Accident Analysis & Prevention*, *50*, 820-829.

W - 06 REFLECTIVE VESTS

Domain (select all that apply)	☑Roadway ☑ Marine ☑ Aviation ☑ Railroad
Description	High quality vests are available with sufficient retroreflective and fluorescent material that can be worn over coats of workers/response personnel in winter and are comfortable in summer. An example can be seen here.[1]
Level of Evidence	☐ Specific Evaluation ☑ Analogous Evaluation ☐ Published Idea ☐ Project Generated Bicyclists that wore a reflective jacket reported 38% less crashes than bicyclists who did not.[2]
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf
Development Still Required	☐ Extensive ☐ Moderate ☑ Limited ☐ None Vests are widely used by response workers, but compliance level may be less than desired. Programs to encourage selection of best vests and promote compliance could help.
Cost to Deploy/Install	☐ Known Cost ☑ Estimated Cost ☐ Unknown Typical unit cost for vest is $8-$27, but maximizing effectiveness could increase cost.
Cost to Maintain	☐Known Cost ☑ Estimated Cost ☐ Unknown Repair or replacement for wear-and-tear. Vests will bleach in sun over time.
Time to Deploy/Install	☐ Known Time ☑ Estimated Time ☐ Unknown Minimal (like putting on a jacket).
Time to Maintain	☐ Known Time ☑ Estimated Time ☐ Unknown Must keep clean and replace if damaged or past service life.
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☑Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☐ Slow down traffic ☐ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☑ **Engineering** ☐ Motorist ☑Worker ☐ Management ☐ Work Vehicle ☐ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	High visibility vests effective during daylight and nighttime are widely available, comfortable in hot weather, and can fit over winter coats; can be put on and removed in several seconds; is easy to store in a readily accessible location
Cons	Requires compliance; provides no benefit if user is screened; works best if wearer is in motion

[1] https://www.reflectiveapparel.com/RAF-586-ET-LM.aspx
[2] Lahrmann, H., Madsen, T. K. O., Olesen, A. V., Madsen, J. C. O., & Hels, T. (2018). The effect of a yellow bicycle jacket on cyclist accidents. *Safety Science*, *108*, 209-217.

W - 07 TEAM RESPONSE/FLAGGER

Domain (select all that apply)	☑ Roadway ☐ Marine ☑ Aviation ☐ Railroad
Description	One person directs traffic away from a roadside incident using gestures, signs or flags, as seen here.[1]
Level of Evidence	☐ Specific Evaluation ☑ Analogous Evaluation ☐ Published Idea ☐ Project Generated Some evidence of effectiveness in work zones.[2]
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☑ Multiple applications ☐ Off the shelf
Development Still Required	☐ Extensive ☑ Moderate ☐ Limited ☐ None Need to work out the scheduling and financial details of the arrangement.
Cost to Deploy/Install	☐ Known Cost ☑ Estimated Cost ☐ Unknown High – approximately double labor costs
Cost to Maintain	☑ Known Cost ☐ Estimated Cost ☐ Unknown Cost of an extra trained worker
Time to Deploy/Install	☐ Known Time ☑ Estimated Time ☐ Unknown Low – Once flagger is hired, trained and equipped, minimal set-up time required
Time to Maintain	☐ Known Time ☑ Estimated Time ☐ Unknown Need to have reserve personnel for absences, vacations, etc.
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☑ Slow down traffic ☑ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☑ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☐ Work Vehicle ☑ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Extra person on site can have additional efficiency or safety advantages; ability to adapt to unusual conditions
Cons	Expensive for recruiting, training, supervision, salary, benefits; may necessitate development of training on traffic management for these types of sites and conditions

[1] https://www.nsc.org/safety-training/workplace/work-zone-safety/flagger-novice
[2] Bai, Y. (2006). *Determining major causes of highway work zone accidents in Kansas*. University of Kansas Center for Research, Inc..

W - 08 TRAFFIC CONTROL OFFICER

Domain (select all that apply)	☑ Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	A police officer who stands at the side of the roadway and directs traffic through the work zone and can radio ahead or stop speeding motorists. An officer would have to be on call (and therefore likely on detail unless a crash scene) to be able to travel to roadside location at appropriate time or be detailed to the response operation and paid by it.
Level of Evidence	☐ Specific Evaluation ☑ Analogous Evaluation ☐ Published Idea ☐ Project Generated Having a traffic control officer stationed in a work zone has shown to reduce speed up to 14 mph.[1]
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf
Development Still Required	☐ Extensive ☑ Moderate ☐ Limited ☐ None Need to work out the scheduling and financial details of the arrangement.
Cost to Deploy/Install	☐ Known Cost ☑ Estimated Cost ☐ Unknown High - Labor and possible transportation costs for non-crash sites.
Cost to Maintain	☐ Known Cost ☑ Estimated Cost ☐ Unknown Moderate to High– pay for enforcement and potential judicial time for ticket processing; may actually make money from tickets issued to violators.
Time to Deploy/Install	☐ Known Time ☑ Estimated Time ☐ Unknown Quick to develop, but individual deployments may take time depending on relative locations of site and police support.
Time to Maintain	☐ Known Time ☑ Estimated Time ☐ Unknown Moderate to High – includes training of new officers, refresher training, and ticket/stop processing time.
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☑ Slow down traffic ☑ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☐ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☐ Work Vehicle ☐Traffic Control	
☑ **Enforcement** ☑ Motorist ☐ Worker ☐ Management	

Review

Pros	Likely effective in speed reduction; provides additional security for worker
Cons	High cost; need for participation of local police department

[1] Richards, S. H., Wunderlich, R. C., & Dudek, C. L. (1985). Field evaluation of work zone speed control techniques. *Transportation Research Record*, *1035*, 66-78.

W - 09 RETROFLECTIVE PANTS

Domain (select all that apply)	☑Roadway ☐ Marine ☑Aviation ☐ Railroad
Description	High quality pants are available with sufficient retroreflective and fluorescent material. An example can be seen here.[1] Retroreflective materials work well when placed low.
Level of Evidence	☐ Specific Evaluation ☐ Analogous Evaluation ☐ Published Idea ☑ Project Generated
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf
Development Still Required	☐ Extensive ☐ Moderate ☑ Limited ☐ None Use procedures need to be developed
Cost to Deploy/Install	☑ Known Cost ☐ Estimated Cost ☐ Unknown $13.99/1 pair of pants
Cost to Maintain	☐Known Cost ☑ Estimated Cost ☐ Unknown Low- Repair or replacement for wear-and-tear.
Time to Deploy/Install	☑ Known Time ☐ Estimated Time ☐ Unknown Minimal
Time to Maintain	☐ Known Time ☑ Estimated Time ☐ Unknown Low- Must keep clean and replace if damaged or past service life.
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☑Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☐ Slow down traffic ☐ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☑ **Engineering** ☐ Motorist ☑Worker ☐ Management ☐ Work Vehicle ☐ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	High visibility pants are widely available, can be put on and removed in several seconds; easy to store in a readily accessible location, and are widely used; strong theoretical benefit.
Cons	No experimental evidence of effectiveness; requires compliance; provides no benefit if user is screened; works best if wearer is in motion

[1] https://www.hivissupply.com/gss-safety-hi-viz-class-e-contrast-mesh-safety-pants.html?gclid=CjwKCAiA7t3yBRADEiwA4GFlI0OEbeSDFbz-lG583vxLlzvLNKaZVWg-S_uT0LRq-4EDy4lasIhoBhoCrIsQAvD_BwE

W - 10 LED OR RETROREFLECTIVE HEADGEAR

Domain (select all that apply)	☑ Roadway ☐ Marine ☑ Aviation ☑ Railroad
Description	LED hard hats (as seen here)[1] or retro-reflective stickers that could be applied to headgear (as seen here).[2]
Level of Evidence	☐ Specific Evaluation ☐ Analogous Evaluation ☐ Published Idea ☑ Project Generated
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf
Development Still Required	☐ Extensive ☐ Moderate ☑ Limited ☐ None Charging apparatus or battery replacement criteria and use procedures need to be developed
Cost to Deploy/Install	☑ Known Cost ☐ Estimated Cost ☐ Unknown $99 for LED hard hat/$13.25 for 1"X4" retroreflective sticker
Cost to Maintain	☐ Known Cost ☑ Estimated Cost ☐ Unknown Low – only necessary if replacements are needed
Time to Deploy/Install	☑ Known Time ☐ Estimated Time ☐ Unknown None
Time to Maintain	☑ Known Time ☐ Estimated Time ☐ Unknown 3-4 hours to charge
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☑ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☐ Slow down traffic ☐ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☑ **Engineering** ☐ Motorist ☑ Worker ☐ Management ☐ Work Vehicle ☐ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	LED hard hats and retro-reflective stickers that could be applied to hard hats are widely available; can be put on and removed in several seconds; easily stored
Cons	No empircal evidence of effectiveness; requires workers' compliance; provides no benefit if headgear is screened

[1]https://www.google.com/shopping/product/2723529085523107647?biw=1882&bih=950&sxsrf=ALeKk00SvsA_k1IXmCl5ALy9GDhvQaHIqQ:1583504203381&q=led+light+hard+hat&oq=led+light+hard+hat&prds=epd:16221346432887677042,prmr:3&sa=X&ved=0ahUKEwj5ovyChYboAhVJmeAKHRa7DUgQ8wIInwM

