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16. ABSTRACT

Highway maintenance operations in California often place workers close to the traveling public, with shadow trucks and truck-mounted attenuators (TMAs) offering protection. In response, the AHMCT Research Center and Caltrans collaborated to develop and field-test a new system known as the Truck-Mounted Attenuator Accessory (TMAA) package. This package was tested over the course of a year in real-world conditions, aimed to improve work zone safety by influencing driver behavior through a combination of technologies: radar speed feedback signs, panic warning lights, mobile digital video recording (mDVR), and iCone alerts for drivers via mobile apps.

The study found that the panic light system had the most immediate effect, successfully gaining driver attention and encouraging speed reduction near work zones. The mDVR system proved valuable not only for incident documentationincluding a recorded TMA truck impactbut also for enabling remote access to footage. While the radar speed sign and iCone alerts showed promise, more research is needed to fully understand their impact and improve data integration with traffic management systems. Feedback from Caltrans operators suggests that the combined systems contributed to an improved work environment.

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# Advanced Highway Maintenance and Construction Technology Research Center

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## Task 4158
## Caltrans Field Trials of the Truck-Mounted Attenuator Accessory (TMAA) Package

Dave Torick, Barbara Linke
Barbara Linke: Principal Investigator

AHMCT Research Report: UCD-ARR-25-03-31-02
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# California Department of Transportation

Division of Research, Innovation and System Information

# Executive Summary

The California Department of Transportation (Caltrans) faces significant safety hazards in highway maintenance operations, particularly from high-speed traffic in work zones. Shadow trucks, equipped with truck-mounted attenuators (TMAs), are used to shield work zones, but they provide limited protection against heavy vehicle impacts, posing a severe risk to operators. To mitigate this risk, the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center, in collaboration with Caltrans, tested an innovative Truck-Mounted Attenuator Accessory (TMAA) package designed to enhance safety by influencing driver behavior.

Over the course of a one-year field study, three TMAA packages were deployed and tested in real-world highway maintenance operations. The package included four key subsystems: a radar speed feedback display, a Mobile Digital Video Recorder (mDVR) system, a panic/warning light system, and iCone technology for public alerts via mobile applications. Researchers procured, installed, and refined the equipment, provided training to Caltrans personnel, and collected extensive feedback through surveys, interviews, and video analysis.

Key findings indicate that the panic light system had the most noticeable effect on driver behavior, prompting motorists to slow down and respond to work zone warnings. The mDVR system successfully recorded critical incidents, including a TMA truck strike, and allowed for remote footage retrieval, enhancing incident documentation. The iCone technology functioned as intended, providing mobile alerts to drivers, with its effectiveness expected to increase as more systems integrate this data. The radar speed feedback sign also showed promise, though further study is needed to quantify its impact on vehicle speeds.

This research supports Caltrans' core goals of improving safety, strengthening operational efficiency, and enhancing stewardship. The successful evaluation of the TMAA package demonstrates its potential for broader deployment, with further research recommended to optimize and expand its implementation in Caltrans highway operations.

# Problem, Need, and Purpose of Research

Caltrans often performs highway maintenance operations in work zones with temporary lane closures adjacent to high-speed traffic. The high-speed traffic provides a significant safety hazard to highway maintenance personnel. To shield the work zones from errant vehicle impacts, Caltrans routinely deploys

shadow trucks with TMAs. The TMAs are designed to decelerate lighter vehicles but impacts of high-speed heavy vehicles can exceed TMA dynamic absorption force limits. The impact risk with physical injury for the shadow truck driver is significant. Since the shadow truck TMAs are mobile and cannot be physically scaled up, the best mitigation strategy for impacts is to influence driver behavior.

# Overview of the Work and Methodology

This project researched and implemented new shadow truck safety accessories for Caltrans deployment. New suppliers were found to meet project timelines and Caltrans requirements. The research methodology was modified to allow for system integration and validation prior to field trials. Upon completion of design and validation work, training materials were developed and delivered prior to field trails. The field trials of the accessories occurred for one year and provided results that support their further implementation within Caltrans.

# Major Results and Recommendations

The TMAA research project introduced significant improvements over previous evaluations, successfully installing, testing, and documenting all subsystems for potential broader deployment. Key advancements included validating a new radar signboard, designing a steel structure for signage support, and overcoming software installation challenges to enable remote access to mDVR footage. Additionally, a one-button panic light system was developed and tested; operators reported it had an impact on alerting approaching drivers. The evaluation of TMA truck operator feedback confirmed that the TMAA package positively influences driver behavior in active work zones by increasing awareness through radar speed displays and iCone alerts, prompting drivers to reduce speed and navigate work zones more safely. Remote access to mDVR footage provided critical incident documentation. Future research should focus on developing a data collection system capable of accurately recording vehicle speeds while the shadow (follower) truck is moving, addressing a current gap in evaluating the effectiveness of safety measures in Caltrans' moving maintenance operations. Future research should also include the integration of iCone data into the Traffic Management Center in a pilot district.

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# Acronyms and Abbreviations

| Acronym | Definition |
|---|---|
| AHMCT | Advanced Highway Maintenance and Construction Technology Research Center |
| Caltrans | California Department of Transportation |
| mDVR | Mobile Digital Video Recorder |
| MPH | Miles Per Hour |
| TMA | Truck-Mounted Attenuator |
| TMAA | Truck-Mounted Attenuator Accessory |

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# Chapter 1: Introduction

## Problem

The California Department of Transportation (Caltrans) frequently conducts highway maintenance operations that require temporary lane closures in areas where traffic is moving at high speeds. Passing vehicles in these work zones may fail to slow down or merge properly, increasing risks of incidents. To enhance worker safety and minimize the risk of errant vehicles, Caltrans routinely deploys shadow trucks equipped with truck-mounted attenuators (TMAs). These TMAs serve as a protective barrier, designed to absorb and dissipate the kinetic energy from vehicle collisions, thereby reducing the severity of impacts.

While TMAs are effective in decelerating lighter vehicles, they have limitations when it comes to high-speed impacts from heavy trucks or other large vehicles. When a heavy vehicle collides with a TMA-equipped shadow truck at high speed, the impact forces can exceed the attenuator's dynamic absorption capacity, resulting in significant damage and posing a severe risk of physical injury to the shadow truck operator. Given these limitations, a key challenge in improving work zone safety is finding alternative ways to mitigate the risks posed by high-speed traffic.

Since the design and mobility requirements of shadow truck TMAs prevent them from being physically scaled up to handle more extreme impacts, the most effective mitigation strategy is to focus on influencing driver behavior. Encouraging drivers to slow down, pay closer attention to work zone warnings, and merge out of closed lanes in a timely manner can significantly reduce the likelihood of collisions. This approach not only enhances the safety of maintenance personnel, but also helps protect motorists by reducing the chances of severe crashes. As a result, Caltrans has prioritized the development and evaluation of new technologies and strategies aimed at increasing driver awareness and compliance with work zone regulations.

## Objectives

The prior project "Review of Equipment and Accessories for Truck-Mounted Attenuator Trucks", 65A0749 Task 3685 has found a Truck-Mounted Attenuator Accessory (TMAA) package, which promises significant safety benefits to Caltrans Maintenance personnel. This package includes an innovative radar speed feedback display sign to display the speed of approaching vehicles while

the shadow truck is moving, video camera systems to record multiple views around the shadow truck, and a panic/warning system to be activated by the shadow truck driver. Multiple TMAA packages need to be deployed in multiple field testing to determine whether the system is suited to regular Caltrans operations and is ready for broad deployment.

# Scope

The Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center worked with Caltrans to test three TMAA packages for approximately one year in the field during normal Caltrans operations on the highway. Working with the project panel, the researchers redefined the equipment and accessories for field trials to alleviate procurement and regulatory constraints. The researchers then procured and installed the newly defined sub-systems onto three TMA trucks and developed training for operators and supervisors. Before the one-year field trials began, the researchers provided classroom and hands-on training to the operators and supervisors. The researchers gathered data from the TMAA systems, validated the new suppliers, and collected operator and supervisor feedback, while the TMAA packages were used in actual Caltrans highway operations.

# Background

In Caltrans highway maintenance operations, one of the most significant safety hazards is the risk of high-speed errant vehicle impacts. To mitigate this, Caltrans deploys shadow trucks equipped with TMAs, called TMA trucks, to shield temporary work zones. However, TMA truck drivers remain at the greatest risk, as TMAs are primarily designed to decelerate lighter vehicles, while high-speed impacts from heavy trucks can exceed their design limits, causing severe injury. Since TMAs cannot be physically scaled up to absorb such impacts, the best mitigation strategy is to reduce collision likelihood by influencing driver behavior. Many impacts result from motorists being inattentive, speeding, or failing to merge out of closed lanes in time.

This research directly supports Caltrans' core goals:

- **Safety First:** The TMAA package enhances safety for both TMA operators and the traveling public. The DVR system provides clear insights into TMA-related incidents, improving safety measures.
- **Strengthen Stewardship and Drive Efficiency:** By improving Maintenance's ability to safely conduct moving closure operations, the TMAA package strengthens stewardship and increases operational efficiency.

# Research Methodology

The AHMCT Research Center procured and installed three (3) TMAA packages, in cooperation with Caltrans Division of Maintenance and Division of Equipment. The original system supplier became unresponsive, and the researchers worked with component suppliers, integrated the components into a system, and installed the systems. The researchers provided training to selected operators, after which field testing by Caltrans Maintenance personnel commenced, with on-site and phone support from the researchers as needed. The researchers developed surveys for operator feedback, performed interviews with supervisors, and analyzed video footage from the mobile digital video recorder (mDVR).

# Overview of Research Results and Benefits

This TMAA research project successfully evaluated four subsystems that compose the accessory package. Through the data available to the researchers, the panic light system appears to show the biggest impact on the public's behavior while driving in a work zone. The other subsystems appeared to have an impact on the public, however, further technology beyond the scope of this research project is necessary to quantify the impact of the full TMAA package.

The panic light system was a new system developed due to supplier and project constraints. The new system was mounted around the LANE CLOSED sign and performed effectively throughout the field trials. The operators all agreed that it had an impact on the traveling public. Operators stated that they were able to see a change in an oncoming vehicle driver's behavior when they pressed the panic light button, indicating the button may gain the attention of the traveling public.

The mDVR system, which was partially evaluated in the previous research task 3685, was fully developed. The researchers proved the ability to download and view camera footage remotely by utilizing a cellular connection. The researchers, in conjunction with supplier Kohltech, were able to provide two methods of access to the mDVR that did not require the installation of any software onto Caltrans computers, instead they utilized a web interface. The mDVR system was able to effectively record a strike on a TMA truck in a moving closure.

Two iCone products were evaluated and worked as advertised. These systems allowed the traveling public to see a warning for an active work zone on their mobile devices when they used the Waze application. iCone is continuing to integrate their system with vehicle manufacturers, traffic management centers, and others. As more companies and applications

integrate data from iCone, the system will have an even larger impact on the traveling public.

The radar signboard evaluated was a different product than the one used in the previous research task, due to several risks described in this report. The new radar signboard from KohlTech met Caltrans requirements and accurately communicated information to the public about vehicle speed. The sign appeared to have an impact on the traveling public, and further research to record and analyze the speed of the traveling public is necessary to fully validate or quantify this impact.

# Chapter 2:
# Procurement and installation of the system

AHMCT tried to procure the same TMAA packages (Level 4 Technology Package) from the previously identified vendor (Royal Truck & Equipment Inc.) that was used in Task 3685. However, the project panel decided to reduce risk and shorten the timeline by finding new vendors to provide similar equipment. It was also determined that AHMCT would perform the installation of the components to ensure the research task would be successful. In the following sections, the procurement and installation of 3 TMAA packages is discussed. Figure 2.1 shows the four sub-systems in each package that AHMCT procured and integrated for this research project.

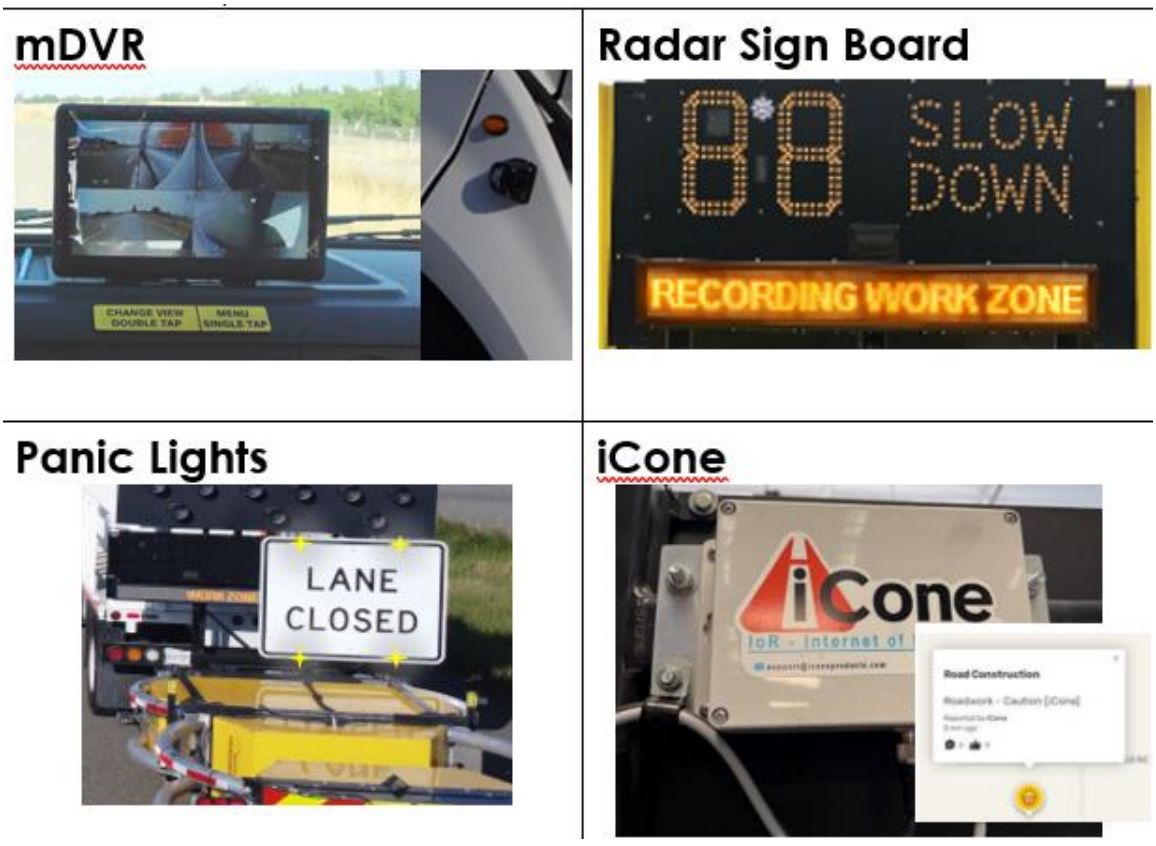



**Figure 2.1: Components of the TMAA system**

# Changes to TMAA design and procurement

There were two main challenges that caused the procurement plan to be changed during this research project. First, after three months of attempted communications with the previous supplier, the project panel determined that new suppliers should be sought to develop a similar technology package from different vendors. A viable technology package was sourced from component manufacturers Kohltech and Road-Tech. The details of the new technology package are discussed in the section below.

The second challenge that required a change to the procurement plan stemmed from the LANE CLOSED sign required in the Standard Plan *T15- Traffic Control System for Moving Lane Closure on Multilane Highways*. Initial analysis showed that the initially specified radar signboard may not fit on the back of the TMA truck with the LANE CLOSED sign. The previously specified radar signboard from Task 3685 was 60“ wide by 26” high, and the LANE CLOSED sign was 54” wide by 42” high . Unfortunately, the two signs cannot be placed horizontally, as the vehicle would then be considered a wide load with a width greater than 102”, introducing additional complications. Mounting the two objects vertically was also evaluated; however, the top component would block the view of the changeable message sign/arrow board that is located on the top of the truck cab. The only viable solution was to procure a radar signboard that was not as wide, to allow the two objects to be located horizontally and still remain under the 102” of vehicle width, in order to not be considered a wide load.

# Procured Components

The initial Level 4 Technology package was intended to change the behavior of the traveling public through multiple different subsystems. Below is a summary of the new and old four subsystems. The justification and rationale for the changes are captured in each section.

## *Radar signboard*

The initial procurement package called for a TrafficCalm 60”x36” full matrix changeable message sign radar board, as shown in Figure 2.2. However, as mentioned previously, this sign was too large to be part of the new TMAA package. An alternative to the TrafficCalm radar board is the Radar Message System and Mini-Messenger system provided by Kohltech. The new system was able to provide similar features and specifications in a smaller package. However, the TrafficCalm system had a Safety Zone Rear Alert system that would alert the oncoming vehicle through a message on the sign. This feature only worked in a stationary setting (without the TMA truck moving) and would not have been utilized in the majority of the field trials, as the TMAA is primarily

evaluated in moving closures. Therefore, this feature was not critical for selecting the radar sign.


**Figure 2.2: TrafficCalm radar signboard evaluated in the previous research task 3685**

The Kohltech system involved sourcing two separate products, a radar signboard and a mini-messenger sign. The system is shown in Figure 2.3, where the truck is a TMA truck used in this research task after the installation.


**Figure 2.3: Kohltech radar signboard and mini-messenger sign next to LANE CLOSED sign**

Together the two components provide the following capabilities when properly configured:

- Acquire vehicle targets beyond 750 feet (a redesign of the system to provide a larger target distance),
- A flashing amber strobe to gain the driver's attention if they were going over the set speed on the sign (a redesign of system to provide an amber strobe instead of white),
- In-radar traffic statistics that can be utilized only when the TMA truck is stationary,
- Acquire targets from multiple lanes of traffic and display the fastest or closest target's speed (configured for display of fastest target),
- Display of the target vehicle speed corrected for the speed of the TMA truck,
- The ability to "stamp" the camera feeds recorded on the mDVR with the displayed vehicle speed,
- A small changeable message sign (the default setting of "RECORDING WORKZONE" was used as message for the field trials).

The system required a redesign from Kohltech to meet the requirement of picking up targets at a distance greater than 750 feet. This included a redesign of their enclosure and coordination with their supplier to modify the software to accommodate a different radar system. Kohltech was able to deliver their design and software modifications that allowed the research project to conduct a full year of field trials.

## *mDVR*

The initial procurement plans involved sourcing the mDVR and camera system through Royal Truck & Equipment. However, the project panel determined it would be more efficient to directly work with the supplier, Kohltech, for this system. The system consisted of an M8 series mDVR and four (4) cameras. The cameras record the following fields of view:

1. Rearview when the TMA is stowed, Figure 2.4,
2. Rearview when the TMA is deployed, Figure 2.4,
3. Left rear view, Figure 2.5,
4. Right rear view (mirror image of Left rear view).


**Figure 2.4: Location of rear facing cameras on the TMA truck**


**Figure 2.5: Location of left rear facing camera on the TMA truck**

## *Panic Lights*

The previous system from Task 3685 required two panic buttons for the operator to fully utilize the system. The first button placed a flag on the mDVR recording that the operator had pressed the panic button. The operator would then need to press a second button to change the radar signboard to a display meant to demand the driver's attention. In the previous project Task 3685, it was recommended that a single button be developed to provide a better and safer experience for the operator.

Since the original TrafficCalm board was no longer being procured, an alternative approach to panic lights was developed by AHMCT. The new system involved a single button solution, shown in Figure 2.6, which activated both the panic lights and also placed a flag on the mDVR system.


**Figure 2.6: Single button panic light button**

AHMCT also procured four amber lights (Whelen, Part# TLIA). These lights are approved by the California Highway Patrol and were mounted on the perimeter of the LANE CLOSED sign shown in Figure 2.7.


**Figure 2.7: Panic lights on the perimeter of the LANE CLOSED sign**

# *iCone*

The Arrow Board Kit and Hazard Light Kit from iCone Products, LLC are two of five products that iCone offers to alert the public to the presence of a work zone and were used in this project. The Arrow Board Kit was connected to an arrow board that is not a changeable message sign. The unit senses which arrow is being used and can then communicate to the public that there is a construction zone and which direction to merge. This model was installed on the TMA truck that is working in District 11, as it has an arrow board. The Hazard Light Kit offered by iCone Products, LLC was used on trucks that have a

changeable message sign that also functions as an arrow board. This model can only sense when there is an active work zone and communicates this information to the public. The second model was installed on the two trucks in District 4, as they had a changeable message sign that functioned as the arrow board. The Arrow Board Kit is able to sense an active work zone when the TMA is deployed. A reed switch was installed on the TMA mounting bracket to sense when the TMA was fully deployed and functioned as a normally open switch.

The iCone products for this project were procured through Road-Tech, a local small business supplier to Caltrans. Both products are small devices, as shown in Figure 2.8.

**Figure 2.8: iCone mounting location on a truck with a changeable message sign**

# Installation

The installation of all three TMAA packages occurred at AHMCT's facility. Due to previously mentioned procurement challenges, additional design work for the radar signboard support structure, one button panic button solution, and panic lights occurred and are described in this section. AHMCT performed the installation of the radar signboard and panic lights. The AHMCT staff also supported the vendors, who traveled to AHMCT's location to install the mDVR and camera system, as well as the iCone.

AHMCT followed the Caltrans wiring guide and insured that the suppliers also followed the requirements of the wiring guide when the systems were being installed. AHMCT worked with the Department of Equipment to have the installation inspected and performed required remediations when necessary to pass the inspection.

