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Highway maintenance operations often require a large truck equipped with a truck-mounted attenuator (TMA) to provide impact protection for workers from errant vehicles. Since the primary purpose of the TMA is to attenuate errant vehicle impacts, the driver of the shadow truck is inherently at risk of injury, especially from high speed impacts by fully loaded semi-trucks, while protecting a highway work zone. The objective of this research was to procure several commercially available TMA truck accessories which are intended to increase the shadow truck operator's safety and conduct a thorough evaluation of the accessories' performance. The systems evaluated included a mobile radar speed signboard, a video monitoring system, an automated work zone reporting system, and a panic button and display.

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Review of Equipment and Accessories for Truck-Mounted Attenuator Trucks

Duane Bennett and
Ty A. Lasky: Principal Investigator

Report Number: CA22-3685
AHMCT Research Report: UCD-ARR-22-04-30-01
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April 11, 2022

California Department of Transportation

Division of Research, Innovation and System Information

Executive Summary

California Department of Transportation (Caltrans) highway maintenance operations are often conducted in work zones that consist of temporary lane closures that are adjacent to high-speed vehicular traffic. To shield these work zones from errant vehicle impacts, Caltrans routinely deploys shadow trucks especially designed to absorb small- to medium-size vehicle impacts and protect both maintenance workers and the motorist from serious injuries. These shadow trucks are much less effective when impacted by large trucks traveling at highway speeds. In either case, reducing the frequency of impact is the key to increasing highway maintenance operational safety.

Problem, Need, Purpose of Research

The immense forces generated by high speed vehicle impacts on the highway can never be completely mitigated by shadow truck mechanical design alone. Implementing technologies that effectively improve the responsiveness of motorists approaching highway temporary work zones, thereby reducing both the frequency and severity of highway work zone vehicular impacts, is a more effective solution.

Caltrans and the highway maintenance safety equipment industry have engineered shadow trucks over many years to attain the highest achievable level of impact protection. Innovative new technologies are now under development by this industry that seek to proactively address the impact issue by enhancing driver responsiveness. Caltrans needs to review these new proactive technologies, particularly those in the form of equipment and accessories that can be added to shadow trucks to potentially reduce impact frequencies in highway work zones. The Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center evaluated specific equipment and accessories available for TMA trucks that can improve the safety and the function of TMA truck operations. These accessories include radar speed feedback signs, camera systems able to record multiple views, communication systems, and panic/warning lights, all of which can improve the safety and function of TMA operations. By identifying and evaluating equipment and accessories that can improve the safety of Caltrans workers and the traveling public, Caltrans can procure these technologies based on tangible, demonstrated benefits, leading to a safer highway environment for all and likely reduced overall costs.

Background

Most shadow truck impacts appear to be the result of motorists not paying attention, driving too fast in the work zone, and/or not merging over out of the approaching closed work zone lane in time. Over the years, Caltrans developed and deployed a host of countermeasures to enhance shadow truck visibility to reduce the likelihood and severity of impacts on the highway. These countermeasures include warning lights, reflective markings, and passive driver information systems such as arrow boards.

Overview of the Work and Methodology

This project researched innovative new shadow truck safety accessory technologies for Caltrans deployment. The research did not progress as originally planned. The commercially available shadow truck safety accessory technologies identified required significant adaptation in order to satisfy the Caltrans performance requirements necessary to be deployable in highway maintenance work zones. Therefore, the Caltrans project advisory panel adapted the project research methodology to be more focused on development of a Caltrans customized Gen 4 Royal Technology Package for functional demonstration and postponed the tasks of highway deployment trials and end user evaluation.

Major Results and Recommendations

This research succeeded in identifying, procuring, customizing, and demonstrating key shadow truck safety equipment technologies that increase highway safety by enhancing motorist responsiveness when encountering temporary highway work zones. The specific technologies deployed included an innovative radar speed feedback display sign capable of displaying the absolute speed of approaching vehicles while the truck and signboard are moving, video camera systems able to continuously record multiple views around the shadow truck, an automated highway work zone reporting system, and a shadow truck driver-activated panic/warning system. These innovative vehicle equipment accessories were combined into a safety Technology Package that can now be commercially purchased for installation on Caltrans TMA shadow trucks to improve safety in highway maintenance work zones.