[2] https://www.accuform.com/safety-label/retro-reflective-helmet-sticker-LHR104

W - 11 LED OR RETROREFLECTIVE FOOTWEAR

Domain (select all that apply)	☑ Roadway ☑ Marine ☑ Aviation ☑ Railroad
Description	Footwear could be retroreflective or flashing LED, as seen here.[1]
Level of Evidence	☐ Specific Evaluation ☐ Analogous Evaluation ☐ Published Idea ☑ Project Generated There is currently no evidence providing the effectiveness of retroreflective or LED footwear in a roadside setting.
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf LED shoes are available for purchase. It is unknown if they would be suitable for emergency roadside settings.
Development Still Required	☐ Extensive ☐ Moderate ☑ Limited ☐ None Charging apparatus or battery replacement criteria and use procedures need to be developed
Cost to Deploy/Install	☑ Known Cost ☐ Estimated Cost ☐ Unknown $27.99–32.99
Cost to Maintain	☐ Known Cost ☑ Estimated Cost ☐ Unknown Low – replacements for wear and batteries
Time to Deploy/Install	☑ Known Time ☐ Estimated Time ☐ Unknown Selection and purchasing
Time to Maintain	☑ Known Time ☐ Estimated Time ☐ Unknown 2-3 hours of charging (for LED footwear)
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both (better at night)

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☑ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☐ Slow down traffic ☐ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☑ **Engineering** ☐ Motorist ☑ Worker ☐ Management ☐ Work Vehicle ☐ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	LED footwear is widely available; can be put on and removed in several seconds; easily stored; actively being patented
Cons	No empirical evidence of effectiveness in this context; currently available footwear may not be durable enough for worker use; requires workers' compliance; provides no benefit if shoes are screened

[1] https://www.amazon.com/LeoVera-Unisex-Charging-Flashing-Sneakers/dp/B07F67JB5V

V - 01 FLEXIBLE LIGHTED ROD

Domain (select all that apply)	☑ Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	A lighted device that is placed around the worker's vehicle and is composed of durable materials to withstand any potential impacts from a passing motorist. Workers would have to keep flexible lighted rods in or on work vehicles.
Level of Evidence	☐ Specific Evaluation ☐ Analogous Evaluation ☐ Published Idea ☑ Project Generated
Technology Readiness	☑ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☐ Off the shelf
Development Still Required	☑ Extensive ☐ Moderate ☐ Limited ☐ None
Cost to Deploy/Install	☐ Known Cost ☑ Estimated Cost ☐ Unknown Low since basic technology exists
Cost to Maintain	☐ Known Cost ☑ Estimated Cost ☐ Unknown None – Effectively no maintenance for service life of rod with durable materials
Time to Deploy/Install	☐ Known Time ☑ Estimated Time ☐ Unknown Low
Time to Maintain	☐ Known Time ☐ Estimated Time ☑ Unknown Depends on final design, but should be low
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☑ Increase conspicuity of response vehicle ☐ Slow down traffic ☐ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☑ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☑ Work Vehicle ☐ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Can take a reasonable impact and return to the original configuration; would not become a projectile when struck; novel appearance should enhance effectiveness
Cons	Requires placement around vehicle, which could put it in harm's way; requires charging or connection to vehicle's electrical system

V - 02 ELECTROLUMINESCENT STRIP LIGHTING TO OUTLINE RESPONSE VEHICLE

Domain (select all that apply)	☑ Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	Electroluminescent (EL) strip lighting are thin and bendable materials that emit light when receiving vehicle power and are relatively insensitive to variations in viewing angle and distance. An example can be here.[1] Strips would be placed around the response vehicle.
Level of Evidence	☐ Specific Evaluation ☑ Analogous Evaluation ☐ Published Idea ☐ Project Generated Pedestrian garments that included both EL material along with retroreflective materials yielded longer response distances at night than the retroreflective material alone.[2]
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑Off the shelf
Development Still Required	☐ Extensive ☑ Moderate ☐ Limited ☐ None
Cost to Deploy/Install	☐ Known cost ☑ Estimated cost ☐ Unknown Low - Varies by vendor and width and length required
Cost to Maintain	☑ Known Cost ☐ Estimated Cost ☐ Unknown None – no battery replacement is required as EL strips are powered by the vehicle
Time to Deploy/Install	☐ Known Time ☑ Estimated Time ☐ Unknown Low
Time to Maintain	☐ Known Time ☐ Estimated Time ☑ Unknown
Lighting Applicability	☐ Daytime ☑ Nighttime ☐ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☑ Increase conspicuity of response vehicle ☐ Slow down traffic ☐ Direct or channel traffic ☐ Prevent worker from being struck ☐Prevent response vehicle from being struck ☐ Protect worker from injury ☐Protect response vehicle from damage ☐ Other _____
☑ **Engineering** ☐Motorist ☐ Worker ☐ Management ☑ Work Vehicle ☐ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Could enhance vehicle conspicuity in situations where retroreflective materials have limited utility, translating into greater recognition distance
Cons	Possibly expensive-dependent on vehicle factors, environmental factors, and characteristics of material that could affect cost; might be ineffective due to flashing vehicle lights; might mask or distract from worker

[1] https://www.firewaterlight.net/products/Electroluminescence-(EL)/Vehicles-/-Automotive/show-products.aspx?ID=36ad092f-72af-4662-9e03-bda124ee46ab&linkPath=3&lID=3_7

[2] Fekety, D. K., Edewaard, D. E., Stafford Sewall, A. A., & Tyrrell, R. A. (2016). Electroluminescent materials can further enhance the nighttime conspicuity of pedestrians wearing retroreflective materials. *Human Factors*, *58*(7), 976-985.

V - 03 LED STRIP LIGHTING TO DELINEATE OUTLINE OF RESPONSE VEHICLE

Domain (select all that apply)	☑ Roadway ☑ Marine ☑ Aviation ☑ Railroad
Description	LED Strip Lighting can delineate the outline of the response vehicle, as seen here.[1]
Level of Evidence	☐ Specific Evaluation ☑ Analogous Evaluation ☐ Published Idea ☐ Project Generated Evidence could not be found on the efficacy of this approach, but studies showing the longer detection and recognition distances with EL material used in conjunction with retroreflective tape [2] should apply generally to this type of material.
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf
Development Still Required	☐ Extensive ☑ Moderate ☐ Limited ☐ None Need to define pattern and total area required for effectiveness
Cost to Deploy/Install	☑ Known cost ☐ Estimated Cost ☐ Unknown The unit cost is low. Total cost will depend on amount used
Cost to Maintain	☐ Known Cost ☑ Estimated Cost ☐ Unknown Replacement for wear-and-tear or damage
Time to Deploy/Install	☐ Known Time ☑ Estimated Time ☐ Unknown Quick to deploy after pattern and engineering defined
Time to Maintain	☑ Known Time ☐ Estimated Time ☐ Unknown Minimal for wear-and-tear or failures
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☑ Increase conspicuity of response vehicle ☐ Slow down traffic ☐ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☑ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☑ Work Vehicle ☐ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Delineation of the response vehicle with LED strip lighting material could complement marking with retroreflective material; visible at angles that might not be optimal for retroreflection of headlight beams; effect should be similar to use of electroluminescent materials but brighter
Cons	More cost and maintenance than retroreflective material alone; some minimal power consumption; potentially more delicate

[1] https://www.carid.com/putco/putco-switchblade-tailgate-led-light-bar-174227908.html

[2] Fekety, D. K., Edewaard, D. E., Stafford Sewall, A. A., & Tyrrell, R. A. (2016). Electroluminescent materials can further enhance the nighttime conspicuity of pedestrians wearing retroreflective materials. *Human Factors*, *58*(7), 976-985.

V - 04 RETROREFLECTIVE SHEETING USED ON RESPONSE VEHICLE

Domain (select all that apply)	☑ Roadway ☐ Marine ☑ Aviation ☑ Railroad
Description	Add retroreflective material to response vehicle. If retroreflective material is already being used on vehicles, consider upgrading materials to highest quality of retroreflective/fluorescent material designed for vehicular use (e,g., school buses). Examples in an analysis by FEMA can be obtained here.[1]
Level of Evidence	☐ Specific Evaluation ☑ Analogous Evaluation ☐ Published Idea ☐ Project Generated Crash analyses comparing heavy trucks with reflective tape versus trucks without it suggest a crash reduction associated with reflective sheeting.[2]
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf
Development Still Required	☐ Extensive ☐ Moderate ☑ Limited ☐ None Need to select material and pattern.
Cost to Deploy/Install	☐Known Cost ☑ Estimated Cost ☐ Unknown Depends on quantity of material. Cost of 3M Diamond Grade DG3 sheeting is $657 for 36" x 50 yards (would cover multiple units). Used to outline school buses at acceptable cost levels
Cost to Maintain	☐Known Cost ☑ Estimated Cost ☐ Unknown Repair or replacement for wear-and-tear. Material has been robust in multiple applications.
Time to Deploy/Install	☐ Known Time ☑ Estimated Time ☐ Unknown Depends on the amount of sheeting used and where it is placed (e.g., number of cuts).
Time to Maintain	☐ Known Time ☑ Estimated Time ☐ Unknown Basic maintenance is washing. Replacement would be more time-consuming.
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☑ Increase conspicuity of response vehicle ☐ Slow down traffic ☐ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☑ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☑ Work Vehicle ☐ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Likely effective; no set up required once installed (worker has nothing to do); no power requirements; material characteristics well known making design of deployment relatively easy
Cons	Cost; sensitive to abrasion; fluorescent material bleaches in sun over time; oncoming vehicle's headlights must be on at night

[1] https://www.usfa.fema.gov/downloads/pdf/publications/fa_323.pdf

[2] Morgan, C. (2001). *The effectiveness of retroreflective tape on heavy trailers* (Report No. HS-809 222,). Washington, DC: National Highway Trafic Safety Administration.