# *Radar signboard and LANE CLOSED sign*

Installing both a radar signboard and a LANE CLOSED sign at the back of the TMA presented several design challenges that were overcome during this research project. This section describes the development and provides the documentation necessary to attach the procured system onto a TMA truck without a liftgate. The solutions presented in the research project have been validated with the independent installation by Caltrans of over 10 other systems in District 11.

The inclusion of a LANE CLOSED sign (54" wide by 42" high) required prototype evaluation and analysis of the field of view of a driver in a vehicle approaching the TMA. A common solution for the three TMAs in this project was sought, regardless of if they had an arrow board on the back or a changeable message sign on top of the truck cab. The researchers evaluated if a horizontal or vertical position would be advantageous, and both a horizontal configuration, Figure 2.9, and a vertical configuration, Figure 2.10, were evaluated. The following were the criteria that the design was evaluated against:

- Design is less than 102" wide,
- Design has 2" of clearance to the TMA when the TMAA is stowed,
- Design mounts onto the existing TMA mounting bracket,
- Design minimizes the obstruction of the arrow board.

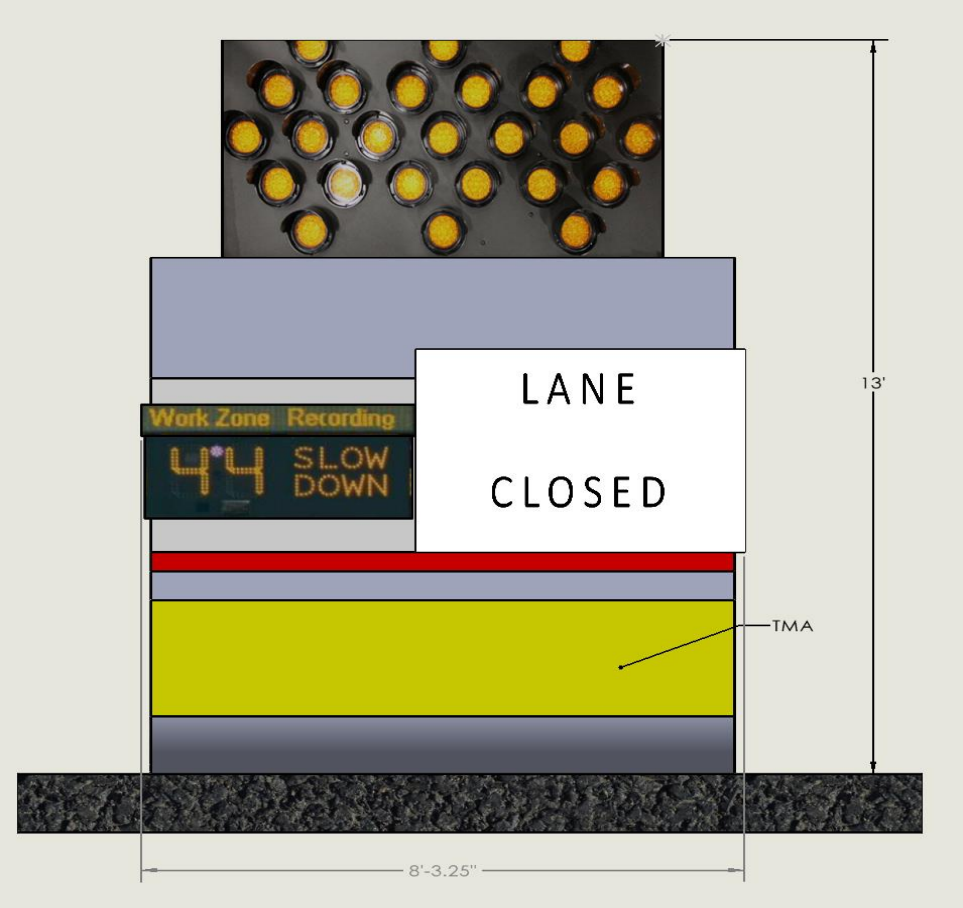



**Figure 2.9: Rear view of virtual prototype of horizontal configuration**

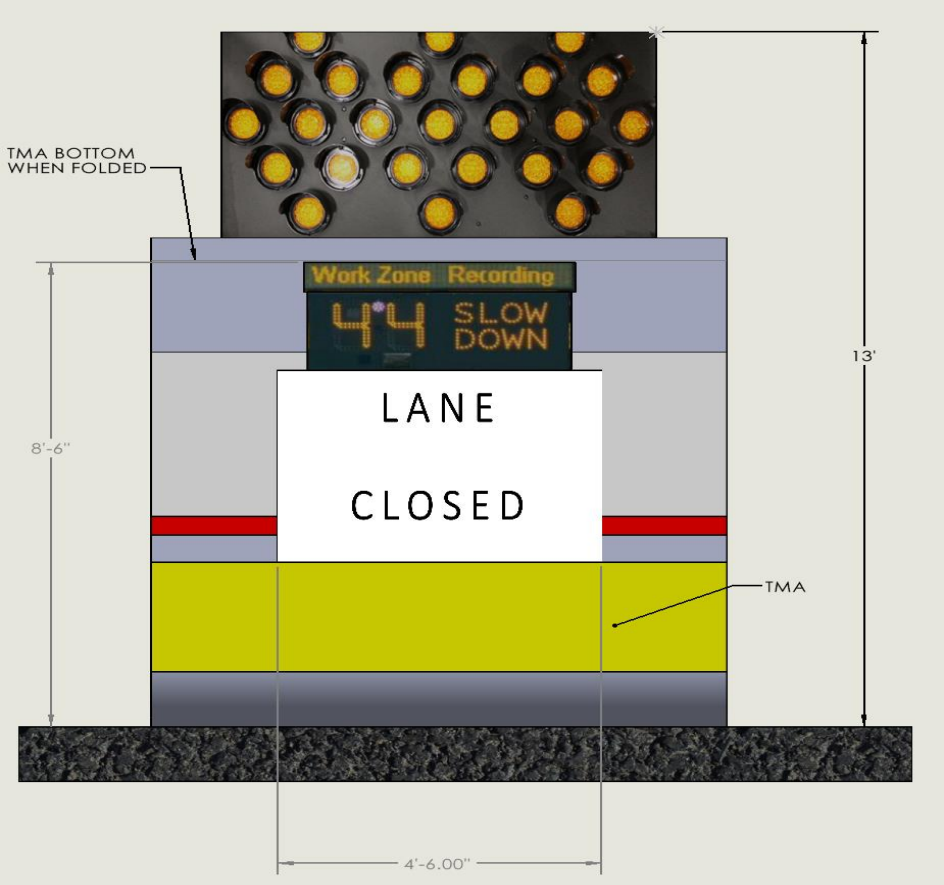



**Figure 2.10: Rear view of virtual prototype of vertical configuration**

The virtual prototype was also used to determine at what distance the arrow board that is mounted on the top of the truck cab would begin to be obstructed. The research panel agreed that the design which minimally obstructed the view of the arrow board was advantageous. The analysis assumed a minimum driver eye height of 45", which is based on a 10$^{th}$ percentile female sitting in a mid-size sedan. Figure 2.11 shows the horizontal configuration, with the arrow board becoming obstructed only when the vehicle is within 26 feet of the back of the truck. Figure 2.12 shows the vertical configuration with the arrow board becoming obstructed when the vehicle is within 182 feet of the back of the truck. Therefore, the horizontal configuration was chosen as the final design.

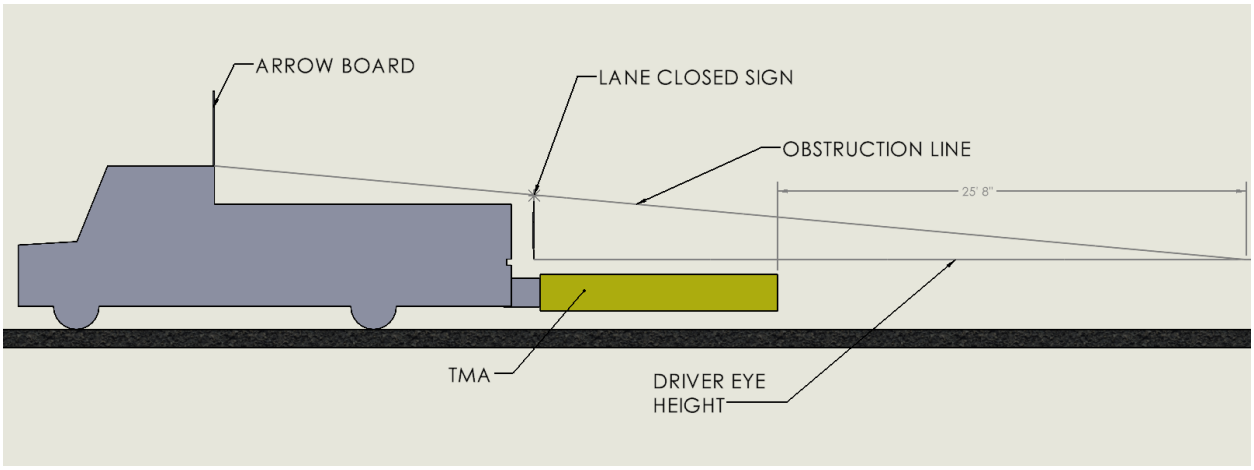



**Figure 2.11: Side view of virtual prototype of horizontal configuration**

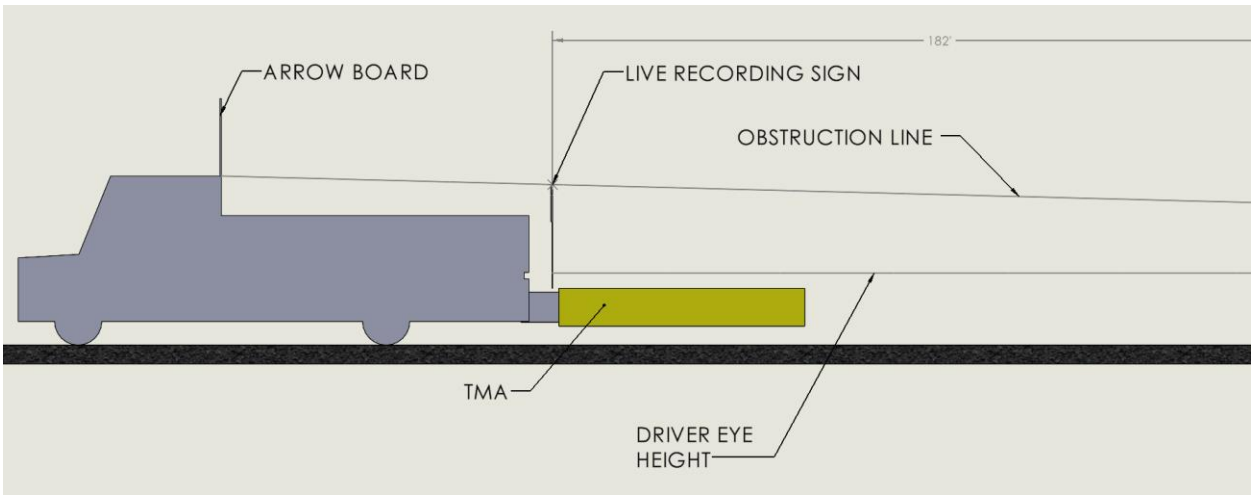



**Figure 2.12: Side view of virtual prototype of vertical configuration (image is cropped for clarity)**

Once the horizontal configuration was approved by the project panel, AHMCT developed a tubular steel structure to be mounted in the existing TMA bracket to support the radar signboard and the LANE CLOSED sign. Steel tubes were chosen for the tubular structure. Prior to assembly, the tubes were primed and painted to prevent corrosion. The LANE CLOSED sign slightly overlaps the radar signboard and mini-messenger sign to reduce the width of the system, but this overlap does not cover any of the display on either unit. Figure 2.11 shows the completed installation of the radar signboard and LANE CLOSED sign. The CAD drawings to replicate this design are shown in Appendix A and the wiring diagrams are shown in Appendix B.


**Figure 2.13: Radar signboard and LANE CLOSED sign installed on a TMA truck**

## *Panic button*

Research Task 3685 utilized two panic buttons to perform the intended functions of attempting to gain the oncoming driver's attention and placing a flag on the mDVR recording. The two buttons were required, due to several different manufacturers' systems needing to interact with each other. AHMCT designed a new panic button system that could be utilized with the new components and the new panic light system. Through this improvement the operators would only be required to press one button to perform both tasks, significantly improving the user experience and safety.

The main design challenges of the new system were to provide a signal to the mDVR, which required a digital switch, and the panic lights, which required a simple, normally open switch to create a ground. The solution was to stack both switches on top of each other and place them into an enclosure, as seen in Figure **2.14**. Both switches/buttons would be activated when the operator pressed the external button. It was determined that a large, red, self-resetting button should be used as the external button with which the operator could interact. It was also decided that a nameplate should be placed on the switch to allow anyone who enters the truck to know the function of the red button.


**Figure** 2.14**: Panic button as seen by the operator of the TMA**

## *Panic lights*

During the previous research task 3685, the radar signboard's display was a changeable message sign. The supplier created a message on the board that would be activated by a panic button in order to gain the driver's attention, as shown in Figure 2.15. As previously mentioned, the radar signboard from Task 3685 did not meet the width requirements with a LANE CLOSED sign. Therefore, a method to gain the attention of the public was developed, based off of the work done by the Missouri Department of Transportation[2].


**Figure 2.15: Panic message from previous research task**

AHMCT developed a system that utilized four amber lights, an off-delay timer, and a panic button activation. The amber lights are described in the Panic Lights subsection within this chapter. An off-delay timer was included in the system design, so that when the operator presses the panic button to activate the panic lights, the lights would remain on for 0 to 10 seconds after the button is released. This would give the operator time to adjust their body position, if necessary, for a potential safety event. The project panel determined that a delay-off of four seconds would be appropriate as the initial setting for the field trials. The delay off-timer model VCM-04-10SA, manufactured by InPower, was utilized in this design. Input B was connected to the panic light switch and ground.

# Chapter 3:
# Test plan development

The AHMCT researchers developed a field-testing plan in coordination with the Caltrans Division of Maintenance. The field testing began in January of 2024 and concluded in December of 2024. Due to vehicle logistics, vehicles were utilized in two Districts, 4 and 11. In District 4, two TMA trucks were upfitted with the accessory package. These trucks were utilized with the paint striping crew and the bridge maintenance crew. In District 11, one TMA truck was upfitted and utilized in sweeping, paint striping, and RPM operations. Through utilizing crews in both districts, the TMAA was able to be evaluated in both rural (District 11) and urban (District 4) locations.

The test plan was developed to ensure that proper training would be provided for the operators in the beginning. The plan required that multiple operators would be trained at each maintenance yard. By having multiple operators trained, the impact of leave, reassignment, or operators leaving the maintenance yard would have a minimal impact on the research project. Surveys were developed for the operators to complete at the end of training and at the end of the field trails.

Previously in Chapter 2, the complications with the procurement process with the original vendor and the actual partnership with Kohltech to provide the radar signboard were discussed. Kohltech components were utilized in the previous research project Task 3685; however, their new radar signboard had not previously been validated. Therefore, a validation plan for the radar signboard was developed and involved validation on roads that were closed to the public.

## Training Material Development

The TMAA package had four main components and two different types of users that require training. Table 3.1 shows the main components and which staff needed training. Although the supervisors only needed training on the mDVR, the project panel decided it would be beneficial for them to be trained on all components to assist in their understanding of this research effort. Future training courses for TMAA deployment can use the suggestions in the table below.

**Table 3.1: TMAA Training Requirements**

| Components | Operators | Supervisors |
|---|---|---|
| mDVR and Cameras | Yes, focused on Cameras | Yes, focused on mDVR |
| Radar Signboard | Yes | No |
| Panic Lights | Yes | No |
| iCone | Yes | No |

# *Operator Training Material*

The agenda for the operator training was discussed in project panel meetings during the Fall of 2023. The research team developed a training agenda that combined in-class presentations of the components followed by hands-on experiences to reinforce the training materials. The following components were part of the training agenda:

- In classroom:
  - Motivation for project
  - Components of TMAA
    - mDVR/camera system
    - Panic lights
    - Radar signboard
    - iCone
  - Start-up/shutdown procedure
  - User experience with
    - mDVR/camera system
    - Panic lights
    - Radar signboard
  - TMA disconnect procedure
- Hands-on
  - Start-up
  - Testing of radar signboard
  - Panic button
  - Live feed of mDVR

- Shutdown procedure
- TMA disconnect procedure

After the agenda was finalized, training materials were developed specifically for use by the operators. All materials were created to be utilized as a reference and were intended to provide the same material delivered by different approaches to better match the learning styles of the operators. The following materials were developed:

1. A PowerPoint Presentation with videos,
2. A PDF version of the PowerPoint Presentation, included in Appendix C,
3. Flowcharts of the step-by-step operations required for the TMAA, included as Appendix D,
4. Videos of the step-by-step operations required for the TMAA.

Items 2 and 3 from above were printed and placed into a 1-inch binder that was labeled and provided to the operators to be an on-truck resource as they participated in the field trails. A copy of Item 3 was also laminated and placed in each TMAA truck for quick reference for operators.

## *Supervisor Training Material*

The agenda for the supervisor training was also discussed in project panel meetings during the Fall of 2023. The research team developed a training agenda, which utilized Kohltech software that would need to be installed onto each operator's computer. The supervisor training contained short demonstrations followed by hands-on activities to reinforce the materials that were just covered in the presentation. The following items were on the agenda for the training:

- In classroom demonstration
  - Getting started
  - Live view navigation (see active operations)
  - Hands-on 1
  - Playback navigation overview (review camera footage)
  - Online playback
  - Hands-on 2
  - Video clip/download (create a record for an incident/accident)
  - Tech support
  - Hands-on 3

Due to the risk of the software not being approved by the Caltrans IT department for use on Caltrans computers, an alternative demonstration was also developed to highlight a web interface that the supervisors could use to download video footage if required.

After the agenda was finalized, training materials were developed specifically for use by the supervisors. Two user manuals were created for the operators based off of the user manuals provided by Kohltech. It should be noted, and will be discussed at the end of this report, that the initial web interface was significantly improved by the vendor over the course of the research and can now function as a viable solution for operators to utilize. The new web interface offered by the supplier is called FleetWatch. Due to feedback from the Caltrans IT approval process, the Kohltech desktop program could not be installed on the supervisors' computers. Further details regarding this are also included later in this report.

A PowerPoint presentation was developed for the supervisor training to demonstrate the use of the desktop and web interface. However, due to the insurmountable objections from the IT approval process, the operators were unable to utilize the desktop version during the field trials. To ensure the research project could progress, AHMCT was available to perform any downloads that the supervisors required utilizing the desktop application on AHMCT computers.

# Preliminary closed course testing and validation

As mentioned in Chapter 2, a validation of the radar signboard was required. During the previous research task, 3865[1], Caltrans DOE and AHMCT developed three classifications for radar signboard verification tests. They included the following:

- Stationary radar signboard with a single target vehicle testing,
- Moving radar signboard with a single target vehicle testing,
- Moving radar signboard with multiple target vehicles testing.

During the previous research task, the following requirements were also established:

- The radar signboard should always report the fastest vehicle when multiple vehicles are present,
- The radar signboard should sense and report the oncoming vehicle's speed when the vehicle is at least 750 feet away,
- The radar signboard shall have an accuracy of 1 miles per hour(MPH) when reporting target vehicle speed, regardless of if the TMA truck is stationary or moving.

## *Stationary radar signboard with a single target vehicle testing*

The stationary validation of the radar signboard utilized the following test plan; the results are shown in the next chapter. The test plan was designed to be performed at META, and the research team determined that the maximum vehicle speed was 30 MPH to ensure safety. The distance from the TMA truck to where the oncoming vehicle was first picked up, the vehicle speed, and speed reported by radar signboard were recorded for each scenario. In several test scenarios a Laser Technology Model LTI 20/20 laser speed gun was used.

Scenarios:

1. Vehicle passes to the left of the TMAA
    a. 10 runs at various speeds from the vehicle speedometer, Laser speed gun data also collected
    b. 5 runs at 20 MPH
    c. 5 runs at 30 MPH
2. Vehicle passes to the right of the TMAA
    a. 5 runs at 20 MPH
3. Vehicle changes speed by 1 MPH
    a. 5 runs at 30 MPH, increase speed by 1 MPH

## *Moving radar signboard with a single target vehicle testing*

The moving validation of the radar signboard utilized the following test plan; the results are shown in the next chapter. The test plan was designed to be performed at a large parking lot in Calexico and the research team determined that the maximum speed to ensure safety was 30 MPH. The reported speed of the TMA, speed of the target vehicle reported by the laser speed gun, and the speed from the radar signboard were recorded for each scenario.

Scenarios:

4. TMA truck moving with one target vehicle
    a. 7 runs

## *Moving radar signboard with multiple target vehicles testing*

The moving validation of the radar signboard with multiple targets utilized the following test plan; the results are shown in the next chapter. The test plan was designed to be performed at a large parking lot in Calexico and the research team determined that the maximum speed to ensure safety was 30 MPH. The reported speed of the TMA truck, speed of the target vehicle reported by the laser speed gun, and the speed displayed from the radar signboard were recorded. In this scenario multiple targets approached the TMA truck at the same time, and the TMA truck should report the fastest target vehicle.

Scenarios:

5. TMA truck moving with multiple target vehicle
    a. 4 runs

# Chapter 4:
# Field Testing & Operator Feedback

AHMCT researchers provided training on the TMAA package to shadow truck operators and supervisors in District 4 and District 11. The field testing by Caltrans operators began on January 16th, 2024, and concluded on December 31st, 2024. A summary of the training events, radar signboard validation, panic button usage, and operator surveys are included in this section.