V - 05 RESPONSE VEHICLE FOUR WAY FLASHER

Domain (select all that apply)	☑ Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	Add a novel flashing pattern to the response vehicles four-way flashers to create an additional stimulus and unique signature.
Level of Evidence	☐ Specific Evaluation ☐ Analogous Evaluation ☐ Published Idea ☑ Project Generated
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf Hardware is readily available. Design of flash pattern and choice of lamps must be done.
Development Still Required	☐ Extensive ☑ Moderate ☐ Limited ☐ None Design of flash pattern and choice of lamps.
Cost to Deploy/Install	☐ Known cost ☐ Ongoing costs ☑ Unknown Some equipment already installed on all vehicles—must be augmented.
Cost to Maintain	☑Known Cost ☐ Estimated Cost ☐ Unknown None
Time to Deploy/Install	☑ Known Time ☐ Estimated Time ☐ Unknown Development time relatively quick. Site deployment just a switch flip.
Time to Maintain	☐ Known Time ☑ Estimated Time ☐ Unknown Should be similar to the basic vehicle flasher system.
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☑ Increase conspicuity of response vehicle ☐ Slow down traffic ☐ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☑ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☑ Work Vehicle ☐ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Already at least partially on the vehicle; likely effective; low cost; can increase conspicuity and recognition
Cons	May cause some motorist confusion; may not be effective in the vicinity of the existing warning lights; can require extensive equipment approvals in some States (e.g., California)

V - 06 VEHICLE-MOUNTED FLOOD LIGHTS

Domain (select all that apply)	☑ Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	Lights that can be mounted on and powered by the response vehicle. This would increase visibility of the response vehicle and assist in any work that needs to be done, such as changing a tire. An example can be seen here.[1]
Level of Evidence	☐ Specific Evaluation ☑ Analogous Evaluation ☐ Published Idea ☐ Project Generated Depending on orientation of lights and driver viewing angle, work zone lights can improve motorists' detection of workers in a construction zone.[2]
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf
Development Still Required	☐ Extensive ☐ Moderate ☑ Limited ☐ None Procedures, analysis of mounting surface, and obtaining approval in some states.
Cost to Deploy/Install	☑ Known cost ☐ Estimated Cost ☐ Unknown $50 -$200 (depending on size and brightness); add additional costs for installation
Cost to Maintain	☐ Known Cost ☑ Estimated Cost ☐ Unknown Repair or replacement for wear-and-tear (LED bulbs have a long life)
Time to Deploy/Install	☐ Known Time ☑ Estimated Time ☐ Unknown Only requires analysis, selection of lamps, development of installation instructions, procurement, and installation.
Time to Maintain	☐ Known Time ☑ Estimated Time ☐ Unknown Low - only time to repair or replace for wear-and-tear.
Lighting Applicability	☐ Daytime ☑ Nighttime ☐ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☐ Slow down traffic ☐ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☑ Other Should speed up work thereby reducing exposure. Also, can make work site more conspicuous.
☑ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☑ Work Vehicle ☐ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Can help efficiency and safety; off-the-shelf; little training or procedural development required; should be reliable
Cons	Possible light pollution; possible masking effect of bright light; depending on worksite configuration, can't always be placed upstream of site (e.g., if loading vehicle onto tow truck)

[1] https://www.ledequipped.com/flood-spot-lights/
[2] Ellis, R. D., Amos, S., & Kumar, A. (2003). *Illumination guidelines for nighttime highway work.* (Report No. 498). Washington, DC: National Cooperative Highway Research Program

V - 07 VEHICLE-MOUNTED POOL NOODLE-LIKE DEVICE WITH HIGH-VIZ SHEETING

Domain (select all that apply)	☑ Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	Pool Noodle-type device covered with retroreflective sheeting to place around the vehicle (permanently or temporarily) to increase response vehicle's conspicuity. A detection system could be added, so an audible warning is provided to worker if struck. As it is a new idea, no picture is available.
Level of Evidence	☐ Specific Evaluation ☐ Analogous Evaluation ☐ Published Idea ☑ Project Generated
Technology Readiness	☑ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☐ Off the shelf
Development Still Required	☐ Extensive ☑ Moderate ☐ Limited ☐ None Need to integrate the noodle with appropriate retroreflective/fluorescent material (can also add LED lights) and to determine deployment strategy.
Cost to Deploy/Install	☐ Known cost ☑ Estimated Cost ☐ Unknown $4.00 for the noodle itself. High visibility materials (and/or lights) will depend on area. Attachment method (TBD) will add cost
Cost to Maintain	☐ Known Cost ☑ Estimated Cost ☐ Unknown Material subject to impact damage and will weather. Thus, repair or replacement for wear-and-tear will be required.
Time to Deploy/Install	☐ Known Time ☐ Estimated Time ☑ Unknown
Time to Maintain	☐ Known Time ☐ Estimated Time ☑ Unknown Device may be easily damaged
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☑ Increase conspicuity of response vehicle ☐ Slow down traffic ☐ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☑ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☑ Work Vehicle ☐ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Low cost of noodle and reflective material; the device is benign if struck; light and easy to handle; should not interfere with normal operations
Cons	Depending on worksite configuration, can't always be placed upstream of site (e.g., if loading vehicle onto tow truck)

V - 08 VEHICLE-MOUNTED ARROW BOARD

Domain (select all that apply)	☑ Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	A magnetic sign, mounted on the roadside vehicle, that contains a series of 5 arrow heads (seen here).[1] Arrow heads sequentially light to create the appearance of movement and encourage a passing motorist to move over.
Level of Evidence	☐ Specific Evaluation ☑ Analogous Evaluation ☐ Published Idea ☐ Project Generated Reduces speed and increases motorists' lateral passing distance when used in work zones.[2]
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf
Development Still Required	☐ Extensive ☐ Moderate ☑ Limited ☐ None Procedures and analysis of mounting surface.
Cost to Deploy/Install	☑Known Cost ☐ Estimated Cost ☐ Unknown $39.95 for the sign itself.
Cost to Maintain	☑ Known Cost ☐ Estimated Cost ☐ Unknown 4 AA batteries plus repair or replacement for wear-and-tear.
Time to Deploy/Install	☐ Known Time ☑ Estimated Time ☐ Unknown Has to be oriented based on position of response vehicle on the roadway.
Time to Maintain	☐ Known Time ☑ Estimated Time ☐ Unknown Repair or replacement for wear-and-tear plus battery changes.
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☑ **Education** ☑ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☑ Slow down traffic ☑ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☑ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☐ Work Vehicle ☑ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Easily rolled up so it can be stored in the truck or can be left on the vehicle; visibility over 800m and will run for 2-3 days in continuous use; presents clear message to move away from truck
Cons	Magnetic mount may not be sufficiently rugged; off-the-shelf model may not be sufficiently bright; depending on worksite configuration, sign can't always be placed upstream of site (e.g., if loading vehicle onto tow truck)

[1] https://trafficsafetyzone.com/product/magnetic-led-direction-sign/

[2] Steele, D.A., Zabecki, J.M., and Zimmerman, L. (2013) *Improving the Effectiveness of Nighttime Temporary Traffic Control Warning Devices, Volume 2: Evaluation of Nighttime Mobile Warning Lights.* Research Report No. FHWA-ICT-13-032.

V - 09 VEHICLE-MOUNTED CHANGEABLE MESSAGE SIGNS

Domain (select all that apply)	☑Roadway ☐ Marine ☑ Aviation ☐ Railroad
Description	Signs mounted on the back end of the work vehicle that convey safety information, warnings, and special instructions to motorists, as seen here.[1] It could be solar- or vehicle-powered.
Level of Evidence	☐ Specific Evaluation ☑ Analogous Evaluation ☐ Published Idea ☐ Project Generated Changeable message signs in work zones can reduce motorist speed or decrease percentage of traffic in closed lane.[2] No evaluation for vehicle-mounted applications.
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf
Development Still Required	☐ Extensive ☐ Moderate ☑ Limited ☐ None Procedures and analysis of mounting surface.
Cost to Deploy/Install	☑ Known Cost ☐ Estimated Cost ☐ Unknown $4,000-$10,900
Cost to Maintain	☐ Known Cost ☑ Estimated Cost ☐ Unknown Repair or replacement for wear-and-tear.
Time to Deploy/Install	☑ Known Time ☐ Estimated Time ☐ Unknown None
Time to Maintain	☑ Known Time ☐ Estimated Time ☐ Unknown Minimal—activate and select message
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☑ **Education** ☑ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☑ Slow down traffic ☑ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other
☑ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☑ Work Vehicle ☐ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Gives specific behavioral advice including directional arrows, “move over,” etc.; can be automated; large and compelling
Cons	Requires vehicle modification; may interfere with work operations; may take up storage space; messages need testing; depending on worksite configuration, sign can’t always be placed upstream of site (e.g., if loading vehicle onto tow truck); vehicle-mounted design has not been evaluated

[1] https://danasafetysupply.com/solar-powered-vehicle-mount-silent-messenger-portable-changeable-message-board-by-solartech/?gclid=CjwKCAiAyeTxBRBvEiwAuM8dnd672JBkQ8B3M4HVJCxpULl5XlCPbN3SNKdlm8OS1HCpUZ9V5p5adxoCR0AQAvD_BwE

[2] Mason, D. D. (2013). *Evaluation of Traffic Control Countermeasures to Improve Speed Limit Compliance in Work Zones on High-Speed Roadways* (Doctoral dissertation, University of New Brunswick)

V - 10 VEHICLE-MOUNTED RADAR SPEED DISPLAYS

Domain (select all that apply)	☑Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	Radar-based sign mounted to the response vehicle that shows the speed of approaching vehicles in an effort to slow approaching vehicles. An example can be seen here.[1]
Level of Evidence	☐ Specific Evaluation ☑ Analogous Evaluation ☐ Published Idea ☐ Project Generated Speed displays are associated with a speed reduction in work zones.[2,3]
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf
Development Still Required	☐ Extensive ☐ Moderate ☑ Limited ☐ None Develop mounting and wiring strategy as well as activation method.
Cost to Deploy/Install	☑ Known Cost ☐ Estimated Cost ☐ Unknown $2,400-$3,520 plus installation.
Cost to Maintain	☐ Known Cost ☑ Estimated Cost ☐ Unknown Repair or replacement for wear-and-tear.
Time to Deploy/Install	☐ Known Time ☑ Estimated Time ☐ Unknown Low
Time to Maintain	☐ Known Time ☑ Estimated Time ☐ Unknown Repair or replacement for wear-and-tear.
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☑ **Education** ☑Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☑ Slow down traffic ☐ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☑ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☑ Work Vehicle ☐ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Shown to be effective in lowering speeds and increasing uniformity of speeds; likely not distracting to motorists; straightforward behavioral message; minimal workload for employee
Cons	Expensive; no associated enforcement; likely needs an associated move over message; depending on worksite configuration, sign can't always be placed upstream of site (e.g., if loading vehicle onto tow truck)

[1] https://www.fleetsafety.com/mph-radar-speed-sign-package-monitor-iv-2-digit-red-display-12-volt-dc-power-cord-display-stand-can-be-mounted-anywhere-with-12v-power/

[2] Benekohal, R. F., Hajbabaie, A., Medina, J. C., Wang, M. H., & Chitturi, M. V. (2010). *Speed photo-radar enforcement evaluation in Illinois work zones*.

[3] Bowie, J. M. (2003). Efficacy of speed monitoring displays in increasing speed limit compliance in highway work zones. Unpublished Master's Thesis.

V - 11 VEHICLE MOUNTED AUTOMATED SPEED ENFORCEMENT

Domain (select all that apply)	☑Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	Worker deploys a radar camera that detects a speeding vehicle and takes a picture of the license plate to send the registered vehicle owner a ticket. Example can be seen here, on page 26, Figure 3-2.[1]
Level of Evidence	☐ Specific Evaluation ☑ Analogous Evaluation ☐ Published Idea ☐ Project Generated Has shown to reduce speed up to 7 mph in work zones.[2] Not evaluated in incident response context.
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☑ Multiple applications ☐ Off the shelf
Development Still Required	☐ Extensive ☐ Moderate ☑ Limited ☐ None Develop installation requirements and use procedures
Cost to Deploy/Install	☐ Known Cost ☑ Estimated Cost ☐ Unknown High depending on the specific system and amount of time to implement legislation.
Cost to Maintain	☐ Known Cost ☑ Estimated Cost ☐ Unknown Depends on the specific system and amount of legislation, enforcement and judicial time.
Time to Deploy/Install	☐ Known Time ☑ Estimated Time ☐ Unknown Low if district already has law permitting use in place but high if new legislation is needed.
Time to Maintain	☐ Known Time ☑ Estimated Time ☐ Unknown Upkeep of portable device plus repair or replacement for wear-and-tear.
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☑ Slow down traffic ☐ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☑ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☑ Work Vehicle ☐ Traffic Control	
☑ **Enforcement** ☑ Motorist ☐ Worker ☐ Management	

Review

Pros	Likely effective in speed reduction; easy to deploy where enabling legislation already exists
Cons	Can be expensive: requires law to implement; vehicle mounting will require development; possibly damaged by wrecker operations; depending on worksite configuration, can't always be placed upstream of site (e.g., if loading vehicle onto tow truck)

[1] https://www.ideals.illinois.edu/bitstream/handle/2142/45957/FHWA-ICT-10-064.pdf?sequence%3D2
[2] Benekohal, R. F., Hajbabaie, A., Medina, J. C., Wang, M. H., & Chitturi, M. V. (2010). *Speed photo-radar enforcement evaluation in Illinois work zones*.

V - 12 VEHICLE MOUNTED SWING ARM

Domain (select all that apply)	☑Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	Warning blade similar to a school bus stop arm but not an octagon installed onto response vehicle. An example of a swing arm used on ice cream trucks can be seen here.[1]
Level of Evidence	☐ Specific Evaluation ☑ Analogous Evaluation ☐ Published Idea ☐ Project Generated 77% reduction in child pedestrian-ice cream truck crashes.[2]
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☑ Multiple applications ☐ Off the shelf
Development Still Required	☐ Extensive ☐ Moderate ☑ Limited ☐ None Need to pick a design, develop installation requirements, and develop use procedures.
Cost to Deploy/Install	☐ Known Cost ☑ Estimated Cost ☐ Unknown Cost is low if existing designs are applicable. Otherwise, cost increases slightly.
Cost to Maintain	☐ Known Cost ☑ Estimated Cost ☐ Unknown Repair or replacement for wear-and-tear.
Time to Deploy/Install	☐ Known Time ☑ Estimated Time ☐ Unknown Can be accomplished quickly
Time to Maintain	☐ Known Time ☑ Estimated Time ☐ Unknown Repair or replacement for wear-and-tear.
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☑ Slow down traffic ☐ Direct or channel traffic ☑ Prevent worker from being struck ☑ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☑ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☑ Work Vehicle ☐ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Known to be effective for reducing ice cream truck and school bus related crashes; easy to install and deploy; includes lighting for night; can include message; can be tailored
Cons	Most effectiveness data from low speed roadways; may be masked by response vehicle flashing lights; depending on worksite configuration, swing-arm can't always be placed upstream of site (e.g., if loading vehicle onto tow truck) so areas are unprotected

[1] https://www.kenosha-reuse.com/NORTH-CHICAGO,IL/Commercial/Industrial/Ice-cream-truck-safety-swing-arm.cfm
[2] Hale, A., Blomberg, R. D., & Preusser, D. V. (1978). *Experimental field test of the model ice cream truck ordinance in Detroit* (No. DOT-HS-803-410 Final Rpt

V - 13 VEHICLE MOUNTED PORTABLE ROADWAY PERIMETER ALARM

Domain (select all that apply)	☑ Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	Consists of proximity sensor and a transmitter unit. The sensor is designed to detect vehicles penetrating the perimeter of the site, and the transmitter receives the warning from the sensor. The transmitter can be mounted on a work vehicle. This system can likely be modified to include sensors that could warn workers immediately. Similar to the patented Pedestrian Alerting System (PAS) (see here).[1]
Level of Evidence	☐ Specific Evaluation ☐ Analogous Evaluation ☑ Published Idea ☐ Project Generated
Technology Readiness	☑ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☐ Off the shelf
Development Still Required	☑ Extensive ☐ Moderate ☐ Limited ☐ None
Cost to Deploy/Install	☐ Known Cost ☐ Estimated Cost ☑ Unknown Likely moderate to high
Cost to Maintain	☐ Known Cost ☑ Estimated Cost ☐ Unknown Repair or replacement for wear-and-tear; may need batteries.
Time to Deploy/Install	☐ Known Time ☑ Estimated Time ☐ Unknown Significant—needs development.
Time to Maintain	☐ Known Time ☑ Estimated Time ☐ Unknown Repair or replacement for wear-and-tear.
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☐ Slow down traffic ☐ Direct or channel traffic ☑ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☑ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☑ Work Vehicle ☐ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Should work even if worker is screened; advance warning
Cons	False positive/negative rates are unknown and would have to be minimized; likely will require periodic recalibration; does not impact driver behavior unless also installed in approaching vehicle; depending on worksite configuration.

[1] https://patents.google.com/patent/US7095336

S - 01 LARGER SUNFLOWER STANDARD FLASHER PI-LIT SEQUENCE

Domain (select all that apply)	☑ Roadway ☐ Marine ☑ Aviation ☐ Railroad
Description	Set of cones with a rabbit-style (synced, sequential flash) beacon that are placed around a response vehicle to alert drivers to move over, as seen here.[1]
Level of Evidence	☐ Specific Evaluation ☑ Analogous Evaluation ☐ Published Idea ☐ Project Generated Shown to reduce speed and the number of vehicles in the closed lane 305m upstream of the lane closure in a work zone.[2,3]
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf
Development Still Required	☐ Extensive ☐ Moderate ☑ Limited ☐ None Need to develop procedures and evaluate for possible counterproductivity
Cost to Deploy/Install	☑ Known Cost ☐ Estimated Cost ☐ Unknown $300 for 6 units
Cost to Maintain	☑ Known Cost ☐ Estimated Cost ☐ Unknown $12.84/24 AA batteries but replacement cycle unknown
Time to Deploy/Install	☑ Known Time ☐ Estimated Time ☐ Unknown 1-2 minutes
Time to Maintain	☑ Known Time ☐Estimated Time ☐ Unknown Very minimal; battery change and damage repair/replacement
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☑ Slow down traffic ☑ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☑ Other Increase conspicuity of assistance site
☑ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☐ Work Vehicle ☑ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Effective for short duration on intermediate-term maintenance/construction projects analogous to service sites; automatic synchronization; durable; novel appearance; low cost
Cons	Cones take up space on work vehicle; possible projectile if struck by motorist; exposure while deploying/retrieving

[1] https://www.pi-lit.com/smart-conetop-lamp

[2]Finley, M. D., Ullman, G. L., & Dudek, C. L. (2001). Sequential warning-light system for work-zone lane closures. *Transportation research record*, *1745*(1), 39-45.

[3]Sun, C., Edara, P., Hou, Y., & Robertson, A. (2012). Safety evaluation of sequential warning lights in tapers at nighttime work zones. *Transportation research record*, *2272*(1), 1-8.