Successful field trials require prompt support for issues with the technology being evaluated. AHMCT was available for onsite and phone support as needed. There were no issues that needed to be resolved by AHMCT or the suppliers during the field trials related to the TMAA. This may be attributed to following the Caltrans wiring guide, remediating the installation to pass the Department of Equipment inspection, and the quality of the suppliers and/or their components.

## Training at District 4

Operator and supervisor training for the TMAA package took place at the District 4 Bay Bridge Training Center on January 11th, 2024. The operator training occurred from 9:00 AM until 11:00 AM. The supervisor training occurred from 11:00 AM until 12:00 PM. Fifteen total participants, including six operators, three supervisors, and three panel members from HQ or District 4, were in attendance. The objective of the operator training was to inform Caltrans fleet vehicle operators of the purpose of the TMAA package as well as teach them how to use it. The supervisor training was intended to inform Caltrans supervisors how to use Kohltech software to view present and past video footage stored on the mDVR. Operator training was split into classroom and hands-on demonstrations, while supervisor training consisted of only a classroom demonstration.

During the operator training classroom demonstration, shown in Figure 4.1, attendees were first informed of the motivation for the TMAA project, which is to decrease the speeds of passing vehicles in work zones and, in turn, increase the safety of operators. Attendees were next shown the components of the TMAA and informed of their functions and locations on the truck. The vehicle startup, shutdown, connection, and disconnection procedures were outlined, and attendees were given detailed instructions on how to operate the mDVR, panic lights and button, as well as the radar signboard. The iCone components and their functionality were also explained. Before attendees left for the hands-on demonstration, packets were distributed containing flowcharts of the interactions the operators would have with the TMAA components.


**Figure 4.1: Classroom training in District 4 for the TMAA**

During the operator training hands-on demonstration, shown in Figure 4.2, attendees were given a group demonstration on how to operate the speed settings on the radar signboard and encouraged to adjust it themselves. Camera locations were also shown, and attendees learned the additional steps required to connect/disconnect the attenuator due to additional electrical connections. Following this, operators entered the TMAA truck cab in pairs and were shown how to navigate the mDVR screen and how to use the panic button. Operators, who were waiting, used this time to ask questions. Following this, operators were given a brief survey by a supervisor to complete. Supervisors were instructed to reenter the classroom for their training after a short break.


**Figure 4.2: Hands-on demonstration in District 4 for the TMAA**

During the supervisor training, supervisors were given detailed instructions on how to navigate the Kohltech software to view both live and past data on the mDVR, including GPS location and camera footage utilizing the web portal. This was shown on only the web portal, but screenshots throughout the presentation also reflected what would be shown on the Kohltech software app. Supervisors were also informed of the duration of time that footage is available to be viewed or downloaded following its date of recording (7 days for this pilot test), as well as its use for multiple purposes. After the presentation concluded, attendees were allowed to ask questions and raise concerns.

# Training at District 11

Operator training for the TMAA package took place at the District 11 El Centro Maintenance Yard Training Center on March 5th, 2024. The operator training occurred from 8:00 AM until 10:00 AM, as shown in Figure 4.3 and Figure 4.4. The supervisor training was not provided at District 11, due to the challenges with Kohltech software being installed on Caltrans computers. The supervisors were informed that if there was a need to download video footage, they should

contact the researchers at AHMCT. Three total participants, all of which were operators, were trained on the TMAA. The objective of this training, agenda, and activities was identical to the District 4 training, with slight modifications to match the TMA truck that was in District 11.


**Figure 4.3: Classroom training in District 11 for the TMAA**

**Figure 4.4: Hands-on demonstration in District 11 for the TMAA**

# Radar Signboard Validation

Kohltech's radar signboard was validated according to the test plan discussed in the Preliminary closed course testing and validation subsection of Chapter 3. Figure 4.5 shows the target vehicle approach the radar signboard while at META.


**Figure 4.5: Validation testing at META**

The key requirements and their status after testing are shown in Figure 4.1. This table also shows which tests were used to validate the requirement. The new radar signboard met all of the requirements established in research task 3685. The results for each test are shown in Figure 4.2 and Table 4.3.

**Table 4.1: Radar Signboard Requirements**

| Requirement | Status | Test Number |
|---|---|---|
| Report vehicle speed with a 1 MPH accuracy | Requirement met | 1.a, 1.b,1.c, 2.a, 3.a, 4.a, 4.b |
| Report vehicle speed when vehicle is at least 750' away | Requirement met; target vehicles were registered at distances over 1,200' away | 1.b,1.c, 2.a, 3.a, 4.a, 4.b |
| Target vehicle speed is corrected for TMA speed | Requirement met | 5.a |
| Report fastest vehicle | Requirement met | 6.a |

**Table 4.2: Validation Results from Stationary TMA Truck Tests**

| Test Number | Test Description | Results | | |
|---|---|---|---|---|
| 1.a | Vehicle passes to the left of the TMAA, various speeds from the vehicle speedometer, Laser speed gun data also collected | Distance to TMA (feet) | Vehicle speed (MPH) (L- laser speed gun, D- Reported by driver) | Vehicle speed reported by radar sign board (MPH) |
| | Run 1 | not recorded | 14 L, 14 D | 14 |
| | Run 2 | not recorded | 15 L, 15 D | 15 |
| | Run 3 | not recorded | 14 L, 14 D | 14 |
| | Run 4 | not recorded | 18 L, 19 D | 19 |
| | Run 5 | not recorded | 19 L, 20 D | 20 |
| | Run 6 | not recorded | 18 L, 19 D | 19 |
| | Run 7 | not recorded | 6 L, 6 D | 6 |
| | Run 8 | not recorded | 6 L, 7 D | 7 |
| | Run 9 | not recorded | 6 L, 7 D | 7 |

| Test Number | Test Description | Results | | |
|---|---|---|---|---|
| | Run 10 | not recorded | 6 L, 6 D | 6 |
| 1.b | Vehicle passes to the left of the TMAA, 5 runs at 20 MPH | Distance to TMA (feet) | Vehicle speed (MPH) (L- laser speed gun, D- Reported by driver) | Vehicle speed reported by radar sign board (MPH) |
| | Run 1 | 1200+ | 22 D | 22 |
| | Run 2 | 1200+ | 20 D | 20 |
| | Run 3 | 1200+ | 22 D | 22 |
| | Run 4 | 1200+ | 21 D | 21 |
| | Run 5 | 1200+ | 20 D | 20 |
| 1.c | Vehicle passes to the left of the TMAA, 5 runs at 30 MPH | Distance to TMA (feet) | Vehicle speed (MPH) (L- laser speed gun, D- Reported by driver) | Vehicle speed reported by radar sign board (MPH) |
| | Run 1 | 1200+ | 31 D | 31 |
| | Run 2 | 1200+ | 28 D | 28 |
| | Run 3 | 1200+ | 31 D | 31 |
| | Run 4 | 1200+ | 31 D | 31 |
| | Run 5 | 1200+ | 31 D | 31 |
| 2.a | Vehicle passes to the right of the TMAA, 5 runs at 20 MPH | Distance to TMA (feet) | Vehicle speed (MPH) (L- laser speed gun, D- Reported by driver) | Vehicle speed reported by radar sign board (MPH) |
| | Run 1 | 1200+ | 21 D | 21 |
| | Run 2 | 1200+ | 20 D | 20 |
| | Run 3 | 1200+ | 22 D | 22 |
| | Run 4 | 1200+ | 21 D | 21 |
| | Run 5 | 1200+ | 20 D | 20 |
| 3.a | Vehicle Changes Speed by 1 MPH, 5 runs at 30 MPH and increase speed by 1 MPH | Distance to TMA (feet) | Vehicle speed (MPH) (L- laser speed gun, D- Reported by driver) | Vehicle speed reported by radar sign board (MPH) |
| | Run 1 | 1200+ | 30 D, 31 D | 30, 31 |
| | Run 2 | 1200+ | 30 D, 31 D | 30, 31 |
| | Run 3 | 1200+ | 31 D, 32 D | 31, 32 |
| | Run 4 | 1200+ | 31 D, 32 D | 31, 32 |
| | Run 5 | 1200+ | 30 D, 31 D | 30, 31 |

**Table 4.3: Validation Results from Moving TMA Truck Tests**

| Test Number | Test Description | Results | | |
|---|---|---|---|---|
| 4.a | TMA moving with 1 target vehicle | TMA speed (MPH) | Vehicle speed (MPH) (L-laser speed gun, D-Reported by driver) | Vehicle speed reported by radar sign board (MPH) |
| | Run 1 | 5 | 13 L | 14 |
| | Run 2 | 7 | 14 L | 15 |
| | Run 3 | 7 | 12 L | 13 |
| | Run 4 | 7 | 13 L | 13 |
| | Run 5 | 8 | 8 L | 9 |
| | Run 6 | 6 | 14 L | 15 |
| | Run 7 | 6 | 12 L | 12 |
| 5.a | TMA moving with 4 target vehicles | | | |
| | Run 1 | 7 | 12 D, 12 D, 13 D, 13 D | 13 |
| | Run 2 | 5 | 16 D, 28 D, 13 D, 28 D | 28 |
| | Run 3 | 5 | 23 D, 22 D, 27 D, 29 D | 29 |
| | Run 4 | 5 | 23 D, 20 D, 14 D, 22 D | 13 |

# Field testing data collection

Field testing data were collected with multiple approaches over the field trials. There were two surveys developed, delivered, and analyzed. The results of these surveys are discussed later in this chapter. The researchers also called or emailed the supervisors on a quarterly basis to gather feedback and respond to issues, if necessary. Finally, the researchers accessed the mDVR remotely to gather information primarily related to panic button usage.

Throughout the project the supervisors did not report any issues during the field trials. From phone conversations and emails, the most common discussion point was focused on the panic lights. The operators felt that they would like to have the lights brighter during the day and the same intensity as currently designed at nighttime. They also would like the panic lights to be able to stay on without having the button pressed, the operators suggested a separate toggle switch to turn on the panic lights. The operators also felt that the large display for the mDVR blocked their view. The operators would have preferred a smaller display, or the display mounted on the headliner to increase their ability to see forward obstacles. The final suggestion from these conversations was to

move the LANE CLOSED sign slightly, as it extended a few inches past the side of the truck. This issue was a prototype error that has since been corrected in the CAD drawings that are included in this final report.

The mDVR was accessed at least two times per week to record when the panic button was pressed. The approach for accessing and recording the data is shown in Appendix E. There were over 3,600 events recorded over the year, and for each event the following information was recorded:

- TMA Truck- ITMA, TMAA 1, TMAA 2,
- Date, Start Time, End Time, Day of Week,
- State- Panic Button Usage, Stationary Closure Start, Moving Closure Start,
- Closure Type- Panic Button Usage, Stationary Closure, Moving Closure,
- Lane- Left Shoulder, 1,2,3,4,5, Right Lane,
- Speed- TMA truck speed,
- Radar- Speed of fastest vehicle approaching the TMA,
- Time category- Daytime, Nightime,
- Duration- total time of stationary or moving closure.

The following graphs depict the panic button usage for the three (3) TMA trucks that were part of the field trials. Each TMA truck was part of different operations, as follows:

- IMTA- Intelligent TMA truck used in District 11. Field trials with this truck started in March of 2024. This truck was also active in another research project. In June of 2024, there was no longer an operator in the truck who could press the panic button. This may be the reason for the small number of panic button usages.
- TMAA 1- This TMA truck was used in District 4 by the paint striping crew, and was removed from active operations due to a vehicle strike.
- TMAA 2- This TMA truck was used in District 4 by the bridge maintenance crew in conducting both day and night operations.

TMAA 2 had the most panic button activations, as shown in Figure 4.6.

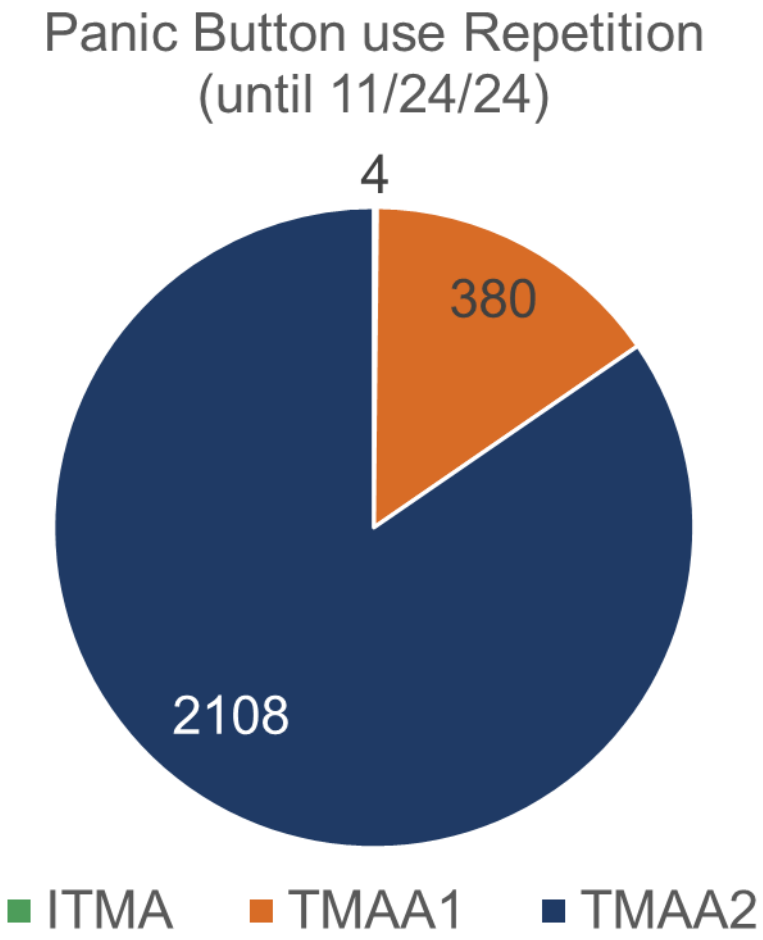



**Figure 4.6: Panic button use repetition**

The most common lane location for using the panic button was Lane 1, followed by the Right Shoulder and then the Left Shoulder, as shown in Figure 4.7.

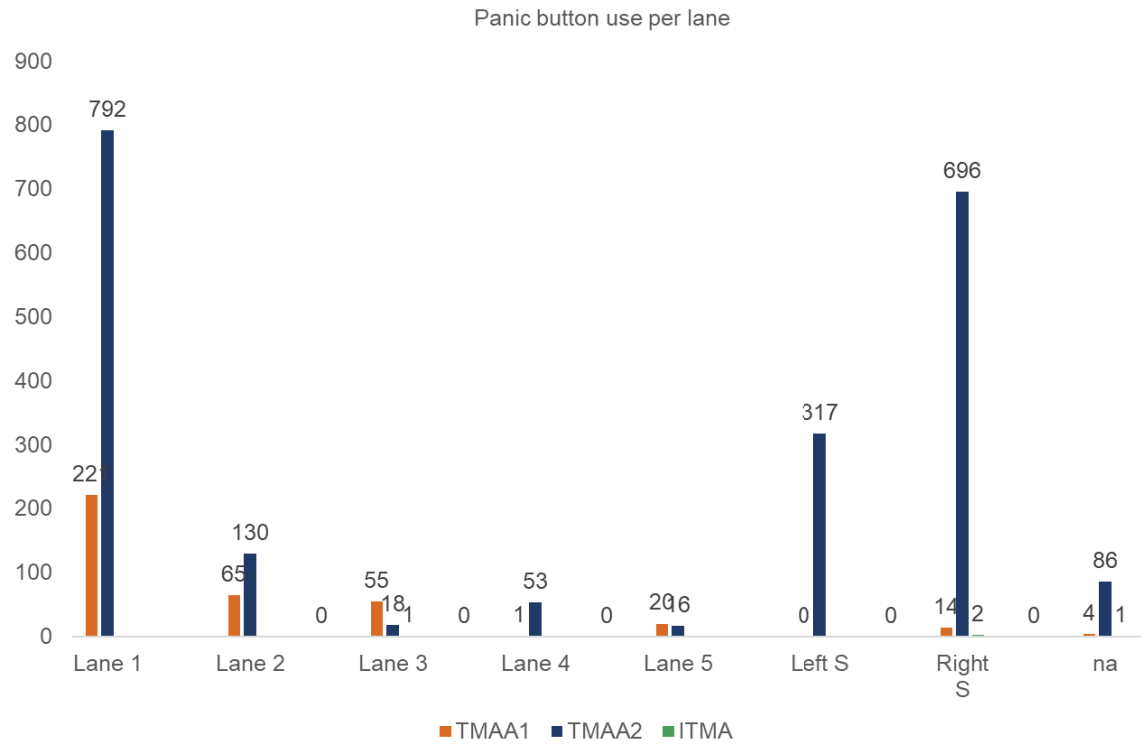



**Figure 4.7: Panic button use per lane**

As expected, the panic button was most often used at slower speeds; only occasionally was it used at higher speeds, as shown in Figure 4.8. Figure 4.9 is a finer look at the mDVR data grouping the panic button usage into 1-mile increments instead of 10 MPH groupings. Through a closer look at the data, most activations occurred when the TMAs were not moving.

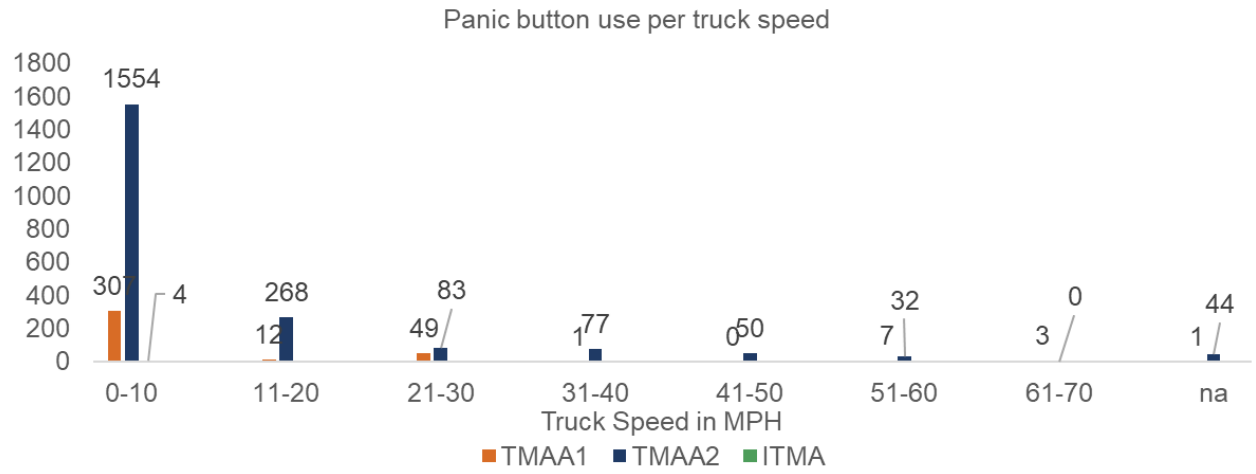



**Figure 4.8: Panic button use per truck speed**

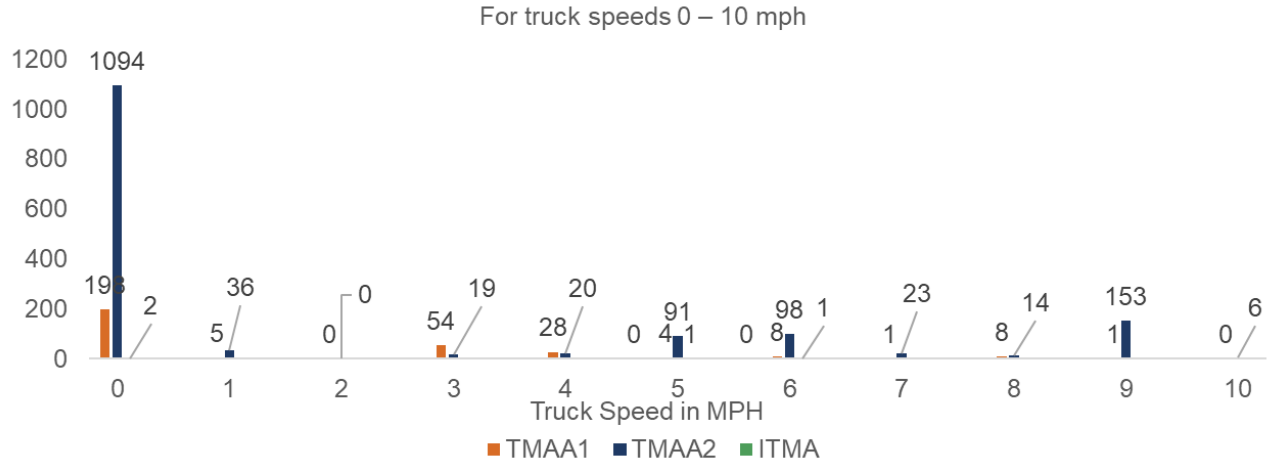



**Figure 4.9: Panic button use per truck speed 0-10 MPH**

# Unplanned Field-Testing Event

TMAA 1, which is assigned to the paint striping crew in District 4 was struck by an errant vehicle, see Figure 4.10. The crew supervisor notified the researchers at AHMCT who were able to remotely access the mDVR and download the footage. The TMA's location, velocity, and acceleration are also available from the mDVR. The video footage included a date and time stamp, TMA truck speed in the upper right, and the speed of the fastest target vehicle in the upper left corner.


**Figure 4.10: Snapshot of video downloaded from mDVR**

# Operator Feedback

Operator feedback can provide substantial data about the fit of the TMAA package to regular Caltrans operations and the appropriateness for broader deployment. To gather this feedback, the AHMCT researchers developed two draft surveys, reviewed them with the project panel, and finalized the surveys. The Caltrans crew supervisors distributed and collected the surveys. The surveys were anonymous and did not have any personnel-identifying information. When the surveys were returned, AHMCT researchers analyzed the operator's feedback.