S - 02 PI-LIT SEQUENTIAL RABBIT STYLE BEACONING

Domain (select all that apply)	☑ Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	Small but powerful LED beacon units with a rabbit (sequential) style runway approach flash sequence to alert drivers to move over for a response vehicle. Device can be seen here.[1]
Level of Evidence	☐ Specific Evaluation ☑ Analogous Evaluation ☐ Published Idea ☐ Project Generated No evaluation on the efficacy of the Pi-Lit device exists, but it is analogous to other similar flare devices that have been evaluated around a disabled vehicle and shown to significantly reduce passing motorist speed and increase lateral separation from the disabled vehicle.[2]
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf
Development Still Required	☐ Extensive ☐ Moderate ☑ Limited ☐ None Use scenarios and procedures need to be developed. Light color must be selected
Cost to Deploy/Install	☑ Known cost ☐ Estimated Cost ☐ Unknown $400 - $625 depending on number of units
Cost to Maintain	☑ Known Cost ☐ Estimated Cost ☐ Unknown Repair or replacement for wear-and-tear.
Time to Deploy/Install	☑ Known Time ☐ Estimated Time ☐ Unknown 1 minute for a standard pattern without cones
Time to Maintain	☑ Known Time ☐ Estimated Time ☐ Unknown Repair or replacement for wear-and-tear.
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☑ Increase conspicuity of response vehicle ☑ Slow down traffic ☑ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☑ Other Increase conspicuity of the work site
☑ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☐ Work Vehicle ☑ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Battery lasts 36 hours on a charge; very robust; can be used on any roadway; can be covered by plastic traffic cones which will then flash in sequence; lightweight; compact
Cons	Exposes worker to traffic during deployment

[1] https://www.pi-lit.com/smart-flare
[2] De la Riva,M., Garvey,P.M., &. Pietrucha, M.T. (2006). Impact of Highway Safety Flares on Driver Behavior. *Transportation Research Record*, *1980*, 39-48

S - 03 PORTABLE BATTERY-OPERATED FLOOD LIGHT

Domain (select all that apply)	☑ Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	Portable battery powered tripod floodlight, as seen here,[1] that a roadside worker could remove from the wrecker and place near the disabled vehicle while stopped for an incident.
Level of Evidence	☐ Specific Evaluation ☑ Analogous Evaluation ☐ Published Idea ☐ Project Generated Depending on orientation of lights and driver viewing angle, work zone lights can improve motorists' detection of workers in a construction zone.[2]
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf
Development Still Required	☐ Extensive ☐ Moderate ☑ Limited ☐ None Need use procedures
Cost to Deploy/Install	☑ Known Cost ☐ Estimated Cost ☐ Unknown $687.00 to $1,579.99 depending on size/brightness and quantity
Cost to Maintain	☐ Known Cost ☑ Estimated Cost ☐ Unknown Repair or replacement for wear-and-tear.
Time to Deploy/Install	☐ Known Time ☑ Estimated Time ☐ Unknown Minimal
Time to Maintain	☐ Known Time ☑ Estimated Time ☐ Unknown Battery recharging and repair or replacement for wear-and-tear.
Lighting Applicability	☐ Daytime ☑ Nighttime ☐ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☐ Slow down traffic ☐ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☑ Other Light the work site to aid task and possibly increase conspicuity of work site.
☑ **Engineering** ☐ Motorist ☑ Worker ☐ Management ☐ Work Vehicle ☐ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Very bright to make the worker's task easier and thereby reduce exposure at the site. Should also increase conspicuity of the site. The units are light (8 lbs.) and fold up
Cons	The batteries would need periodic charging. Light intensity will vary with distance and glare/masking of worker could be an issue. Research has not evaluated smaller units. However, the more expensive units should be fairly bright. High cost

[1] https://www.pacatlantic.com/samalite/product/eco-flood-led-14k6/
[2] Bhagavathula, R. & Gibbons. R.B. (2017). Effect of Work Zone Lighting on Drivers' Visual Performance and Perceptions of Glare. *Transportation Research Record. 2617*, 44-51.

S - 04 LED ROAD FLARES

Domain (select all that apply)	☑Roadway ☐ Marine ☑ Aviation ☐ Railroad
Description	A type of pyrotechnic that produces a bright light to increase conspicuity of worker/response vehicle, as can be seen here.[1]
Level of Evidence	☑ Specific Evaluation ☐ Analogous Evaluation ☐ Published Idea ☐ Project Generated Road flares caused up to a 12.2% speed reduction in vehicles passing an emergency event when lights present versus not.[2]
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf
Development Still Required	☐ Extensive ☐ Moderate ☑Limited ☐ None Need use procedures
Cost to Deploy/Install	☑ Known Cost ☐ Estimated Cost ☐ Unknown $94.59/flare
Cost to Maintain	☐ Known Cost ☑ Estimated Cost ☐ Unknown Low – need to replace AA batteries after 72 hours of use
Time to Deploy/Install	☑Known Time ☐ Estimated Time ☐ Unknown Minimal
Time to Maintain	☑ Known Time ☐ Estimated Time ☐ Unknown None aside from the minimal time required to change battery
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☑ Increase conspicuity of worker ☑ Increase conspicuity of response vehicle ☑Slow down traffic
☑ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☐ Work Vehicle ☑ Traffic Control	☑ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	☐ Protect response vehicle from damage ☐ Other _____

Review

Pros	Ultra-bright; Long battery life; Durable; can be placed in road to light up area around disabled vehicle
Cons	Requires placement around vehicle; requires battery maintenance; expensive

[1] https://www.pi-lit.com/landing-zone-kit
[2] De La Riva, M., Garvey, P. M., & Pietrucha, M. T. (2006). Impact of highway safety flares on driver behavior. *Transportation research record*, *1980*(1), 39-48.

S - 05 FOLDABLE REFLECTIVE TRAFFIC CONES

Domain (select all that apply)	☑Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	The use of multiple portable, foldable traffic cones with reflective material (seen here)[1] to reduce the width of a lane to slow down and move passing motorists away from a response vehicle.
Level of Evidence	☐ Specific Evaluation ☑ Analogous Evaluation ☐ Published Idea ☐ Project Generated Lane narrowing has been evaluated in work zones and can cause speed reduction but increases risk of some types of crashes when lane width is below 12 ft.[2,3,4]
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf
Development Still Required	☐ Extensive ☐ Moderate ☑ Limited ☐ None Need to develop deployment patterns and training materials
Cost to Deploy/Install	☑Known Cost ☐ Estimated Cost ☐ Unknown $200 for a set of 5 mesh (36-inch cone)
Cost to Maintain	☑Known Cost ☐ Estimated Cost ☐ Unknown None other than periodic replacement due to end of service life, loss, or in-service damage
Time to Deploy/Install	☑Known Time ☐ Estimated Time ☐ Unknown 2-3 minutes
Time to Maintain	☑ Known Time ☐ Estimated Time ☐ Unknown None
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☑ Slow down traffic ☑ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☑ Other Increase conspicuity of site and improve motorist search
☑ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☐ Work Vehicle ☑Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	The five cones fold down and are held in a tote system that takes up little space; easy for worker to carry; lightweight (3-5 lbs. each); multiple cones for better chance of recognition
Cons	Drivers may hit cones making them projectiles; additional time to unpack and pack; exposure of worker during deployment and retrieval

[1] https://www.trafficsafetystore.com/traffic-cones/collapsible-28-hd#CC30-5RB
[2] Brewer, M. A., Pesti, G., & Schneider, W. H. (2005). *Identification and testing of measures to improve work zone speed limit compliance* (No. FHWA/TX-06/0-4707-1). Texas Transportation Institute, Texas A & M University System.
[3] Mason, D. D. (2013). *Evaluation of Traffic Control Countermeasures to Improve Speed Limit Compliance in Work Zones on High-Speed Roadways* (Doctoral dissertation, University of New Brunswick).
[4] Richards, S. H., Wunderlich, R. C., & Dudek, C. L. (1985). Field evaluation of work zone speed control techniques. *Transportation Research Record*, *1035*, 66-78.

S - 06 FOLDABLE ROADSIDE SIGN

Domain (select all that apply)	☑ Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	One or more foldable signs that are set up in advance of the response vehicle, as seen here.[1] Different messages can be used.
Level of Evidence	☐ Specific Evaluation ☑ Analogous Evaluation ☐ Published Idea ☐ Project Generated Only evaluated as part of a collection of items at work zones, no study examining the sign alone. Similar signs have shown to be effective in speed reduction.[2] No data on how it well it works in the absence of other devices.
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf.
Development Still Required	☐ Extensive ☐ Moderate ☑ Limited ☐ None Need to develop message to be used and placement procedures; decide number of signs
Cost to Deploy/Install	☑ Known cost ☐ Estimated Cost ☐ Unknown $70 for base. Diamond Grade 48x48 inch sign is $220.00
Cost to Maintain	☑ Known Cost ☐ Estimated Cost ☐ Unknown None other than periodic replacement
Time to Deploy/Install	☑ Known Time ☐ Estimated Time ☐ Unknown Less than 5-10 minutes
Time to Maintain	☑ Known Time ☐ Estimated Time ☐ Unknown Very low. Periodic cleaning
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☑ Slow down traffic ☑ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☑ Other Increase conspicuity of site; promote better search
☑ **Engineering** ☐Motorist ☐ Worker ☐ Management ☐ Work Vehicle ☑ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Very light and easy to handle; flexible selection of message; both the stand and the sign fold down into a relatively small space; sign is retroreflective and fluorescent; base withstands moderately strong windspeeds
Cons	Exposes worker during deploy/retrieve; deployment distance may have to be greater on high-speed roads

[1] https://www.trafficsafetywarehouse.com/36-Fold-Roll-Sign-System-Pink-Superbrite/productinfo/DF3000X36-PNKESA/

[2] Mason, D. D. (2013). *Evaluation of Traffic Control Countermeasures to Improve Speed Limit Compliance in Work Zones on High-Speed Roadways* (Doctoral dissertation, University of New Brunswick).