The first survey, shown in Appendix F, was administered after the initial training on the TMAA package and contained the following feedback to inform training practices:

- Feedback on training content and quality,
- Further training needs, and
- Time needed to learn the system and operate safely.

The second survey, shown in Appendix G, was administered at the end of the one-year field testing. The survey questions included:

- User-friendliness/ease of system operation,
- Distractions by the system,
- Perceived usefulness,

- Perceived impact on work zones and driver behavior,
- Examples from use.

Figure 4.11 shows the results from 11 respondents to the first survey. A Likert-score of 5 of 5 is *strongly agree* and a score of 1 of 5 is *strongly disagree*. The feedback confirms that the training approach designed with classroom and hand-on experiences and materials designed to support different learning styles was well received. During the project, AHMCT researchers did not need to provide additional support to the operators as they were able to utilize the training information and materials to interact with the TMAA.

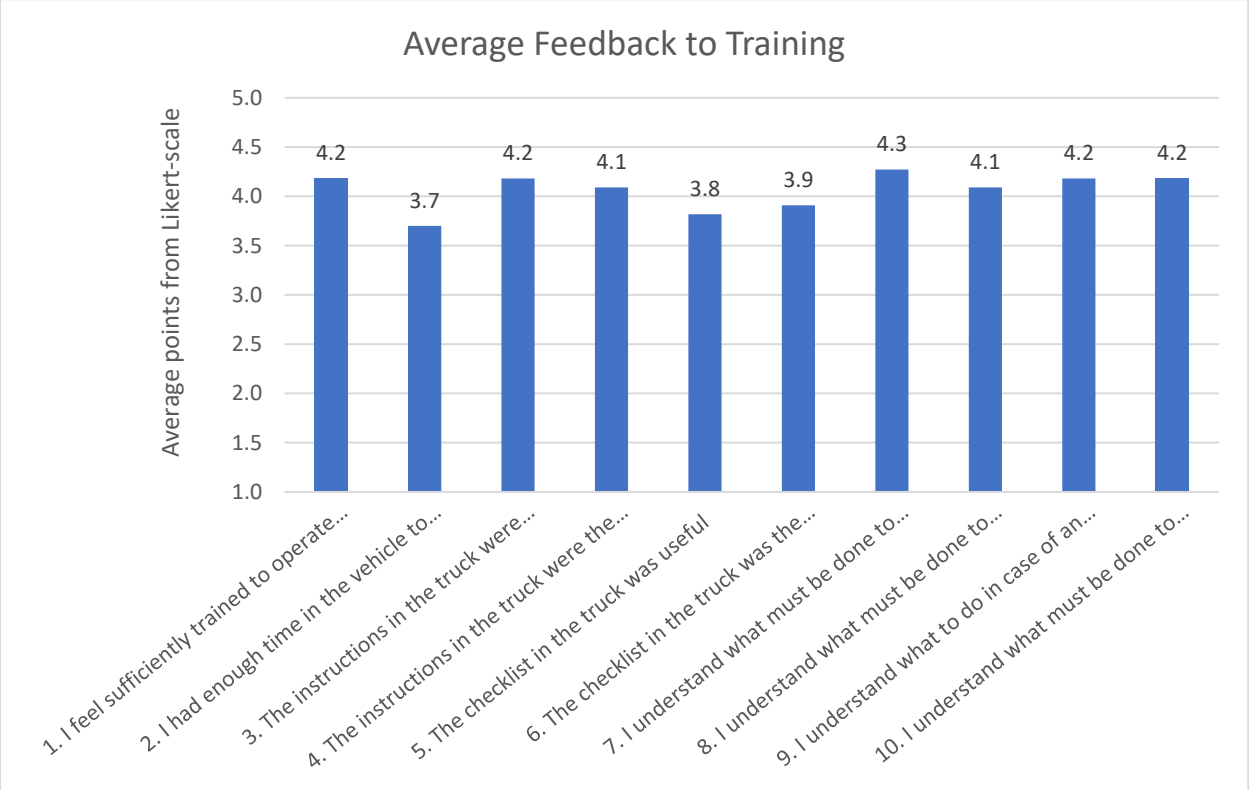



**Figure 4.11: Results from first survey given to TMA truck operators (*n* = 11)**

In developing the first survey, the researchers provided a snapshot view of the 4 subsystems of the TMAA package. This was included to help the operators answer free response questions and determine which subsystems may require more training or reference materials. The free-response section provided feedback that was similar to feedback received throughout the project, including:

- Unfamiliarity with adjusting the radar board speed,
- The placement of the mDVR screen obstructed their view,
- The LANE CLOSED sign should be further in,

- Wish to include a toggle switch on the panic button.

The second survey had 5 responses. Although the second survey went through the same development and panel feedback process as the first survey, the responses show evidence of survey design flaws. In the previous survey, the subsystems were shown as an image at the start, the researchers believe that this survey would have benefited from a similar reminder at the beginning of the survey. Unfortunately, the operators referenced all systems that were installed on the truck, many of which are not related to this research project. There were numerous comments related to the changeable message sign and the actual TMA.

The second survey did have several questions that were designed properly to elicit feedback about the TMAA. The operators "do believe that the panic lights have an impact" on the approaching vehicle driver's awareness to their truck when they press the button, as demonstrated by an average Likert-score of 3.8 out of 5. The majority of the operators also utilized the instructions and the checklist as they became familiar with the technology.

# Chapter 5:
# Conclusions and Recommendations

There were several significant changes made to the technology package that was planned for installation and evaluation in research task 3685. However, all of the new subsystems were successfully evaluated, installed, and documented for further deployment efforts. The new radar signboard was successfully validated, and a steel structure was designed to support the new signboard and LANE CLOSED sign. The information was disseminated to multiple groups within Caltrans. The researchers worked with the supplier, Kohltech, and overcame the challenges of installing software in order to remotely view and download mDVR video footage. Lastly, a new panic light system that utilizes a one button solution was successfully designed, tested, evaluated, and documented through this research project.

## Procurement Summary for Current and Future TMAA

There are several models and configurations for TMAA that are available from the manufacturers. However, the researchers suggest that the equipment used in this study be used for future deployment. A summary of the equipment used in this research is shown in Table 5.1

**Table 5.1: Procurement Information for TMAA**

| Subsystem and Product | Manufacturer | Specifications/model # |
|---|---|---|
| mDVR | Kohltech | 1- M5 Series DVR<br>2- CAM-1080SV<br>2- CAM-1080N |
| Panic Lights | Panic Lights- Whelen<br>Delay Off Timer- InPower | 4- TLIA<br>1- VCM-04-10SA |
| Radar Signboard | Kohltech | 1- Radar Message system with Mini-Messenger<br>Amber strobe light |

| Subsystem and Product | Manufacturer | Specifications/model # |
|---|---|---|
| | | Target acquisition greater than 750 feet<br>Display fastest speed |
| iCone | iCone | 1- Arrow Board Kit (if LED bulb arrow board) OR<br>1- Hazard Light Kit (if arrow board is part of CMS) |

# TMAA Evaluation Conclusions

This TMAA research project successfully demonstrated that the TMAA has an impact on the traveling public's behavior in an active work zone. By raising awareness through the iCone products or radar signboard, the oncoming vehicle drivers get increased attention to the work zone, as well as guidance on if they should decrease their speed to protect Caltrans employees. The panic light system was able to gain the attention of drivers of approaching vehicles to alert them to the lane being closed, as reported by the operators. Finally, the mDVR video footage was remotely accessed when there was an incident.

# Issues that may affect full implementation

During this research project, using a viable software to download the video footage from the mDVR on Caltrans computers was challenging. The researchers, in partnership with META staff, sought for IT approval to install the mDVR viewing software into Caltrans laptops. However, this process was denied, and as an alternative solution a web interface was utilized instead. The initial web interface that was evaluated prior to field trails was slow and created a frustrating user experience. In the final two months of the active research, Kohltech was able to overcome this obstacle and improved their web interface by releasing a new web interface that performed with acceptable latency. Kohltech also worked with Geotab, and now Kohltech mDVR footage is available on a Geotab web portal. Installing any software onto a Caltrans computer can be an obstacle to full implementation. For full implementation, it is recommended to seek web interfaces whenever possible to reduce the potential risk associated with installing software.

# Future Research

As the TMAA subsystems were evaluated, it became apparent that a data collection system of the traveling publics speed is necessary while the shadow truck is moving. The commercially available products utilized in this research project, as well as in research task 3919, Targeted Warning Messages to Protect Moving and Stationary Maintenance Lane Closures, lack the ability to accurately store vehicle speeds while the shadow truck is moving. A system developed by researchers and/or vendors would allow for a quantitative analysis of the behavior of the traveling public, thereby allowing researchers the ability to evaluate safety improvements necessary for Caltrans moving maintenance operations. The researchers have confirmed that Kohltech's supply would be able to improve the radar board to allow for the above functionality.

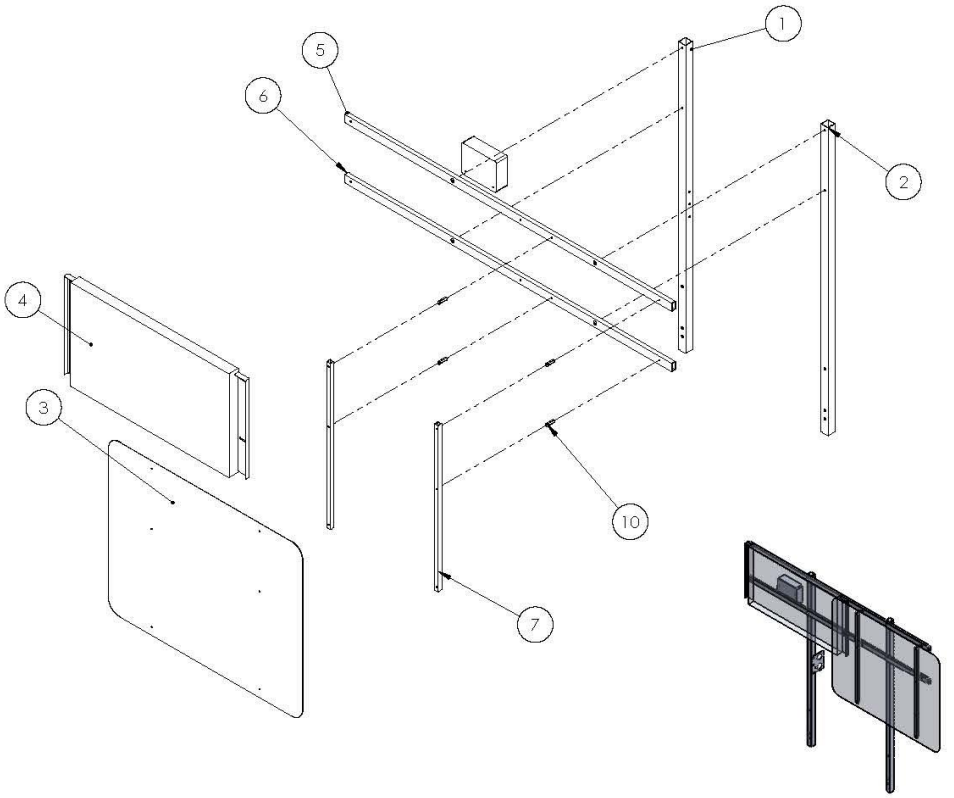
The iCone products were not evaluated for their ability to provide data to a Traffic Management Center. Being able to provide this information to the public in multiple modes may increase the public's awareness and improve safety in work zones.

# References


1. Duane Bennett and Ty A. Lasky, Review of Equipment and Accessories for Truck-Mounted Attenuator Trucks (https://ahmct.sf.ucdavis.edu/sites/g/files/dgvnsk8581/files/inline-files/UCD-ARR-22-04-30-01.pdf), AHMCT Research Center, UC Davis Dept. of Mechanical & Aerospace Engineering, UCD-ARR-22-04-30-01, April 2022.
2. J. Russell, "LED Panic Lights," Missouri DOT Innovations Showcase- LED Panic Lights, https://www.modot.org/sites/default/files/documents/LED%20Panic%20Lights.pdf (accessed Feb. 19, 2025).

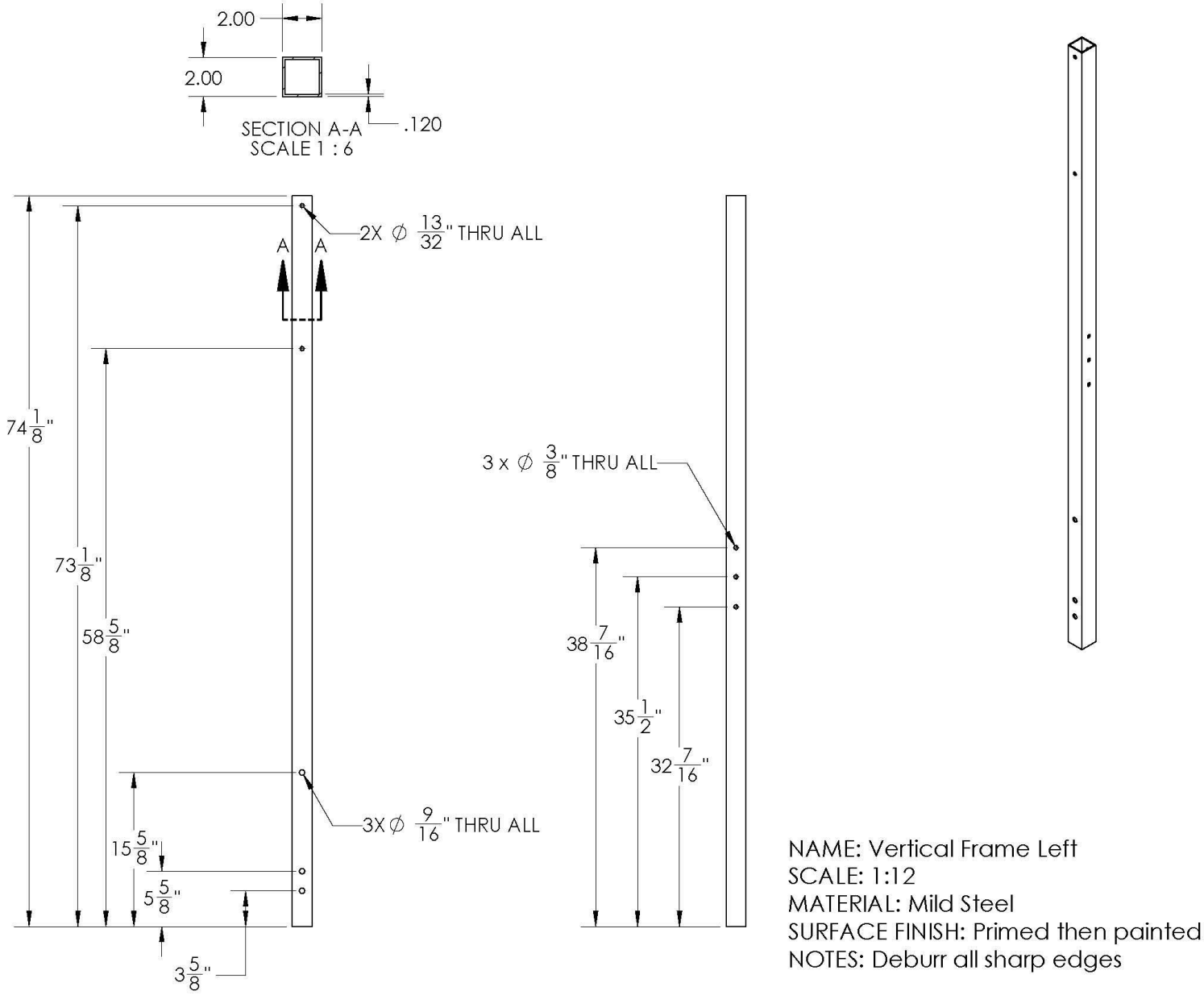
# Appendix A:
# CAD Assembly and Part Drawings

| ITEM NO. | MCMASTER PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | - | Vertical Frame Left | 1 |
| 2 | - | Vertical Frame Right | 1 |
| 3 | - | Lane Closed Sign | 1 |
| 4 | - | Radar Sign Board | 1 |
| 5 | - | Horizontal Cross Member Top | 1 |
| 6 | - | Horizontal Cross Member Bottom | 1 |
| 7 | - | Vertical Sign Support | 2 |
| 8 | - | Trailer Plug Panel | 1 |
| 9 | - | Junction Box | 1 |
| 10 | 91115A905 | Female Threaded Hex Standoff | 4 |
| 11 | 91247A221 | Medium-Strength Grade 5 Steel Hex Head Screw | 4 |
| 12 | 90107A127 | 316 Stainless Steel Washer | 23 |
| 13 | 90566A220 | Low-Strength Steel Thin Nylon-Insert Locknut | 7 |
| 14 | 91247A548 | Medium-Strength Grade 5 Steel Hex Head Screw | 10 |
| 15 | 90107A029 | 316 Stainless Steel Washer | 12 |
| 16 | 95615A102 | Medium-Strength Steel Nylon-Insert Locknut | 2 |
| 17 | 91247A635 | Medium-Strength Grade 5 Steel Hex Head Screw | 7 |
| 18 | 95615A106 | Medium-Strength Steel Nylon-Insert Locknut | 4 |
| 19 | 90107A033 | 316 Stainless Steel Washer | 12 |
| 20 | 91247A362 | Medium-Strength Grade 5 Steel Hex Head Screw | 6 |
| 21 | 90630A160 | High-Strength Steel Nylon-Insert Locknut | 6 |
| 22 | 9283K14 | Polyethylene Plastic Snap-in Round Plug | 4 |
| 23 | 9565K52 | Polyethylene Square Plug | 4 |
| 24 | 9474K45 | Rectangular Plugs | 4 |
| 25 | 9565K38 | Polyethylene Square Plug | 2 |

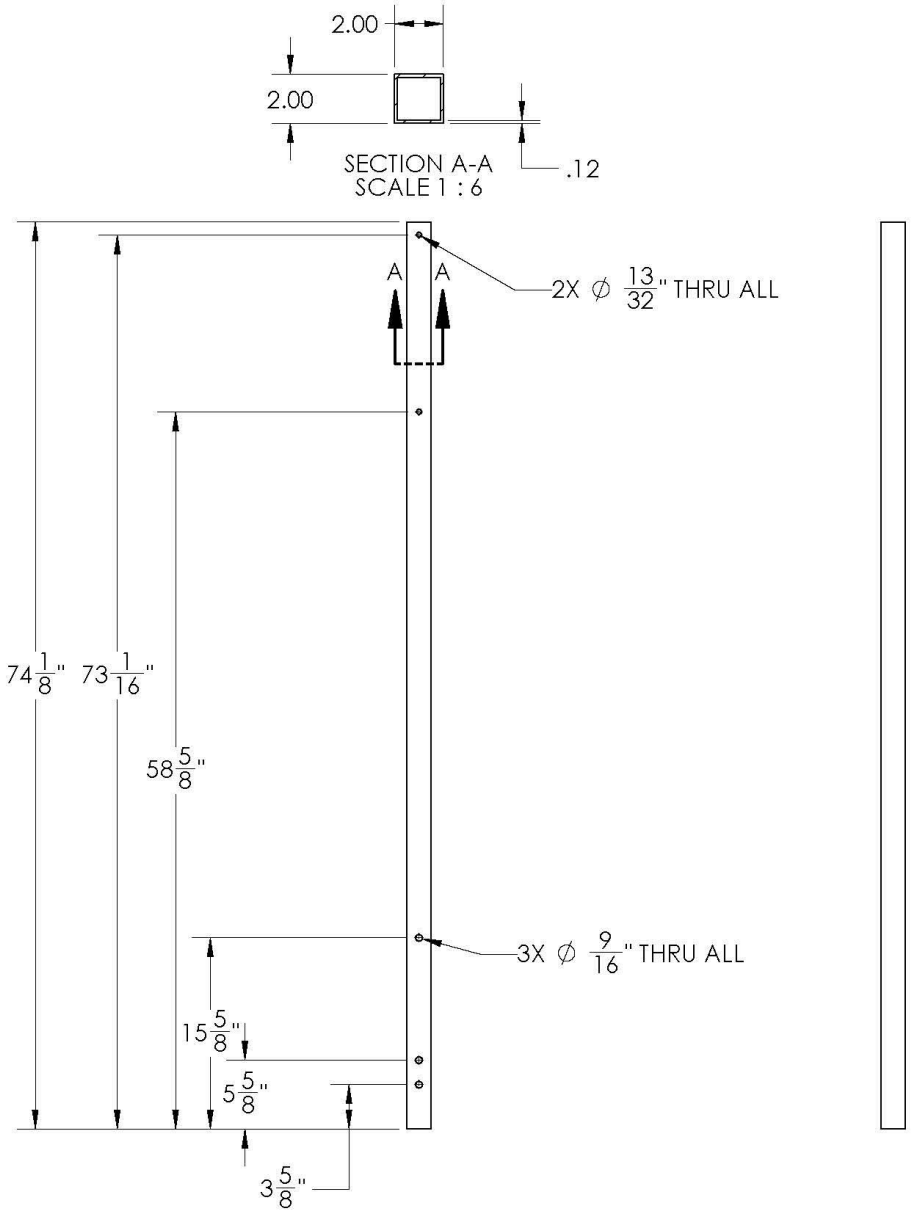



Isometric view of assembly

NAME: TMAA Sign Holder
SCALE: 1:20
NOTES:
1. Fasteners excluded from exploded view
2. Junction Box excluded from exploded view
3. Trailer Plug Panel excluded from exploded view

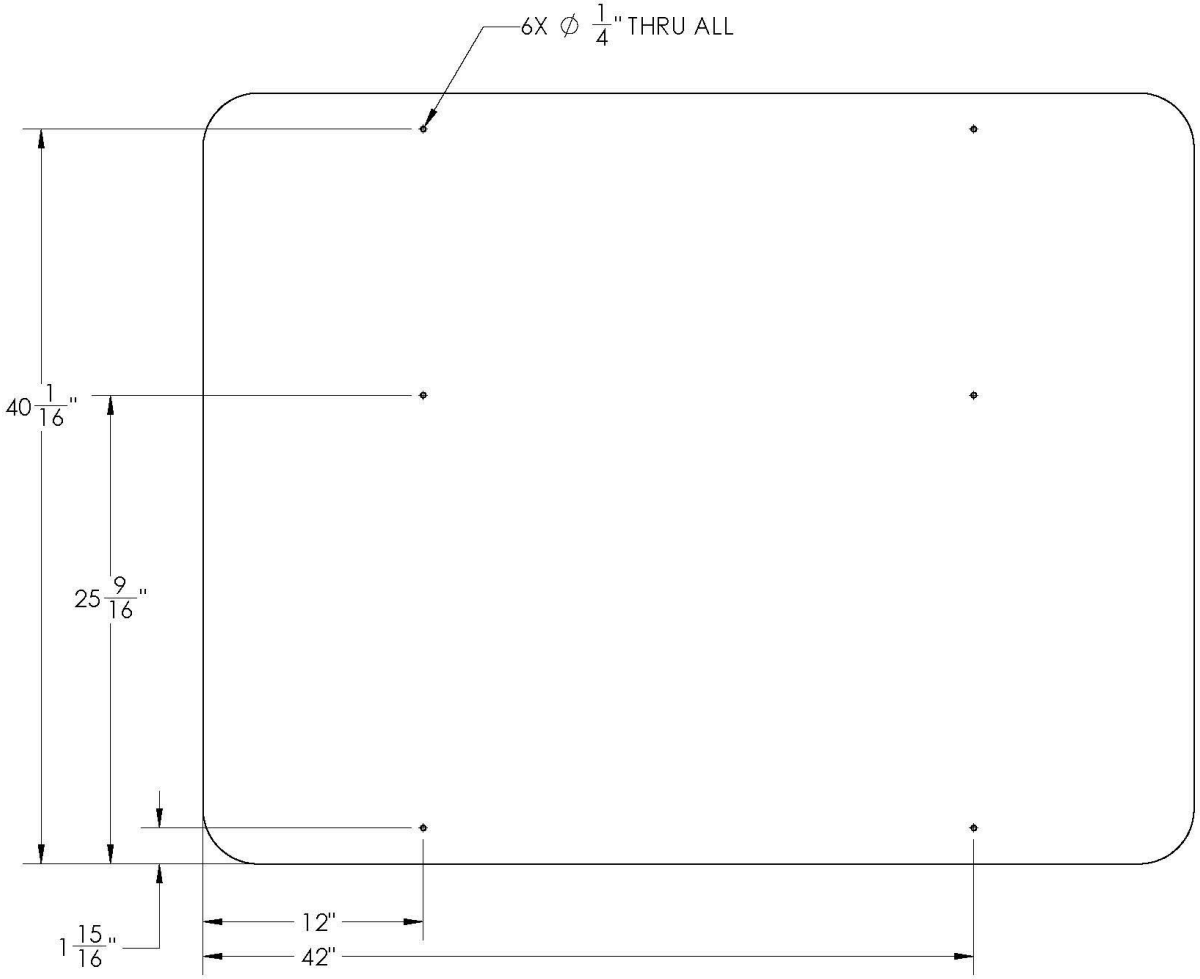



NAME: Vertical Frame Left
SCALE: 1:12
MATERIAL: Mild Steel
SURFACE FINISH: Primed then painted
NOTES: Deburr all sharp edges



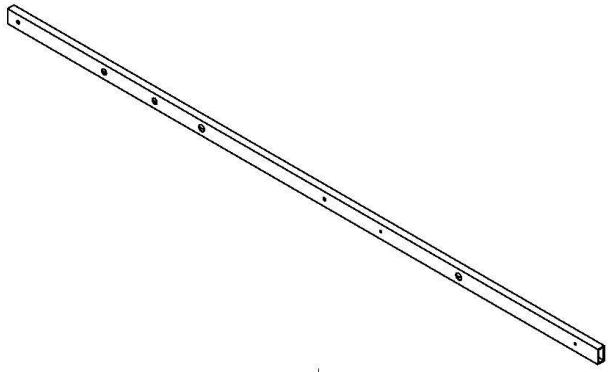


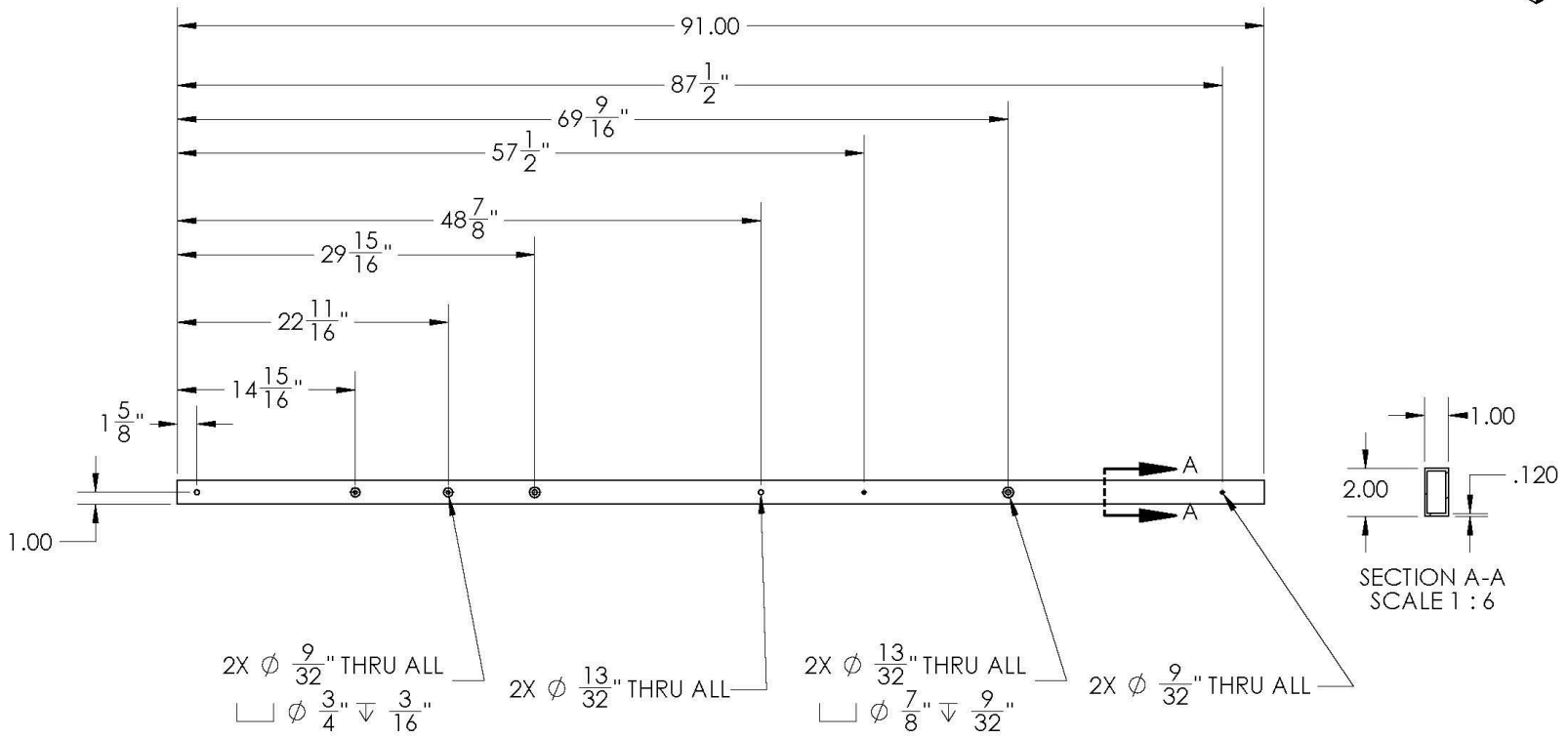

NAME: Vertical Frame Right
SCALE: 1:12
MATERIAL: Mild Steel
SURFACE FINISH: Primed then painted
NOTES: Deburr all sharp edges



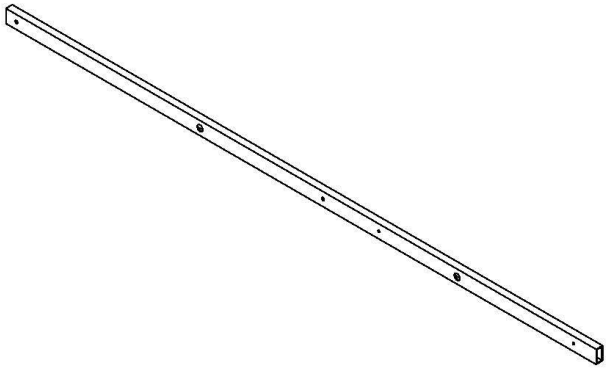

NAME: Lane Closed Sign (Hole Positions)
SCALE: 1:8

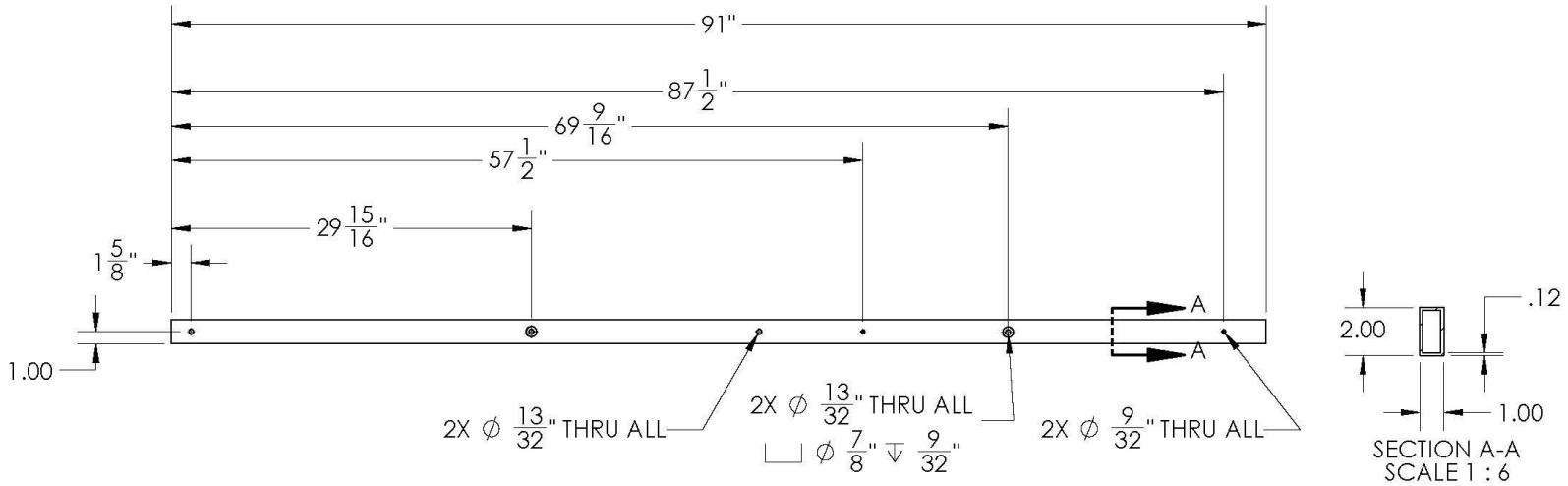
NAME: Horizontal Cross Member Bottom
SCALE: 1:12
MATERIAL: Mild Steel
SURFACE FINISH: Primed then painted
NOTES: Deburr all sharp edges

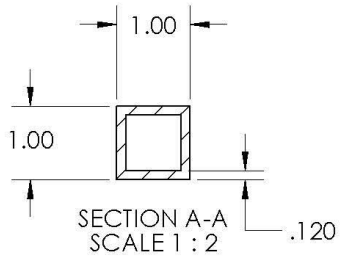


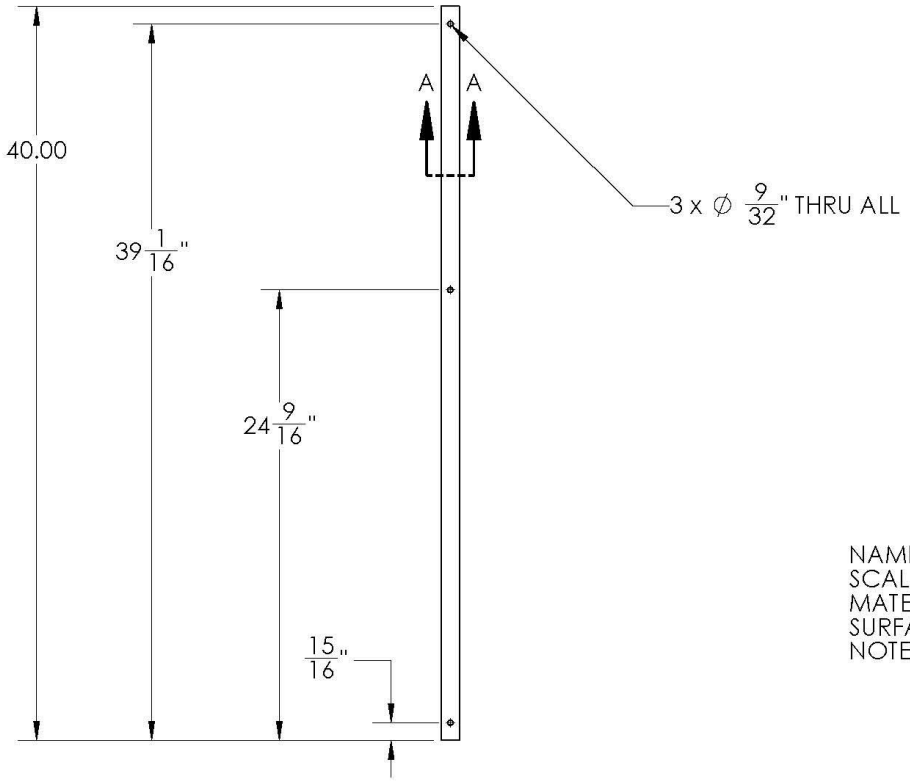


NAME: Horizontal Cross Member Top
SCALE: 1:12
MATERIAL: Mild Steel
SURFACE FINISH: Primed then painted
NOTES: Deburr all sharp edges

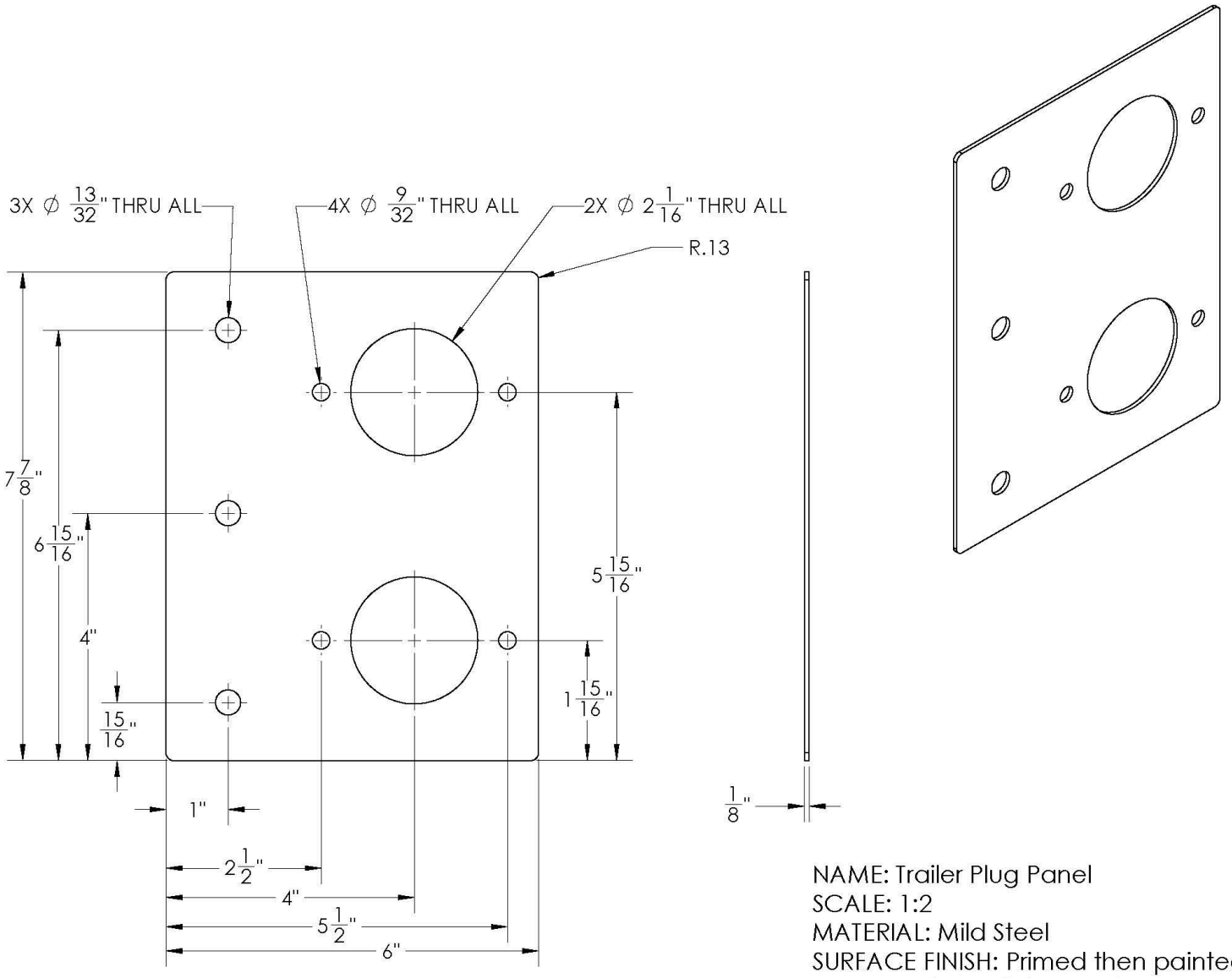






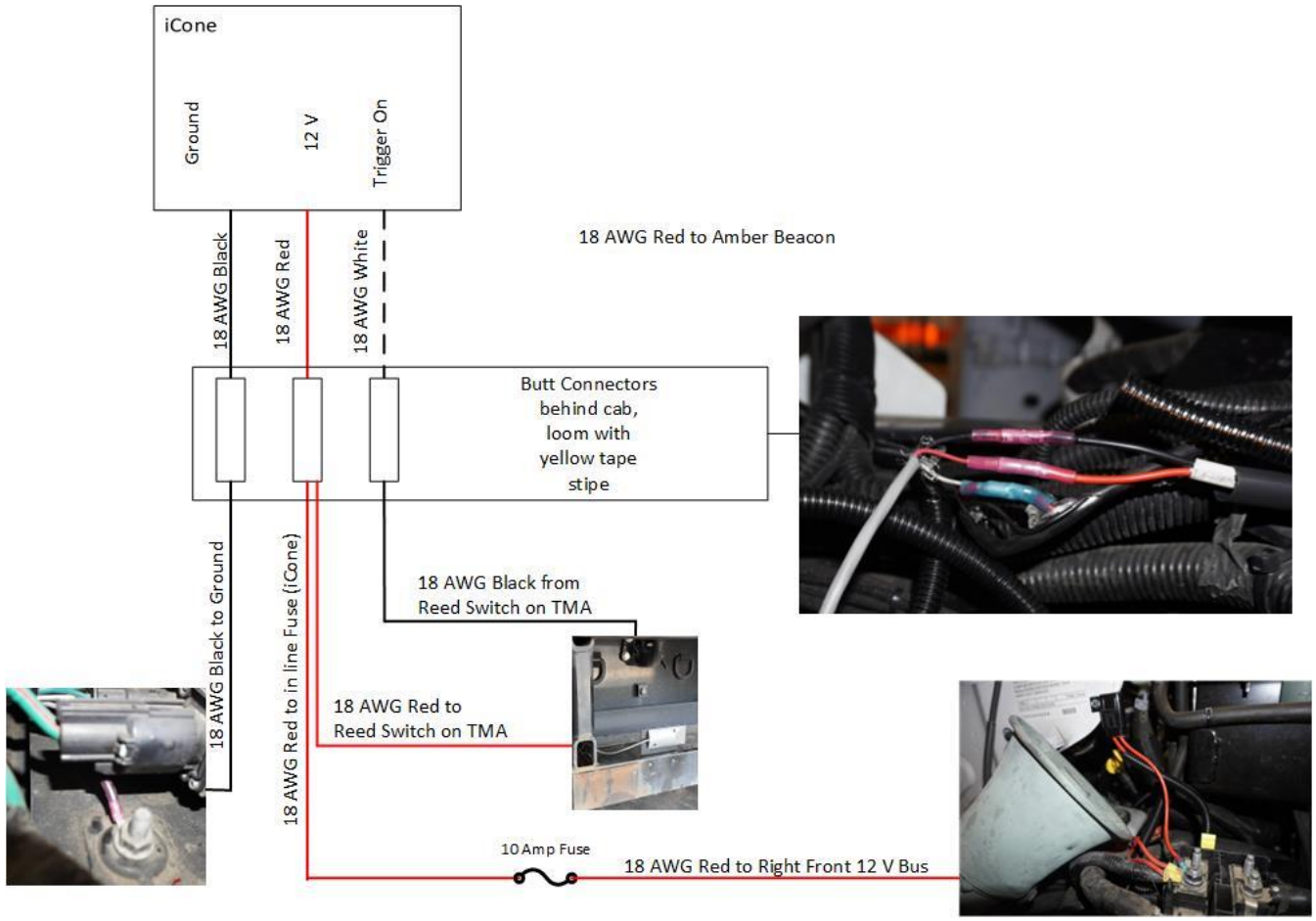

NAME: Vertical Sign Support
SCALE: 1:8
MATERIAL: 6061 Aluminum
SURFACE FINISH: Primed then painted
NOTES: Deburr all sharp edges