S - 07 DIRECTION INDICATOR BARRICADE

Domain (select all that apply)	☑ Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	A barricade with an arrow directing drivers away from the work/emergency response vehicle. The barricade has an arrow at the top, and an orange and white diagonal stripe panel is at the bottom of the barricade, as seen here.[3]
Level of Evidence	☐ Specific Evaluation ☑ Analogous Evaluation ☐ Published Idea ☐ Project Generated Research on barricades show they are effective for lane diversions.[4]
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf
Development Still Required	☐ Extensive ☐ Moderate ☐ Limited ☑ None
Cost to Deploy/Install	☑ Known cost ☐ Estimated Cost ☐ Unknown $60-$100
Cost to Maintain	☑ Known Cost ☐ Estimated Cost ☐ Unknown None beyond periodic replacement
Time to Deploy/Install	☑ Known Time ☐ Estimated Time ☐ Unknown Minimal
Time to Maintain	☑ Known Time ☐ Estimated Time ☐ Unknown None, beyond periodic replacement
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☑ Increase conspicuity of response vehicle ☑Slow down traffic ☑ Direct or channel traffic ☐Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☑ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☐ Work Vehicle ☑ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Compact size and fast setup; collapsible, spring loaded feet; "knockdown" (lies flat when struck); low weight (7.5 lb. with feet filled with sand); low cost
Cons	Typically used in multiples (unknown how effective a single would be); need for worker to be exposed during deploy and retrieve; need to remember to deploy/retrieve

[3] http://www.atksafetysupply.com/product/directional-indicator-barricades/
[4] Pain, R.F., McGee, H.W. & Knapp, B.G. (1982). *Evaluation of the traffic controls for highway work zones*. (Report No. 236). Washington, DC: National Cooperative Highway Research Program.

S - 08 SAFETY ALERT MAN

Domain (select all that apply)	☑ Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	A recognizable symbol or figure that alerts motorists to slow down for upcoming roadway hazards, including broken-down vehicles and response vehicles, as can be seen here.[1] Could be coupled with an awareness campaign
Level of Evidence	☐ Specific Evaluation ☐ Analogous Evaluation ☑ Published Idea ☐ Project Generated
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf Lots of different figures available and used for sales and promotion. Also similar to robot flagmen used at road work sites.
Development Still Required	☐ Extensive ☑ Moderate ☐ Limited ☐ None Have to pick the analytically most cost-effective approach and test its effect.
Cost to Deploy/Install	☐ Known Cost ☑ Estimated Cost ☐ Unknown $300 ($100 - Figure, $200 – Fan) if inflatable; likely more for robot flaggers.
Cost to Maintain	☐ Known Cost ☐ Estimated Cost ☑ Unknown Dependent on durability of figure actually used.
Time to Deploy/Install	☐ Known Time ☐ Estimated Time ☑ Unknown Can be relatively long for inflatable, but shorter for robot.
Time to Maintain	☐ Known Time ☐ Estimated Time ☑ Unknown Can be relatively long for inflatable, but shorter for robot.
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both Requires adding lighting or retroreflective material to figure for nighttime use.

Classification

Mode/Target	Intention
☑ **Education** ☑ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☑ Slow down traffic ☐ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other Increase driver recognition of work site.
☐ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☐ Work Vehicle ☐ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Easily detectable and compelling; existing commercial components
Cons	Not necessarily inherently associated with work site or response work; might require companion publicity program; could be high cost; could be high deployment/recover time

[1] https://patentimages.storage.googleapis.com/6b/04/31/209ecc3bc0086b/US20130047477A1.pdf

S - 09 PSEUDO BARRICADE

Domain (select all that apply)	☑ Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	Use of lightweight, retroreflective/fluorescent, 4ft high barricade material to mark off the area around a work/response vehicle, as seen here.[1] The high visibility material can be strung between portable posts to install.
Level of Evidence	☐ Specific Evaluation ☐ Analogous Evaluation ☐ Published Idea ☑ Project Generated
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf High visibility plastic fence material is readily available but stanchions and deployment system must be developed or adapted.
Development Still Required	☐ Extensive ☑ Moderate ☐ Limited ☐ None Developing a system will take some time and effort but should be possible from commercially-available components.
Cost to Deploy/Install	☐ Known cost ☐ Estimated Cost ☑ Unknown $110 for half of a 50 ft roll of barricade material, but development cost for deployment component is unknown.
Cost to Maintain	☑ Known Cost ☐ Estimated Cost ☐ Unknown Repair or replacement for wear-and-tear will be needed but cannot be estimated until design is finalized.
Time to Deploy/Install	☐ Known Time ☑ Estimated Time ☐ Unknown Low – 5-10 minutes per stop assuming good deployment system.
Time to Maintain	☐ Known Time ☐ Estimated Time ☑ Unknown Repair or replacement for wear-and-tear.
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☑ Slow down traffic ☑ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☑ Other Increase conspicuity of the work site.
☑ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☐ Work Vehicle ☑ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Material is lightweight, flexible, easy to install, and rolls easily for storage; combines retroreflective and fluorescent; should be a low-cost system
Cons	Effectiveness unknown; may not always have room to deploy it; not very durable, but inexpensive to replace; may have a wind speed limit

[1] https://www.pss-innovations.com/safety-products/delineators-fencing/nitelite-ii-plastic-reflective-fence

S - 10 PANEL ROADSIDE SIGN WITH FLASHER

Domain (select all that apply)	☑ Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	A vertical panel with a rubber base to be placed at the roadside near the response vehicle. A variety of messages and legends can be printed on one or two sides of the panel. Engineer, High Performance or Diamond Grade reflective sheeting can be ordered, as seen here.[1] Widely used in *Click-It-or-Ticket* programs.
Level of Evidence	☐ Specific Evaluation ☐ Analogous Evaluation ☐ Published Idea ☑ Project Generated
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf
Development Still Required	☐ Extensive ☐ Moderate ☑ Limited ☐ None Need to determine best messages, sign shape and size, and number to deploy per site.
Cost to Deploy/Install	☑ Known cost ☐ Estimated Cost ☐ Unknown $30 each for panel with hi prismatic sheeting (add $30 for standard D cell flashing barricade light).
Cost to Maintain	☐ Known Cost ☑ Estimated Cost ☐ Unknown Periodic replacement from wear-and-tear.
Time to Deploy/Install	☑ Known Time ☐ Estimated Time ☐ Unknown None
Time to Maintain	☑Known Time ☐ Estimated Time ☐ Unknown Minimal—must be unstowed and opened. Can be done very quickly.
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☑ Slow down traffic ☑ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☑ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☐ Work Vehicle ☑ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Low cost. The device should increase detection and recognition distances. Signs are reasonable cost and weight. Various messages could be carried to cover different situations.
Cons	Harder to store than foldable cones. Could distract passing drivers

[1] https://www.traffixdevices.com/products/barricades/vertical-panels

S - 11 PORTABLE SPEED MESSAGE SIGN

Domain (select all that apply)	☑ Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	Standard speed feedback sign (also called dynamic speed display) mounted on a dolly, as can be seen here.[1] Sign would be carried in the response vehicle to be positioned nearby during a stop.
Level of Evidence	☐ Specific Evaluation ☑Analogous Evaluation ☐ Published Idea ☐ Project Generated Reduces speed and crashes on rural highways.[2,3]
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf
Development Still Required	☐ Extensive ☐ Moderate ☑ Limited ☐ None
Cost to Deploy/Install	☑ Known cost ☐ Estimated Cost ☐ Unknown $4,017.94 +
Cost to Maintain	☐ Known Cost ☑ Estimated Cost ☐ Unknown Repair or replacement for wear-and-tear.
Time to Deploy/Install	☐ Known Time ☑ Estimated Time ☐ Unknown Low – take off truck, possibly assemble, and turn on
Time to Maintain	☐ Known Time ☐ Estimated Time ☑ Unknown Repair or replacement for wear-and-tear.
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☑**Education** ☑ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☑ Slow down traffic ☐ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☐ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☐ Work Vehicle ☐Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Speed can be alternated with a set cautious speed; additional sign can attach to base (e.g., one with reason for lower recommended speed); batteries charged in 6 hours and last 10 to 14 days of continuous use
Cons	Device may be difficult to fit in trunk and cumbersome; the total dolly system is heavy (80-100 lbs.); numbers designed to be read at 400ft-inadequate for freeway use; expensive

[1] https://www.emedco.com/safepace-100-radar-feedback-sign-with-dolly-mm2047.html?utm_campaign=PC-03-Traffic%26ParkingSigns_CatchallBURST_Emedco_PLA_NB_C_Google_US&utm_source=google&utm_medium=cpc&utm_term=&matchtype=&device=c&adgroupid=PC-03&keycode=WB0139&gclid=EAIaIQobChMI1NDW5O2N5wIVDfDACh0l3w1IEAQYAyABEgLgDfD_BwE&gclsrc=aw.ds

[2]Sandberg, W., Schoenecker, T., Sebastian, K., & Soler, D. (2009). *Long-Term Effectiveness of Dynamic Speed Monitoring Displays (DSMD) for Speed Management at Speed Limit Transitions*. Washington, DC: Federal Highway Administration

Hallmark, S. L., Qiu, Y., Hawkins, N., & Smadi, O. (2015). Crash modification factors for dynamic speed feedback signs on rural curves. *Journal of Transportation Technologies*, *5*(01), 9.