NAME: Trailer Plug Panel
SCALE: 1:2
MATERIAL: Mild Steel
SURFACE FINISH: Primed then painted
NOTES: Deburr all sharp edges

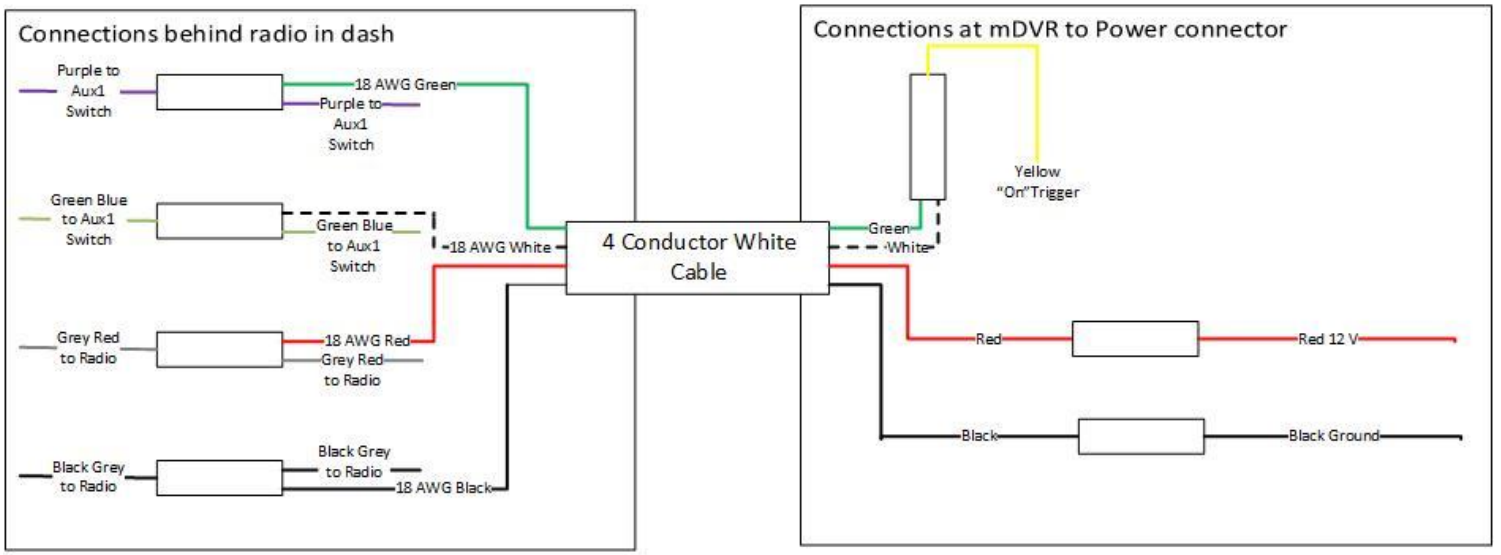
# Appendix B:
# Wiring Diagrams

iCone Wiring Diagram

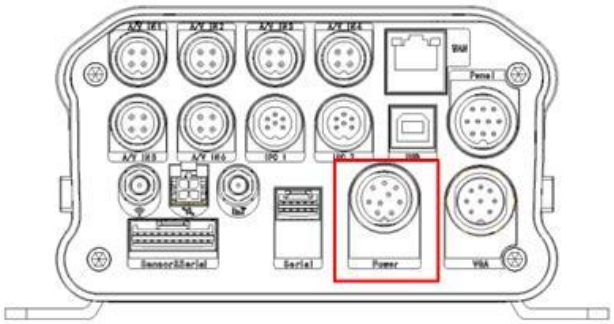


# mDVR Power Wiring Diagram

Connections to mDVR
Power connector

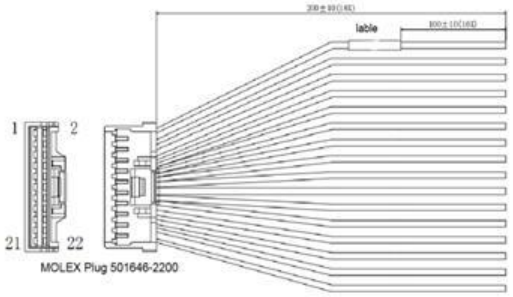



**Rear Panel**



# mDVR Trigger Wiring Diagram

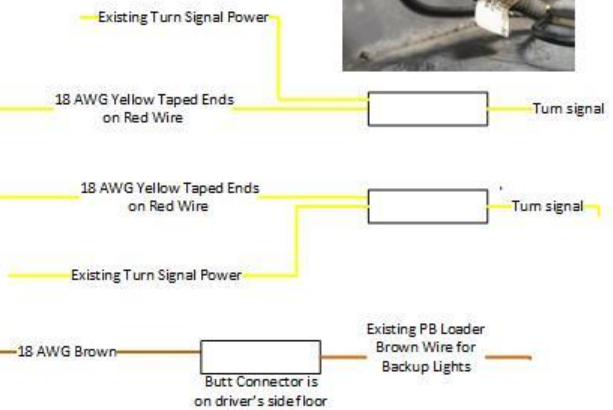
Camera trigger connections to mDVR 22 pin connector



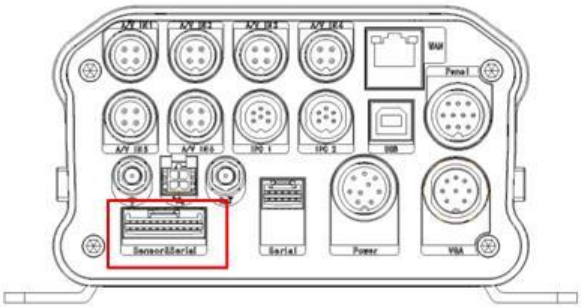

Diagram

501646-2200

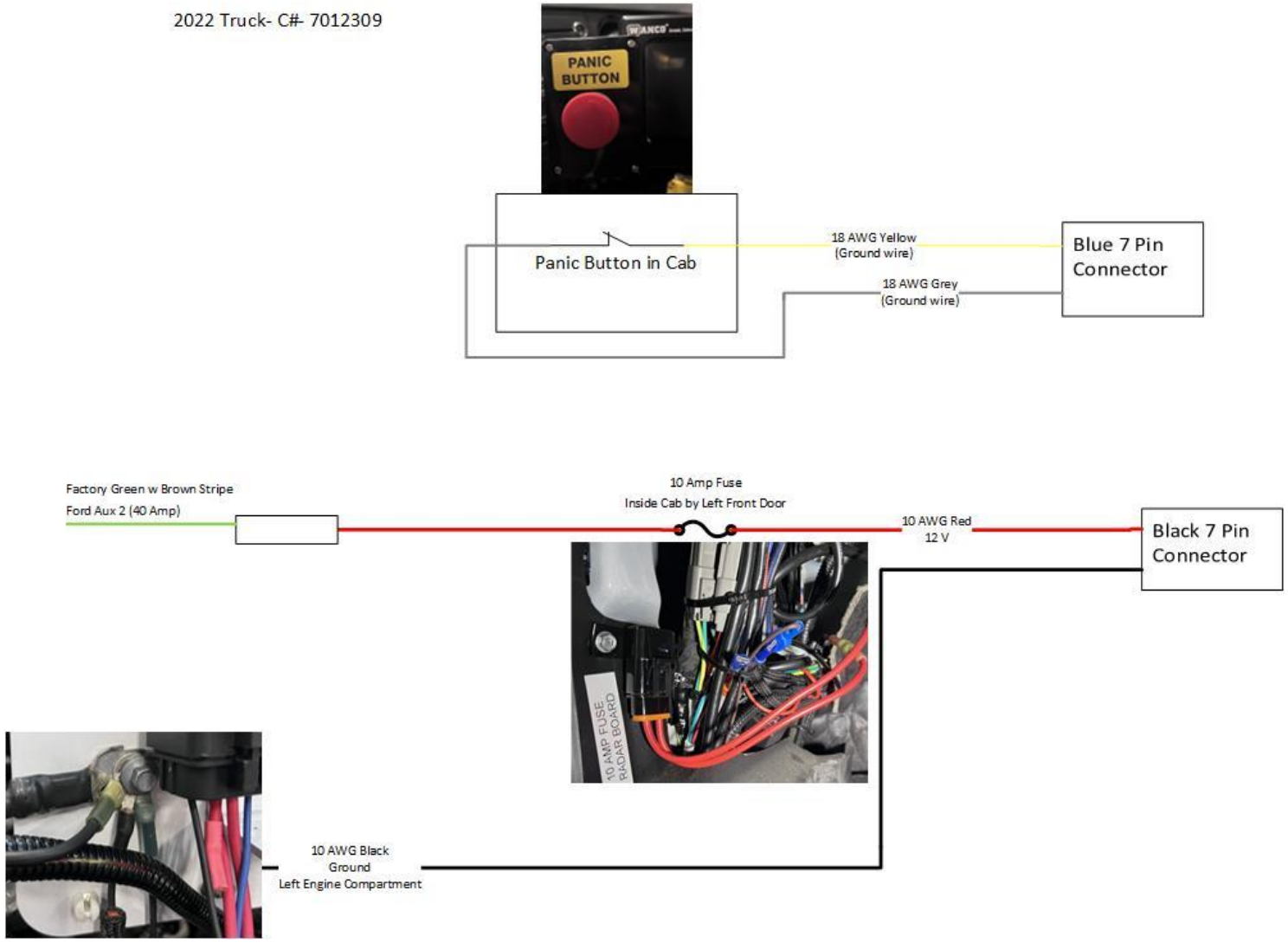
| | | |
|---|---|---|
| 1 | red | SENSOR IN1 |
| 3 | gray | SENSOR IN2 |
| 5 | light green | SENSOR IN3 |
| 7 | light blue | SENSOR IN4 |
| 9 | gray | SENSOR IN5 |
| 11 | orange | SENSOR IN6 |
| 13 | blue&black | SENSOR IN7 |
| 15 | blue&white | SENSOR IN8 |
| 17 | blue | SPEED IN |
| 12 | red&white | SENSOR OUT1 |
| 14 | red&yellow | SENSOR OUT2 |
| 19 | black | GND |
| 21 | red | +5V |
| 18 | black | GND |
| 10 | green | 232RX-1 |
| 8 | whiten | 232TX-1 |


**Rear Panel**



# 7 Pin Trailer Connectors for Truck with C# 7012309



# 7 Pin Trailer Connectors for Truck with C# 7012308

2019 Truck- C#- 7012308


Panic Button in Cab

18 AWG Yellow
(Ground wire)

18 AWG Grey
(Ground wire)

Blue 7 Pin
Connector

Factory Green w Brown Stripe
Ford Aux 2 (25 Amp)

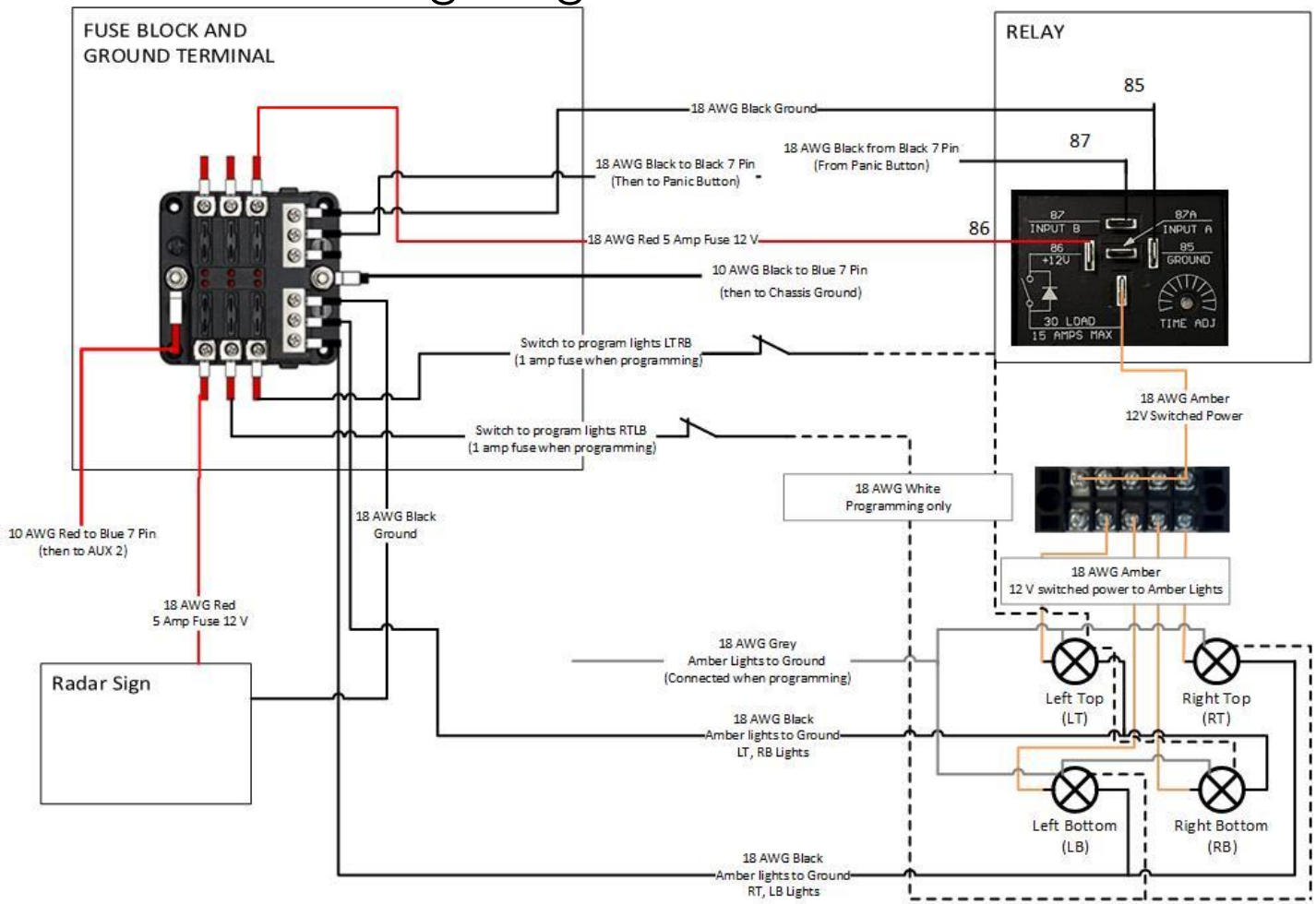
10 Amp Fuse
Inside Cab by Left Front Door

10 AWG Red
12 V

Black 7 Pin
Connector


10 AWG Black
Ground
Driver Side by front door

# Junction Box Wiring Diagram



# Appendix C: Operator Training

# Operating Training Task 4158 "Caltrans field trials of the Truck-Mounted Attenuator Accessory (TMAA) package"

Barbara S Linke, Dave Torick, Evan Sim
AHMCT Research Center
University of California, Davis
1/11/2024

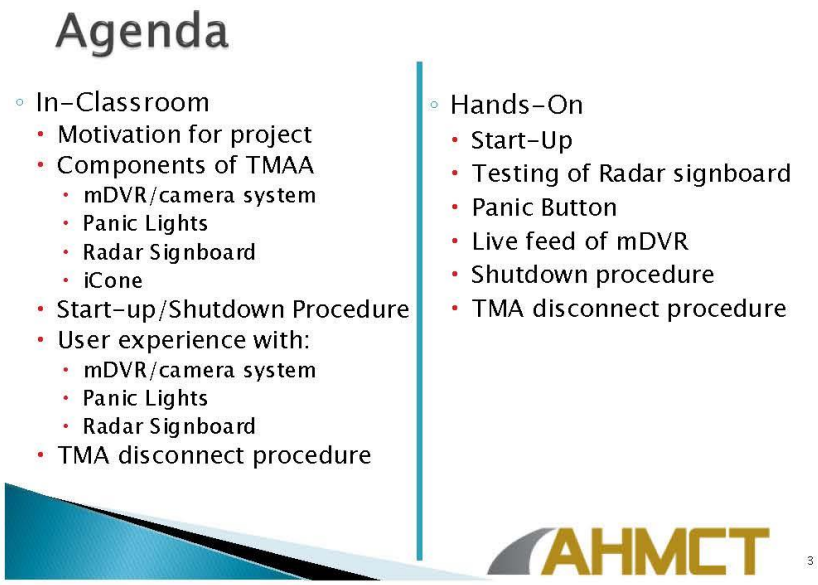
1

## In case an accident occurs

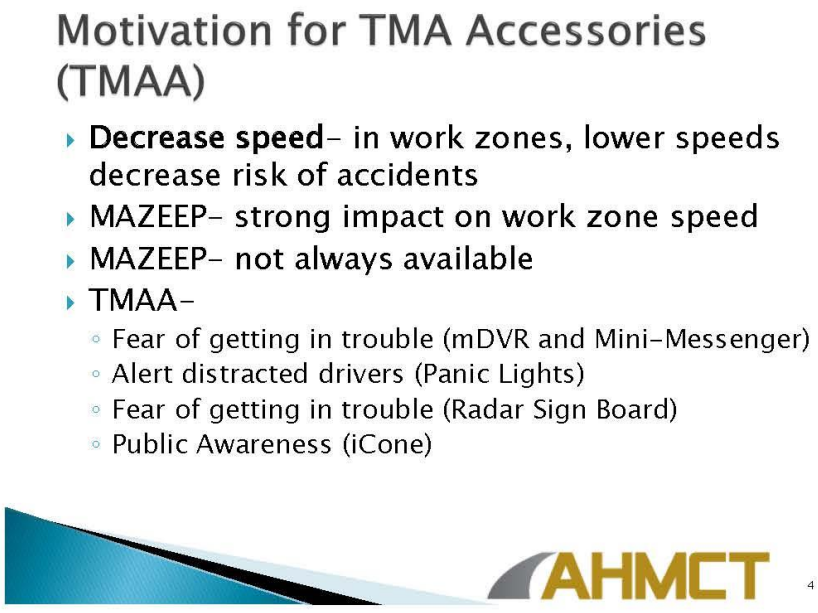
- After the scene, people, and vehicle are safe and before 6 days time has elapsed
  - Be sure vehicle is running, or at least the ignition switch is on
    - This may require connecting a battery charger to the truck if it cannot start
  - Log in to the web portal at Fleetweb.kohl-tech.com
    - Download all 4 cameras footage for 1 minutes before the accident till 1 minute after the accident
    - You would be able to see the accident occur if you look at the speed view around the time the accident was reported to have happened
    - This will most likely take a long time
  - Save this footage on your computer in case Caltrans has a need for it due to litigation

2

2

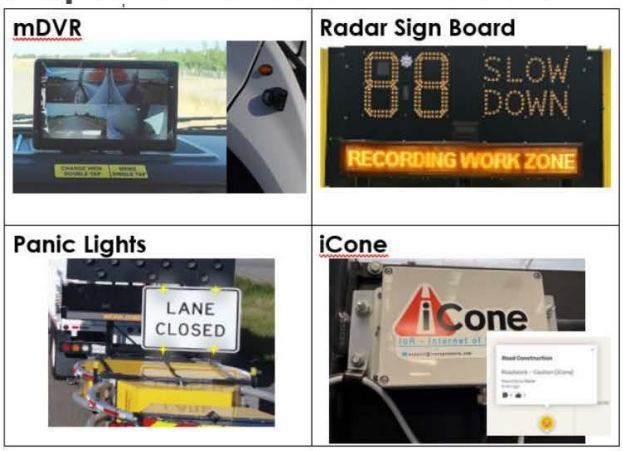



3




4

## Components of the TMAA




AHMCT

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## mDVR Components
## Larger 10-inch Touch Screen Display

- Self-initializes with ignition switch
- Default 4 views
- Turns off automatically, 1-hour after ignition


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6

6

## mDVR Components
## 2 Rear Cameras


- Camera 1 for TMA up
- Camera 2 for TMA down
- Flag on mDVR for back-up event

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7

## mDVR Components
## 2 Side Cameras

- Camera 3 for Left View
- Camera 4 for Right View
- Flag on mDVR for turn signal usage

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8

8

## mDVR Components
## Mini-messenger sign


- Turns on with AUX 2
- Current Message
  - RECORDING WORK ZONE
  - The word RECORDING Flashes
- Programmable

AHMCT 9

9

## mDVR software

AHMCT 10

10

## mDVR Abilities

- No operator interaction required
- 2 side cameras, 2 rear facing cameras
- Only 4 cameras are being recorded
- Stores information for 1 week
- Storage motivation if for litigation in case of an accident
- Utilizes 4G cellular networks
- Allows real-time remote viewing of cameras

AHMCT 11

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## Panic Light Components

- Turns on with AUX 2
- Flashes with PANIC BUTTON
- Continues flashing for 3 seconds after button is released, adjustable delay
- 4 CHP Approved Amber Flashing lights
- Synchronized Flashing Pattern



AHMCT 12

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## Radar Sign Board Components

- Turns on with AUX 2
- Programmable SLOW DOWN speed
  - 5, 15, 25, 35, … MPH


AHMCT 13

13

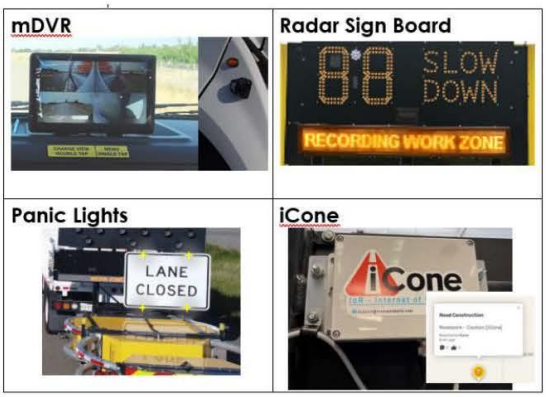
## iCone Components

- Turns on when TMA is fully deployed
- Currently sends information to Waze App

AHMCT 14

14

# Hands-On- Components



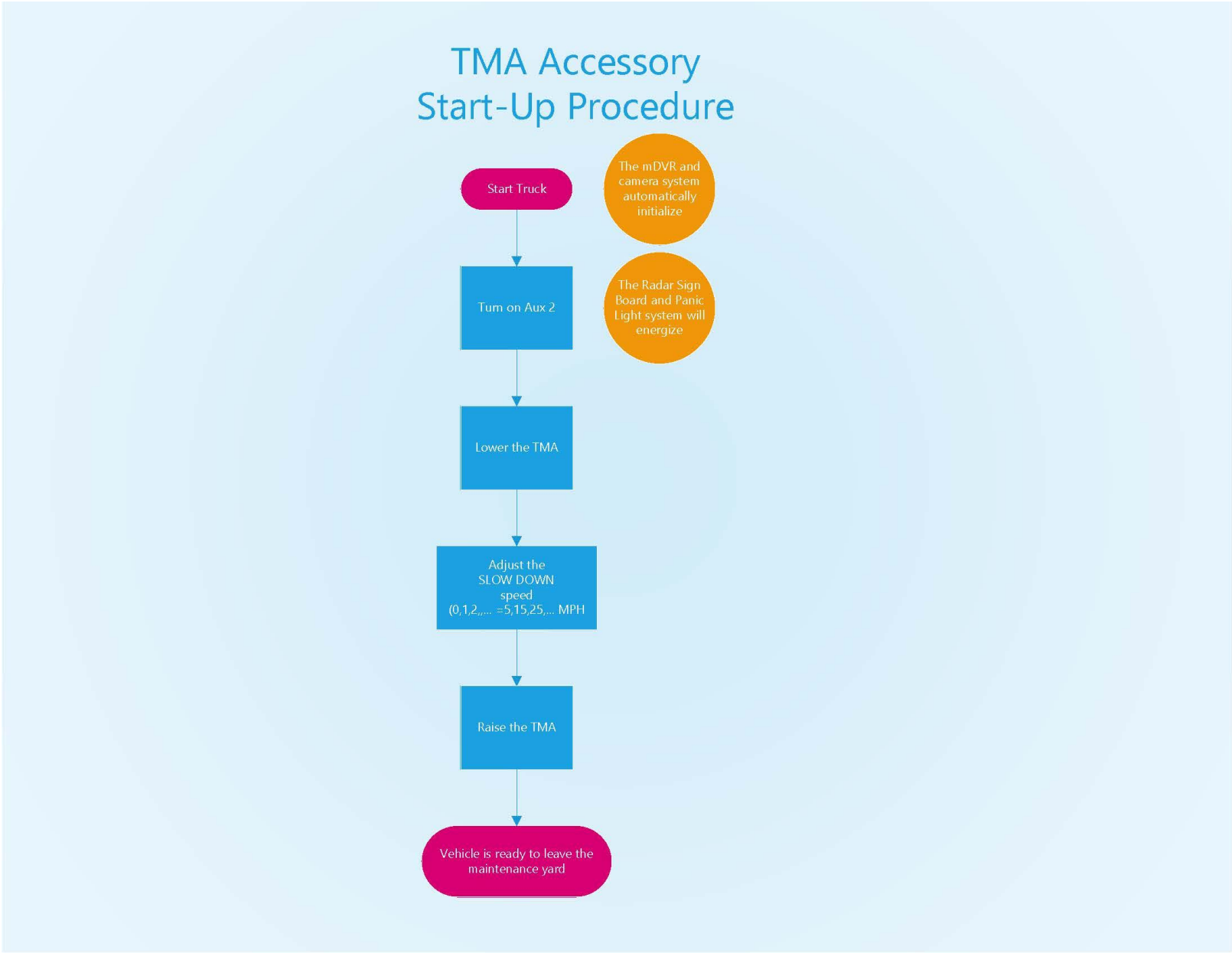

AHMCT

15

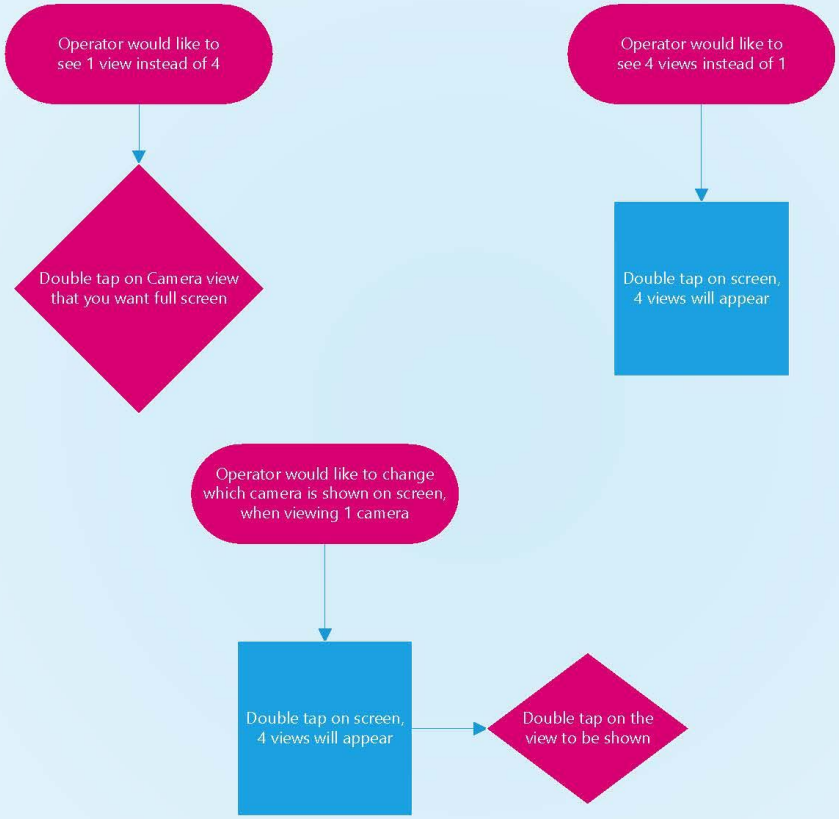
15

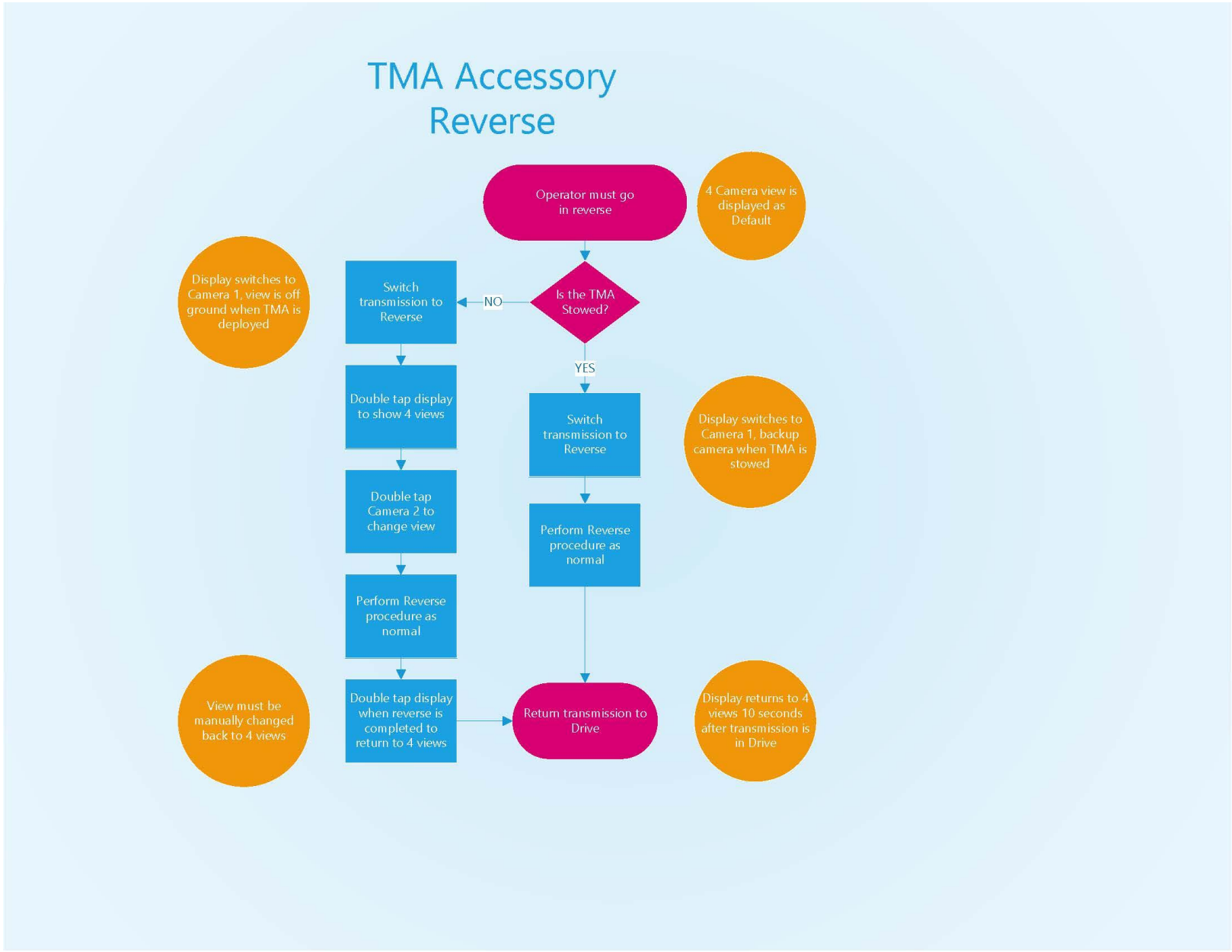
# Appendix D:
# TMAA Procedure Flowcharts

The following pages contain 11 flowcharts of procedures that an operator may need in order to work with a TMAA truck.

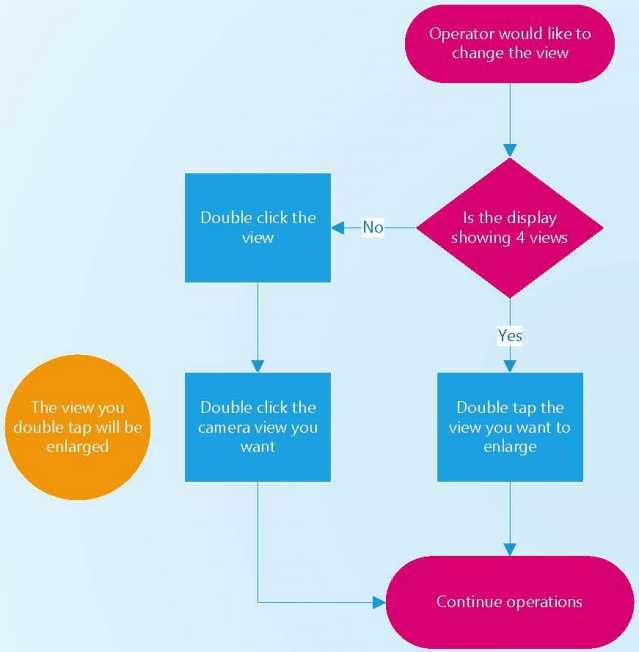


# TMA Accessory
# Changing Camera View

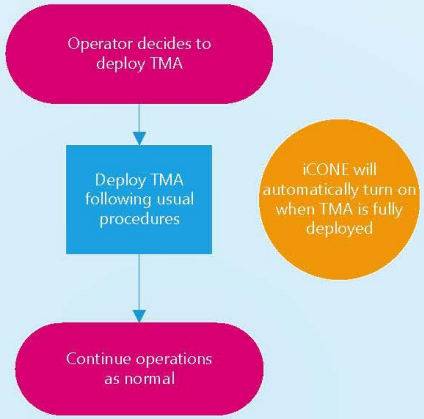




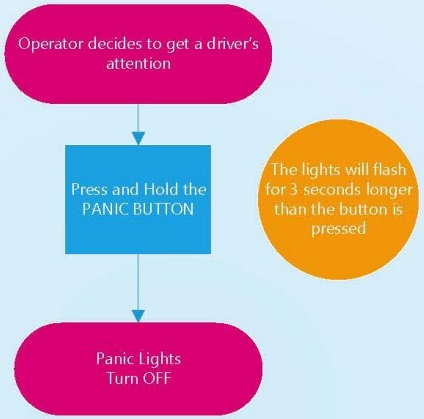
# TMA Accessory
# mDVR Changing View



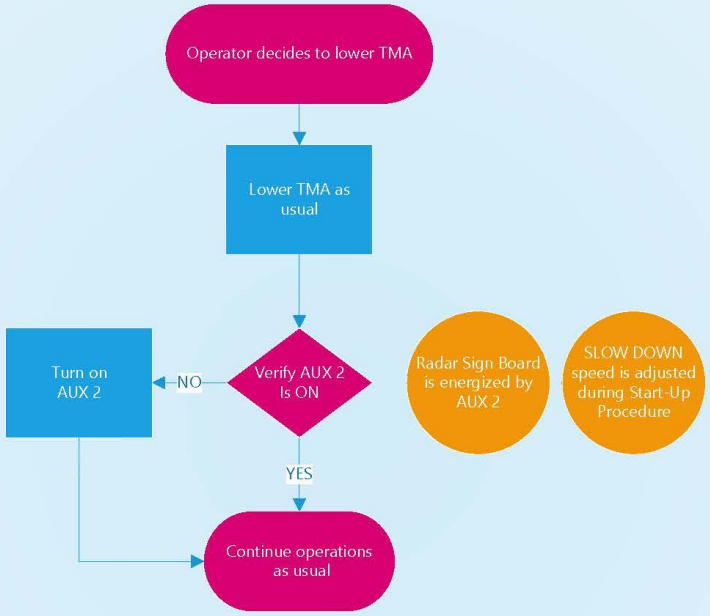
# TMA Accessory iCone Operation



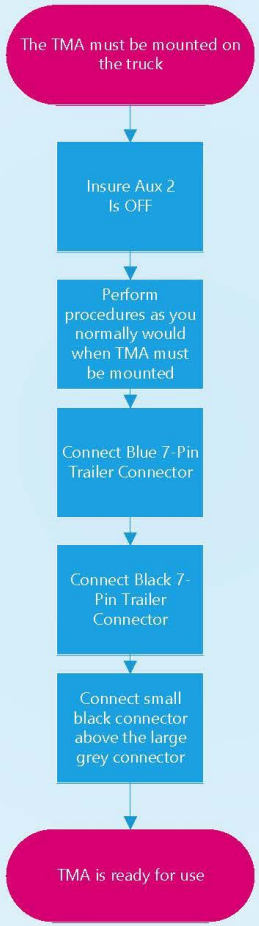
# TMA Accessory
# Panic Lights Operation



# TMA Accessory
# Radar Sign Board Operation

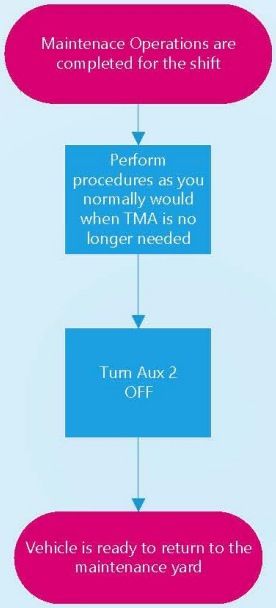


# TMA Accessory Connection Procedure



# TMA Accessory Disconnection Procedure

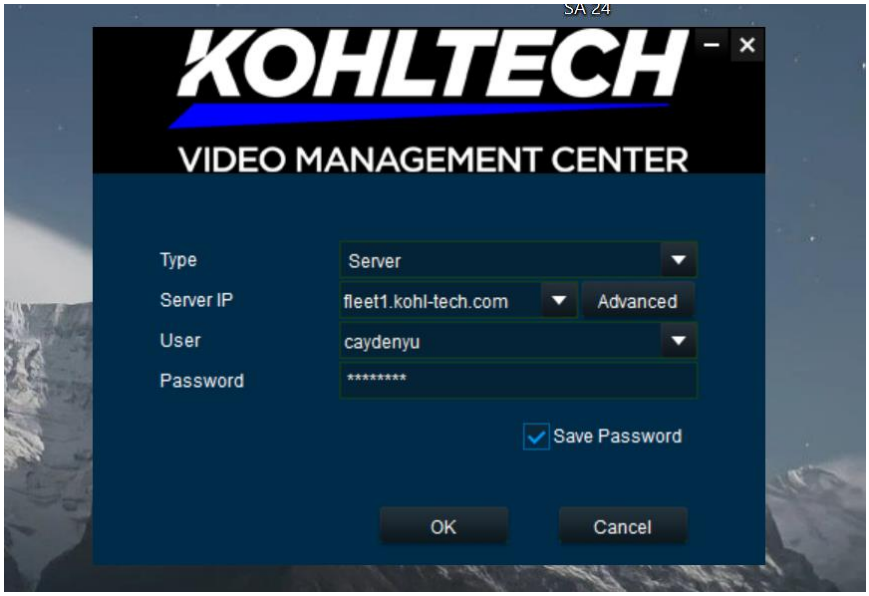
# TMA Accessory Shutdown Procedure



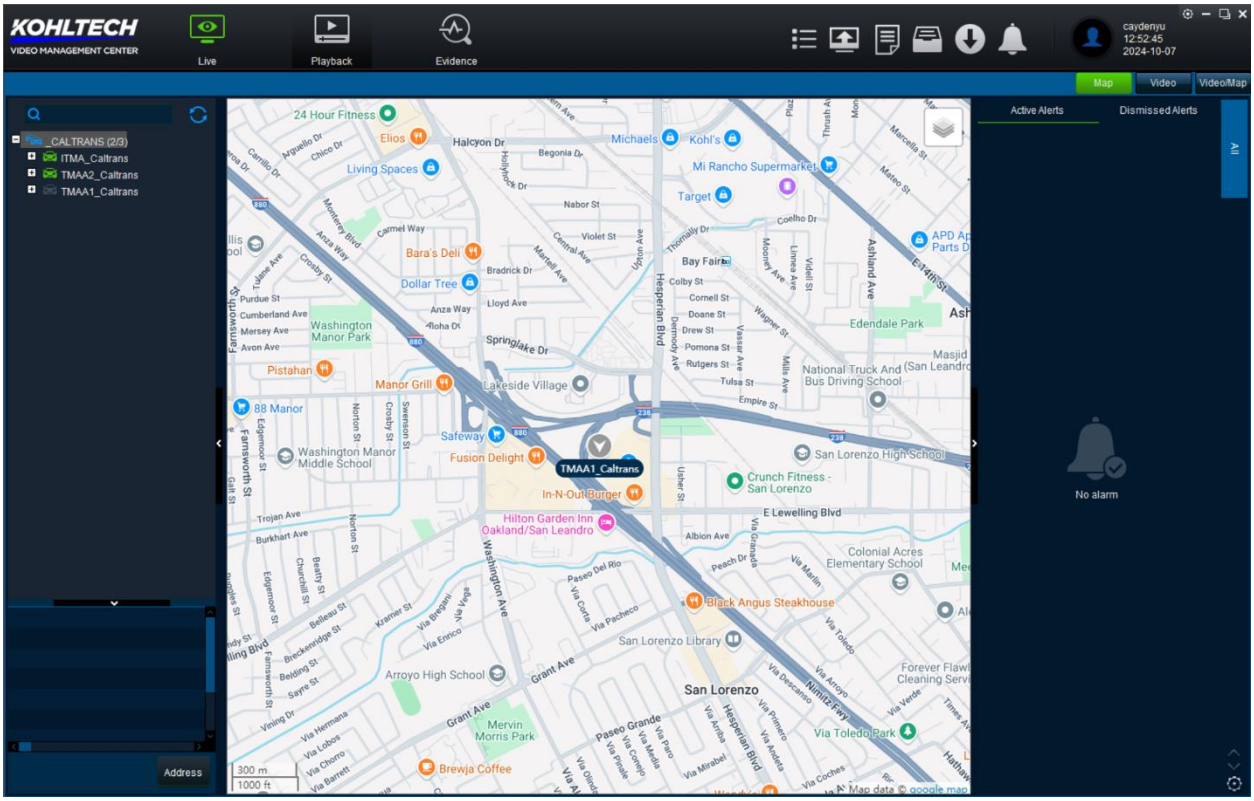
# Appendix E:
# TMAA Data Collection Procedure for mDVR