S - 12 STATIONARY POLICE PATROL CAR

Domain (select all that apply)	☑ Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	Circulating, stationary, or empty police patrol car visible to motorists to encourage them to slow down. A police officer would need to be available for non-emergency roadside personnel.
Level of Evidence	☐ Specific Evaluation ☑ Analogous Evaluation ☐ Published Idea ☐ Project Generated A visible police patrol car can reduce motorists' speeds in work zones.[1]
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☑ Multiple applications ☐ Off the shelf
Development Still Required	☐ Extensive ☑ Moderate ☐ Limited ☐ None Have to move from the idea to the practical.
Cost to Deploy/Install	☐ Known Cost ☑ Estimated Cost ☐ Unknown Mostly labor and equipment (vehicle) costs.
Cost to Maintain	☐ Known Cost ☑Estimated Cost ☐ Unknown Repair or replacement for wear-and-tear plus ticket processing costs.
Time to Deploy/Install	☐ Known Time ☑ Estimated Time ☐ Unknown Low—just need to develop a plan.
Time to Maintain	☐ Known Time ☑ Estimated Time ☐ Unknown Repair or replacement for wear-and-tear.
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☑ Slow down traffic ☐ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☐ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☐ Work Vehicle ☐ Traffic Control	
☑ **Enforcement** ☑ Motorist ☐ Worker ☐ Management	

Review

Likely effectiveness	Likely effectiveness; mostly hardware; replicates successful previous countermeasures
Cons	Additional labor and vehicle costs; need participation from local police department; difficult for clubs to control

[1] Mason, D. D. (2013). *Evaluation of Traffic Control Countermeasures to Improve Speed Limit Compliance in Work Zones on High-Speed Roadways* (Doctoral dissertation, University of New Brunswick).

S - 13 TEMPORARY RUMBLE STRIPS

Domain (select all that apply)	☑ Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	Temporary in-lane raised rumble strip comes in three 24-pound segments that fit together like puzzle pieces as seen here.[1] Each truck would carry a single rumble strip.
Level of Evidence	☐ Specific Evaluation ☑ Analogous Evaluation ☐ Published Idea ☐ Project Generated Shown to reduce speed and increase lane crosser-overs around work zones,[2] but the effects of a single rumble strip beside a response vehicle is unknown. Also, may require advance signage to be acceptable and avoid liability.
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf
Development Still Required	☐ Extensive ☑ Moderate ☐ Limited ☐ None Need to turn the off-the-shelf product into a viable system for response work.
Cost to Deploy/Install	☑ Known cost ☐ Estimated Cost ☐ Unknown $900 for a full strip for low-speed roads (up to 35 mph); $3000 for high speed roads. Signage would be additional.
Cost to Maintain	☐ Known Cost ☑ Estimated Cost ☐ Unknown Repair or replacement for wear-and-tear.
Time to Deploy/Install	☐ Known Time ☑ Estimated Time ☐ Unknown 5-10 minutes depending on traffic; more if signage added.
Time to Maintain	☐ Known Time ☐ Estimated Time ☑ Unknown Depends on need for repair or replacement for wear-and-tear.
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☑ Slow down traffic ☐ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☑ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☐ Work Vehicle ☑ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Applicable to all weather conditions; jigsaw connections on each end of strip allows for easy connection of one strip to another; physical "barrier"
Cons	Risky if installer needs to enter roadway; more than one rumble strip may be needed; expensive; heavy

[1] https://www.traffixdevices.com/products/additional/traffix-alert
[2] Yang, ., Ozbay, K., & Bartin, B. (2015). Effectiveness of temporary rumble strips in alerting motorists in short-term surveying work zones. *Journal of Transportation Engineering*, *141*(10), 0501500

M - 01 DRONE RADAR

Domain (select all that apply)	☑ Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	Drone radar is an electronic device that emits signals that activate radar detectors used by the traveling public, as seen here on page 8, Figure 1.[1] Workers would have drone radars with them in response vehicles that would be deployed manually or semi-automatically (e.g., pushbutton) on site.
Level of Evidence	☐ Specific Evaluation ☑ Analogous Evaluation ☐ Published Idea ☐ Project Generated Decreases motorist speed in work zones by an average of 2 mph and up to 8 mph for individual vehicles equipped with radar detectors.[2]
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf
Development Still Required	☐ Extensive ☐ Moderate ☑ Limited ☐ None
Cost to Deploy/Install	☑ Known Cost ☐ Estimated Cost ☐ Unknown $400-600
Cost to Maintain	☐ Known Cost ☑ Estimated Cost ☐ Unknown Low – May need to replace batteries or parts to service
Time to Deploy/Install	☐ Known Time ☑ Estimated Time ☐ Unknown Low to Moderate – depending on type of structure and deployment scheme.
Time to Maintain	☐ Known Time ☑ Estimated Time ☐ Unknown Low _____
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☑ Slow down traffic ☐ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☑ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☐ Work Vehicle ☑ Traffic Control	
☑ **Enforcement** ☑ Motorist ☐ Worker ☐ Management	

Review

Pros	Effective in speed reduction even without traditional enforcement if vehicle has radar detector, which is illegal in many States
Cons	Speed reductions are temporary and restricted to near location of drone; somewhat expensive to acquire; may be time-consuming or require special deployment training; percentage of vehicles with radar detectors likely varies, across State and type of roadway; could be acknowledging illegal device use

[1] https://www.workzonesafety.org/files/documents/database_documents/07-2908.pdf
[2] Eckenrode, R. T., Sarasua, W. A., Mattox III, J. H., Ogle, J. H., & Chowdhury, M. (2007). Revisiting the use of drone radar to reduce speed in work zones: South Carolina's experience. *Transportation Research Record*, *2015*(1), 19-27.

M - 02 INCREASED FINES NEARBY ROADSIDE INCIDENTS

Domain (select all that apply)	☑Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	Double fines for motorists failing to slow down and/or move-over for response vehicles
Level of Evidence	☐ Specific Evaluation ☑ Analogous Evaluation ☐ Published Idea ☐ Project Generated Traffic speeds of motorists in work zones did not change four to six months after the double-fine law was implemented.[1]
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☑ Multiple applications ☐ Off the shelf
Development Still Required	☐ Extensive ☑ Moderate ☐ Limited ☐ None Need to modify emergency vehicle slow/move over law in some States to include service vehicles
Cost to Deploy/Install	☐ Known Cost ☑ Estimated Cost ☐ Unknown Depending on the amount of legislation, enforcement and publicity time
Cost to Maintain	☐ Known Cost ☑ Estimated Cost ☐ Unknown Depending on the amount of enforcement and continuing education time
Time to Deploy/Install	☐ Known Time ☑ Estimated Time ☐ Unknown Depends largely on whether legislative change is needed
Time to Maintain	☐ Known Time ☑ Estimated Time ☐Unknown Low once everything is in place
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☑ Slow down traffic ☑ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☐ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☐ Work Vehicle ☐ Traffic Control	
☑ **Enforcement** ☑ Motorist ☐ Worker ☐ Management	

Review

Pros	No hardware; promotes good behavior; consistent with current practices
Cons	Will take time to implement and enforce; possible pushback on law change; limited evidence on effectiveness of increased fines in work zones

[1] Ullman, G. L., Carlson, P. J., & Trout, N. D. (2000). Effect of the work zone double-fine law in Texas. *Transportation Research Record*, *1715*(1), 24-29.

M - 03 MOVE-OVER LAWS

Domain (select all that apply)	☑Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	Move-Over laws require drivers approaching a scene where emergency responders are present to either change lanes when possible and/or reduce vehicle speed.
Level of Evidence	☑ Specific Evaluation ☐ Analogous Evaluation ☐ Published Idea ☐ Project Generated Overall compliance with the move over component of the Florida laws was 75.9%, but compliance with the legal requirement to slow to 20 mph below the speed limit when not moving over was just 5.8%.[1] Not all current move over laws apply to road service vehicles.
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple application ☑Off the shelf Enough model laws exist to make legislative service time minimal to draft new law.
Development Still Required	☐ Extensive ☑ Moderate ☐ Limited ☐ None If law exists, it must be further publicized. If it doesn't exist, it must be passed.
Cost to Deploy/Install	☐ Known Cost ☑ Estimated Cost ☐ Unknown Low – Moderate - Depending on extent law is paired with enforcement and media efforts
Cost to Maintain	☐ Known Cost ☑ Estimated Cost ☐ Unknown Low – Moderate depending on level of enforcement and judicial efforts
Time to Deploy/Install	☐ Known Time ☑ Estimated Time ☐ Unknown Low to Moderate - Depends on whether law exists and the extent of enforcement and media
Time to Maintain	☐ Known Time ☑ Estimated Time ☐ Unknown Low – Moderate depending on level of enforcement and judicial efforts
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☑ Slow down traffic
☐ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☐ Work Vehicle ☐ Traffic Control	☑ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury
☑ **Enforcement** ☑ Motorist ☐ Worker ☐ Management	☐ Protect response vehicle from damage ☐ Other _____

Review

Pros	Relatively low cost – every State has a move-over law, but some may not apply specifically to wreckers; publicity about law should improve motorist search for workers
Cons	Maximally effective only when enforced; currently does not apply everywhere to transportation maintenance personnel, towing/recovery operators, and service patrol operators; not proven to be effective – very dependent on motorists' public awareness and enforcement

[1] Carrick, G., & Washburn, S. (2012). The move over law: effect of emergency vehicle lighting on driver compliance on Florida freeways. *Transportation Research Record*, *2281*(1), 1-7.