TMAA Data Collection Procedure

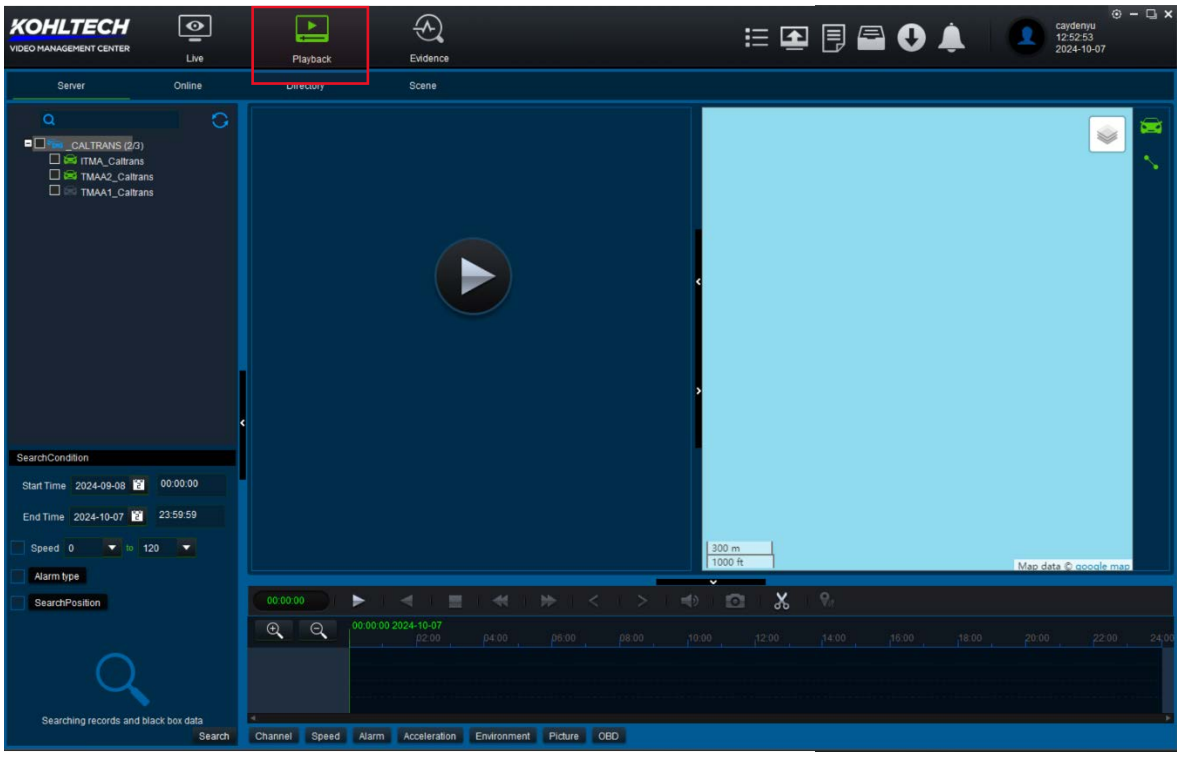
1. Sign in with your username and password



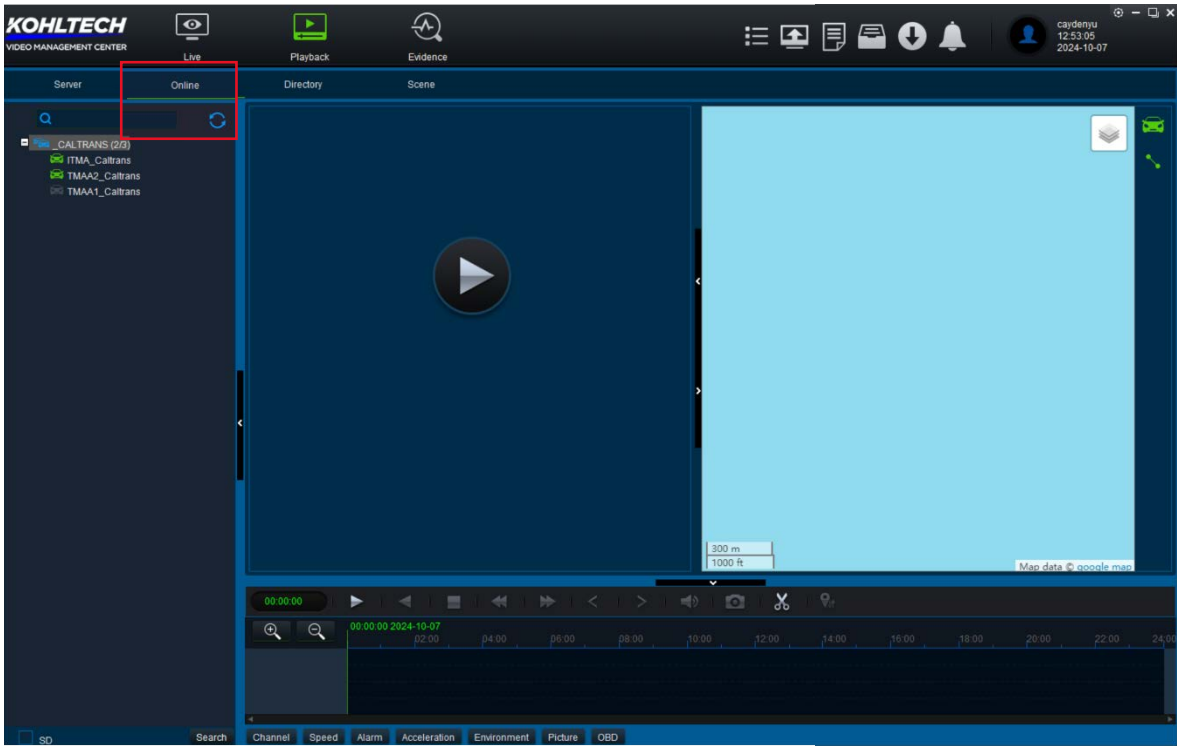
2. Enter the user interface as below



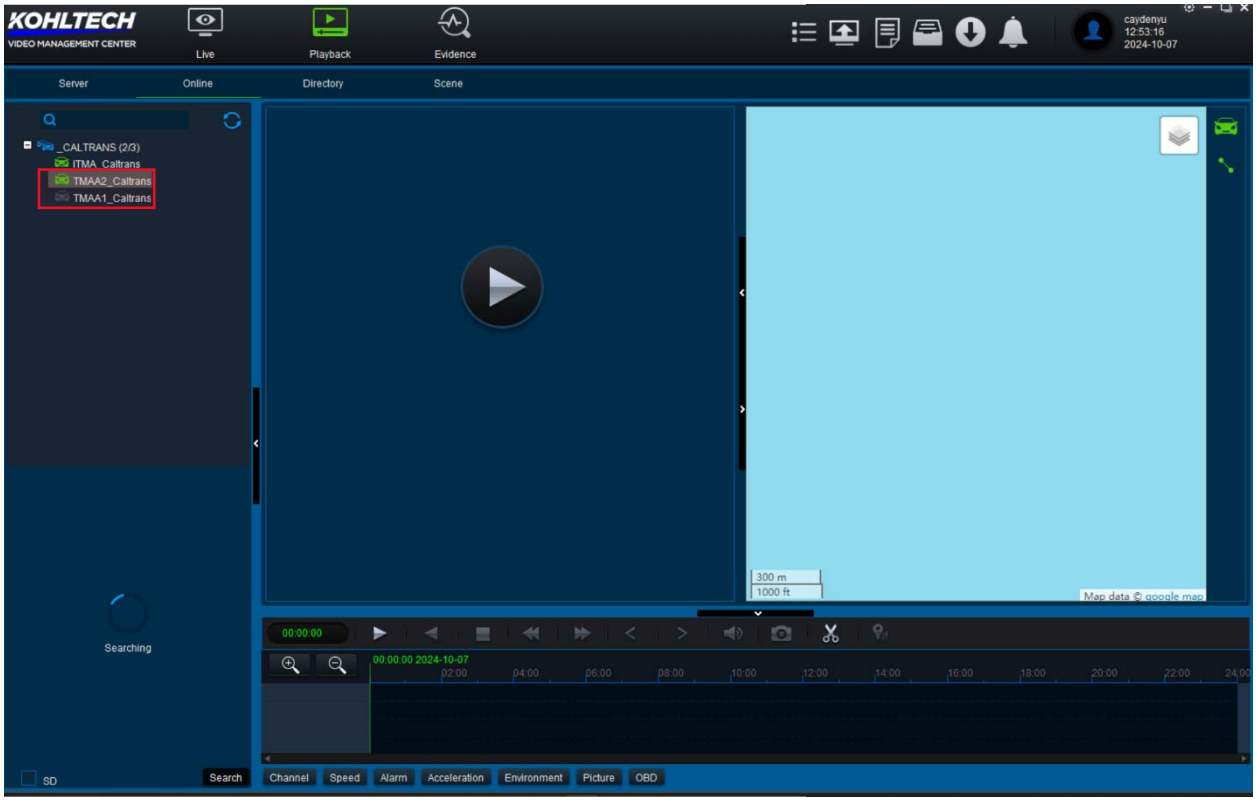

3. Select “playback” at the topmost tab



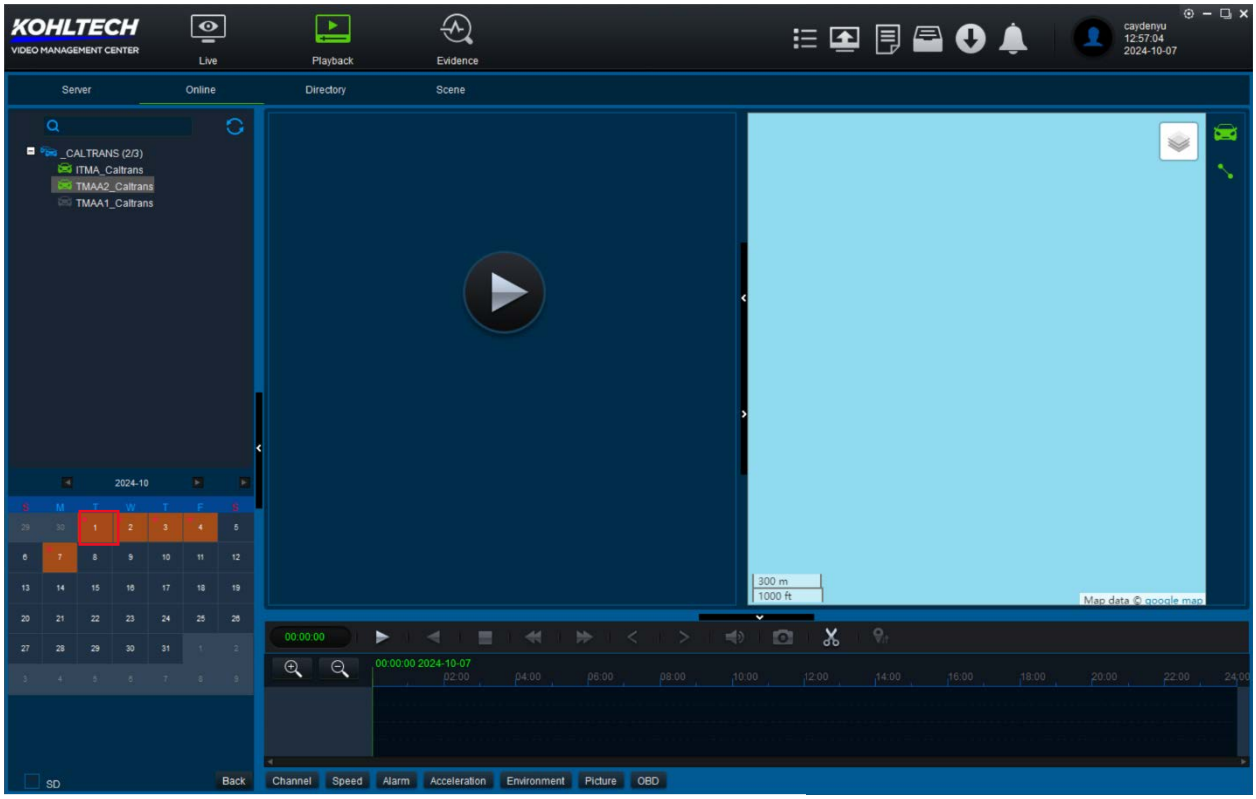
4. Select “Online” at the tab underneath the topmost tab:




5. Select the desired vehicle to collect data on:



6. Select the date desired to collect data on:




7. Interface should look as follows:

Example of a Stationary closure:

8. Collect data for the vehicle under certain circumstances:

## Circumstances in which record needs to be taken on excel:

1. The vehicle is at a stationary closure OR the vehicle is at a moving closure. The information needed to record are as follows:
    a. Module (i.e. Vehicle name: TMAA1, TMAA2, ITMA, etc.)
    b. Date, date of which the vehicle had these closures
    c. State:
        i. stationary closure OR moving closure OR panic button usage
    d. Need to record the starting time, ending time
        i. Adjust the time frame at the bottom of the screen to select the time instance.
        ii. Recommend doing at increments of 10 minutes
    e. The lane in which the vehicle is in
        i. Need to be determined visually
        ii. Count from 1, from left to right.
    f. The speed the vehicle is travelling at:
        i. Speed can be seen at the top right corner of every window
    g. The radar speed
        i. Radar speed can be seen at the top left corner of every window
    h. Day of the week (automated by excel)
    i. Time category
        i. Daytime: 5am-6pm
        ii. Nighttime: before 5 am and after 6pm
    j. Additional comments (if any)
    k. Duration of the closure
        i. Ending time – starting time
        ii. automated by excel
2. The vehicle used the panic button
    a. Need to record starting time, ending time
    b. Lane in vehicle is in
    c. Speed the vehicle is travelling at
    d. Radar Speed at the instance

## Circumstances in which records does NOT need to be taken:

1. The vehicle is at a normal condition

## Example of a Stationary Closure

- Window 4 (bottom right window) has the panel opened up and the vehicle is not moving

## Example of a Moving Closure

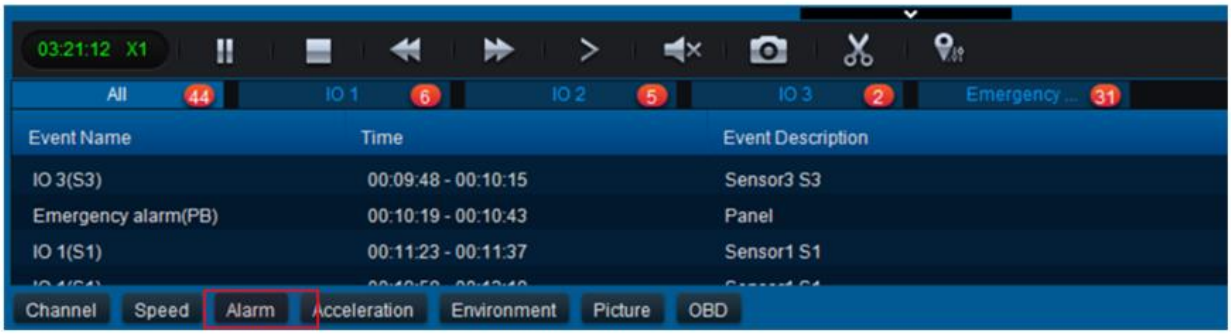

- Window 4 (bottom right window) has the panel opened up and the vehicle is moving.

Example of a Normal Condition

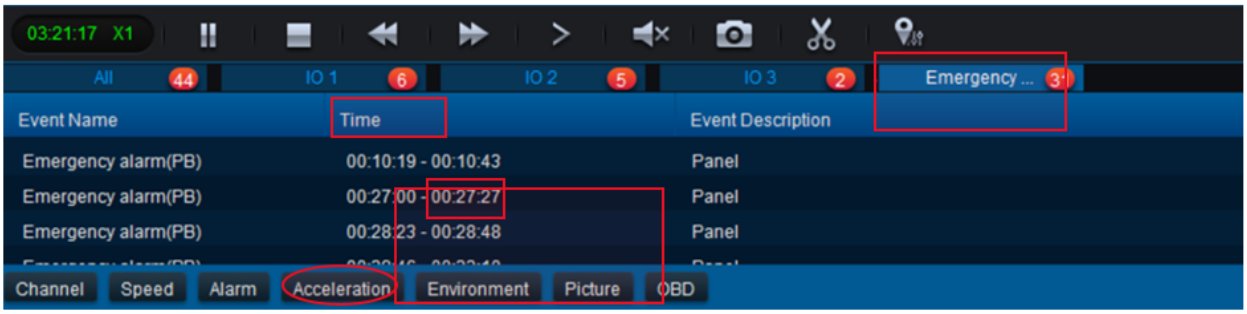
- Window 4 (bottom right window) has the panel closed up, vehicle can be stationary or moving.

Example of a panic button condition:

- When channel 4 has orange lines
- When there are red lines at the lower tab
- Select “Alarm” at the bottom most tab



- Select Emergency tab


-

- Collect start and ending time on Excel.

# Appendix F:
# First Survey Given to Operators After the Training Session

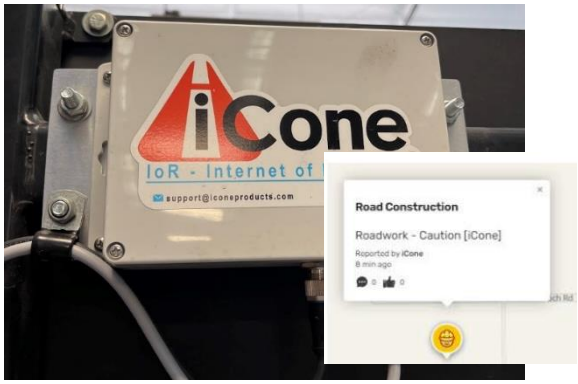
- **Survey for TMAA operators after the initial training (to be administered by Caltrans to operators)**
- Do not include personal identifiable information.

## mDVR


## Radar Signboard


## Panic Lights


## iCone




-

- I feel sufficiently trained to operate the accessory package on my own.

☐ ☐ ☐ ☐ ☐

1 - Strongly disagree | 2 - Disagree | 3 - Neutral | 4 - Agree | 5 - Strongly agree

-

- What systems, if any, are you unsure about? Please explain:
-
- _____
- _____
- _____
- _____

- I had enough time in the vehicle to practice using the system.

☐ ☐ ☐ ☐ ☐

1 - Strongly disagree | 2 - Disagree | 3 - Neutral | 4 - Agree | 5 - Strongly agree

- What parts of the system did you find challenging to use? Please explain:
- _____
- _____
- _____
- _____

- The instructions in the truck were useful.

☐ ☐ ☐ ☐ ☐

1 - Strongly disagree | 2 - Disagree | 3 - Neutral | 4 - Agree | 5 - Strongly agree

- The instructions in the truck were the right length.

☐ ☐ ☐ ☐ ☐

1 - Strongly disagree | 2 - Disagree | 3 - Neutral | 4 - Agree | 5 - Strongly agree

- The checklist in the truck was useful.

☐ ☐ ☐ ☐ ☐

1 - Strongly disagree | 2 - Disagree | 3 - Neutral | 4 - Agree | 5 - Strongly agree

- The checklist in the truck was the right length.

| ☐ | ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|---|
| 1 - Strongly disagree | 2 - Disagree | 3 - Neutral | 4 - Agree | 5 - Strongly agree |

- I understand what must be done to start the system.

| ☐ | ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|---|
| 1 - Strongly disagree | 2 - Disagree | 3 - Neutral | 4 - Agree | 5 - Strongly agree |

- I understand what must be done to operate the system.

| ☐ | ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|---|
| 1 - Strongly disagree | 2 - Disagree | 3 - Neutral | 4 - Agree | 5 - Strongly agree |

- I understand what to do in case of an emergency/panic situation.

| ☐ | ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|---|
| 1 - Strongly disagree | 2 - Disagree | 3 - Neutral | 4 - Agree | 5 - Strongly agree |

- I understand what must be done to shut down the system.

| ☐ | ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|---|
| 1 - Strongly disagree | 2 - Disagree | 3 - Neutral | 4 - Agree | 5 - Strongly agree |

-
- Further comments:
- _____
- _____
- _____
- _____

# Appendix G:
# Second Survey Given to Operators at the End of Field Trials

- **Survey for TMAA operators during system use (to be administered by Caltrans to operators)**
- Do not include personal identifiable information.
- How much time does it take you to get the TMA operational at the side of the road compared to no Tech package?
-
- _____
- How many times have you used the instructions, and do you still use the instructions?
-
-
- _____
- Do you use the checklist?

☐ Yes, often ☐ Yes, sometimes ☐ Not at all

- The new TMA accessories made it much safer to prepare for a moving lane closure.

☐ 1 - Strongly disagree ☐ 2 - Disagree ☐ 3 - Neutral ☐ 4 - Agree ☐ 5 - Strongly agree

- The system has impacted my ability to operate the TMA safely.

☐ ☐ ☐ ☐ ☐

| 1 - Strongly disagree | 2 - Disagree | 3 - Neutral | 4 - Agree | 5 - Strongly agree |
|---|---|---|---|---|

- 
- Why or why not:
- 
- _____
- What parts of the system did you find challenging to use? Please explain:
- 
- 
- _____
- If you feel you operate the TMA safely, how many times did it take to get to that level?
- 
- _____
- The shutdown procedure has the right length and is easy.

| ☐ | ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|---|
| 1 - Strongly disagree | 2 - Disagree | 3 - Neutral | 4 - Agree | 5 - Strongly agree |

- I believe that the panic lights have an impact when I press the panic button.

| ☐ | ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|---|
| 1 - Strongly disagree | 2 - Disagree | 3 - Neutral | 4 - Agree | 5 - Strongly agree |

- 
- How many weeks, months or years of experience do you have in operating a TMA truck?
- 
- _____
- Should Caltrans invest in more TMA accessory packages?
- 
- _____

- Further comments, especially on errors you observed, operating challenges, and things to change:
-
-
- _____