M - 04 REPORT LOCATION AS A SPEED TRAP ON WAZE

Domain (select all that apply)	☑ Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	The response vehicle itself (automated) or the driver of the response vehicle (manual) makes a report of a speed trap at their location using WAZE.
Level of Evidence	☐ Specific Evaluation ☐ Analogous Evaluation ☐ Published Idea ☑ Project Generated
Technology Readiness	☑ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☐ Off the shelf
Development Still Required	☐ Extensive ☑ Moderate ☐ Limited ☐ None Have to develop requirements for entire system.
Cost to Deploy/Install	☐ Known cost ☐ Estimated Cost ☑ Unknown Could be low depending on extent of software development.
Cost to Maintain	☐ Known Cost ☐ Estimated Cost ☑ Unknown Likely low
Time to Deploy/Install	☐ Known Time ☐ Estimated Time ☑ Unknown Depends on software complexity.
Time to Maintain	☐ Known Time ☐ Estimated Time ☑ Unknown Should be typical for software.
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

Classification

Mode/Target	Intention
☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☐ Increase conspicuity of response vehicle ☑ Slow down traffic ☐ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☐ **Engineering** ☐ Motorist ☐ Worker ☐ Management ☐ Work Vehicle ☐ Traffic Control	
☑ **Enforcement** ☑ Motorist ☐ Worker ☐ Management	

Review

Pros	Drivers are used to slowing based on Waze inputs; can "disguise" site or simply call out the site and the desired/required behavior; almost totally a software solution; limited or no tasks for worker
Cons	Only a limited number of drivers follow Waze, but there is much "herd behavior" that can help

M - 05 HAAS ALERT

Domain (select all that apply)	☑ Roadway ☐ Marine ☐ Aviation ☐ Railroad
Description	A collision prevention service keeping response vehicles and worker safe as they respond to incident. Approaching motorists receive advanced warning inside their vehicles either via the built-in GPS technology or through the GPS technology within a portable electronic device when emergency crews are on-scene nearby as seen here.[1]
Level of Evidence	☐ Specific Evaluation ☐ Analogous Evaluation ☐ Published Idea ☑ Project Generated
Technology Readiness	☐ Idea ☐ Prototype ☐ Demonstration ☐ Multiple applications ☑ Off the shelf
Development Still Required	☑ Extensive ☐ Moderate ☐ Limited ☐ None Needs thorough definition of proof of concept with HAAS and tabletop analysis
Cost to Deploy/Install	☐ Known Cost ☐ Estimated Cost ☑ Unknown Need to contact HAAS alert for their system cost and details on applicability
Cost to Maintain	☐ Known Cost ☑ Estimated Cost ☐ Unknown Low (excluding phone & carrier rates)
Time to Deploy/Install	☐ Known Time ☑ Estimated Time ☐ Unknown Low
Time to Maintain	☐ Known Time ☑ Estimated Time ☐ Unknown Low (assuming reasonable hardware reliability)
Lighting Applicability	☐ Daytime ☐ Nighttime ☑ Both

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☐ **Education** ☐ Motorist ☐ Worker ☐ Management	☐ Increase conspicuity of worker ☑ Increase conspicuity of response vehicle ☐ Slow down traffic ☐ Direct or channel traffic ☐ Prevent worker from being struck ☐ Prevent response vehicle from being struck ☐ Protect worker from injury ☐ Protect response vehicle from damage ☐ Other _____
☑ **Engineering** ☑ Motorist ☐ Worker ☐ Management ☐ Work Vehicle ☐ Traffic Control	
☐ **Enforcement** ☐ Motorist ☐ Worker ☐ Management	

Review

Pros	Automatically alerts motorist through users' vehicle system or through their portable electronic device (not unlike Waze)
Cons	No evidence it is effective; may have distracting effects; not applicable to all vehicles (i.e., those without built-in GPS technology)

[1] https://www.haasalert.com/

Appendix C: Countermeasure Research Candidates

This Appendix presents a table of the key evaluation/field test considerations for the 13 countermeasures considered for the on-road evaluation. The data table consists of the following:

- A countermeasure description presented in Appendix B—using the same numbering system described in that Appendix
- Possible test approaches to conduct an evaluation
- Support resources needed to accomplish an evaluation
- Pros/cons of undertaking the research
- A judgement on whether or not the research could be accomplished under COVID-19 pandemic conditions

Countermeasure	Test Approach(es)	Needed Support	Pros	Cons	Can Do Under Pandemic Conditions?
W-02-Worker Vest Warning System: Consists of an impact sensor and a transmitter unit. The impact sensor is designed to detect vehicles penetrating the perimeter of a zone (e.g., roadside incident area), and the transmitter receives the warning from the sensor. The transmitter can be placed in the pocket of a worker's vest.	• Staged test with car and tow truck and natural traffic • Remain for time (TBD) and measure alarms • Analyze alarms to see if real threat or false alarm • Analyze response time alarm provides to worker • Analyze worker reactions to alarm	• Tow truck and driver • Patent holder's help in getting operational system • Possible ability to trigger alarm for staged threat • Club host	• Novel system that requires only a binary response from the operator—no action if off; bail-out if triggered	• Likely not commercial off the shelf (COTS) • Would take some engineering to get working prototype • If not COTS, clubs couldn't use immediately	• Yes

Countermeasure	Test Approach(es)	Needed Support	Pros	Cons	Can Do Under Pandemic Conditions?
W-03-Basing Worker Pay on Safety Compliance: Increase or reduce worker or emergency response personnel pay based on rate of compliance with safety standards.	• Naturalistic test • Take baseline then implement and take post • Observe compliance (chase calls) • Survey of worker reactions	• Club willing to modify policies • Union approval	• No hardware or software • Covers broad safety principles	• Requires chasing calls under social distancing • Must hide paradigm from workers to avoid Hawthorne Effect	• Probably (Can certainly gauge response using a survey)
W-04-Electroluminescent Materials on Worker Vests: Electroluminescent (EL) materials are bendable materials that emit light when powered and enhance pedestrian conspicuity in situations where retroreflective materials have limited utility. EL are relatively insensitive to variations in viewing angle. Commercial vests that use EL are available. Some also have good retro- reflective qualities.	• Staged test (electroluminescent vest/standard vest) • Look at speed and lateral distance of passing vehicles	• Tow truck and driver • Purchase commercial vests • Club host	• COTS equipment • Straightforward to implement •	• Nighttime only • Staged test can't measure worker compliance with use of vest	• Yes
W-05-Wearable Safety Light: Wearable safety lights consists of shoulder mounted lights. Lights attach magnetically to a point on the top of a worker's shoulder and project light to the front and back. Steady burn or flashing lights can be deployed.	• Staged test (lights/standard equipment with no lights) • Look at speed and lateral distance of passing vehicles	• Tow truck and driver • Purchase lights • Club host	• COTS equipment • Straightforward to implement	• Light maintenance • Nighttime only	• Yes

Countermeasure	Test Approach(es)	Needed Support	Pros	Cons	Can Do Under Pandemic Conditions?
W-06-Reflective Vests: High quality vests are available with sufficient retroreflective and fluorescent material that can be worn over coats of workers/response personnel in winter and are comfortable in summer.	• Staged test (enhanced vest/standard vest) • Look at speed and lateral distance of passing vehicles	• Tow truck and driver • Agree on what constitutes a "high quality vest" • Purchase commercial vests • Club host	• COTS equipment • Straightforward to implement	• Nighttime only • Staged test can't measure worker compliance with use of the vest	• Yes
W-07-Team Response/Flagger: One person directs traffic away from a roadside incident using gestures, signs or flags.	• Staged test (regular/2-person) • Look at speed and lateral distance of passing vehicles	• Tow truck and driver • Purchase signs/flags • Specify safety gear for assistant • Club host • Second worker • Training as a team	• Good evidence • Straightforward to implement • 24-hour	• Need to decide on level of training for extra person and who/how it will be implemented	• Yes
V-04-Retroreflective Sheeting Used on Response Vehicle: Add retroreflective material to response vehicle. If retroreflective material is already being used on vehicles, consider upgrading materials to highest quality of retroreflective/fluorescent material designed for vehicular use (e,g., school buses).	• Staged test (regular/enhanced) • Look at speed and lateral distance of passing vehicles	• Tow truck to enhance + standard truck and driver • Purchase retroreflective enhancement • Club host	• No worker compliance issue • COTS materials • Reasonable cost	• Nighttime only	• Yes
V-08-Vehicle-Mounted Arrow Board: A magnetic sign, mounted on the roadside vehicle that contains a series of 5 arrow heads. Arrow heads sequentially light to create the appearance of movement and encourage a passing motorist to move over.	• Staged test (no sign/sign) • Look at speed and lateral distance of passing vehicles	• Tow truck and driver • Sign • Some training • Club host	• COTS • Doesn't require worker in the roadway • 24-hour if lights are bright enough	• No obvious ones	• Yes

Countermeasure	Test Approach(es)	Needed Support	Pros	Cons	Can Do Under Pandemic Conditions?
S-02 PI-Lit Sequential Rabbit Style Beaconing: Small but powerful LED beacon units with a rabbit (sequential) style runway approach flash sequence to alert drivers to move over for a response vehicle.	• Staged test (with/without beacons) • Look at speed and lateral distance of passing vehicles	• Tow truck and driver • Beacons • Some training • Club host	• COTS • 24-hour but best at night • Novel	• Small additional exposure to traffic • Possible projectile if hit during test	• Yes
S-06-Foldable Roadside Sign: One or more foldable signs that are set up in advance of the response vehicle. Different messages can be used.	• Staged test (sign/no sign/varied message) • Look at speed and lateral distance of passing vehicles	• Tow truck and driver • Sign(s) • Club host	• COTS • 24-hours • Compact and easy to store	• Small additional exposure to traffic to deploy and retrieve • Possible projectile if hit during test	• Yes
M-03-Move-Ocer Laws: Move-Over laws require drivers approaching a scene where emergency responders are present to either change lanes when possible and/or reduce vehicle speed.	• Pre/post law or ordinance • Simulate law with publicity • Look at speed and lateral distance of passing vehicles	• Legislature or city/county council • Tow truck and driver • Club host	• No hardware or software • Minimal expense to clubs except for publicity	• Getting legislation passed on study schedule • Controlling publicity	• Questionable
M-04-Report Location as a Speed Trap on WAZE: The response vehicle itself (automated) or the driver of the response vehicle (manual) makes a report of a speed trap at their location using WAZE.	• Staged test (with/without WAZE) • Look at speed and lateral distance of passing vehicles	• Tow truck and driver • Club host • Support if using vehicle-report method used • WAZE involvement (or at least notification)?	• Software is free and easily accessible	• Vehicle-report approach requires some engineering/development • Does not address whether driver would remember to send notification	• Yes