Gen 4 Specification Recommendation

Royal Gen 4 Specification

The specifications for the Royal Technology Package were insufficient and ultimately rejected by Caltrans Division of Equipment. AHMCT worked with Caltrans to develop a revised safety accessory technologies performance

specification. AHMCT then collaborated with Royal Mfg. to develop an updated Gen 4 Technology Package, which provided the necessary functionality to achieve the Caltrans performance specification. Royal provided an updated Gen 4 specification (Appendix E).

When Royal completed the Gen 4 Technology Package upgrade installation on the ATMA, several outstanding issues remained for AHMCT to resolve. As of the end of this research project, a few outstanding safety accessory issues remain to be resolved, Caltrans customizations finalized, and future Gen 4 Technology Package installation procedures to be defined. Therefore, the final AHMCT research task of developing a Caltrans Gen 4 Technology Package specification will consist of the Royal Gen 4 specification and a list of AHMCT specification recommendations to better satisfy Caltrans performance requirements.

The following list is a series of tasks AHMCT recommends be conducted on the current Gen 4 safety accessory systems:

1) Gain Caltrans IT approval for installing the Kohltech video viewing software on Caltrans Getac K-12 tablet computers.
2) Verify the wireless cellular link connection between the shadow truck-mounted DVR and the Getac computer to transfer video recordings.
3) Investigate if the Caltrans Traffic Management Center (TMC) could use the iCone automated work zone reporting data.

AHMCT Gen 4 Recommendations

The final specification for the Caltrans customized shadow truck safety accessories developed in this research project is a combination of the Royal Gen 4 specification with the addition of the following AHMCT recommendations outlining additional features not completed in this research development and new functionality to enhance Caltrans safety and performance benefits.

AHMCT recommends the following modifications to the Royal Gen 4 system specification:

1) Combine panic buttons to use the Alertor serial button mounted on the dashboard.
2) Obtain 360-degree video coverage. The forward-pointing side cameras should be specified to obtain full surrounding video coverage. This can be easily accomplished by attaching a forward-facing side camera to the one unused camera input currently available and by replacing the hitch camera with the other side camera.
3) Caltrans should plan on installing the Gen 4 Technology Packages on shadow trucks fitted with Scorpion TMA units, because Royal Mfg. has already engineered a working design for shadow trucks with a Scorpion

TMA. The process of designing a different mount to accommodate a different TMA would most certainly incur additional engineering development time and result in higher installation costs.

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List of Acronyms and Abbreviations

Acronym	Definition
AHMCT	Advanced Highway Maintenance and Construction Technology
ATMA	Autonomous Truck-Mounted Attenuator
Caltrans	California Department of Transportation
COTS	Commercial Off–The-Shelf
DOE	Division of Equipment
DOM	Division of Maintenance
DOT	Department of Transportation
DRISI	Division of Research, Innovation and System Information
DVR	Digital Video Recorder
HD	High-definition
IT	Information Technology
LED	Light-Emitting Diode
MoDOT	Missouri Department of Transportation
PM	Project Manager
RFI	Request for Information
MAZEEP	Maintenance Zone Enhanced Enforcement Program
SD	Secure Digital
TMA	Truck-Mounted Attenuator
TMAA	Truck-Mounted Attenuator Accessories
TMC	Traffic Management Center

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Chapter 1: Introduction

Problem

California Department of Transportation (Caltrans) maintenance workers are exposed to risk of vehicle impact, particularly in temporary highway work zones. These work zones also present hazards to the traveling public related to the presence of fixed and mobile equipment and vehicles.

Objectives

Improving the safety of roadway workers has been a key and critical strategic priority for Caltrans. The Department has continued to support research that specifically investigates near-term safety innovations that seek to positively impact the safety of Caltrans workers and the traveling public. The key objective of the current research was to identify new technologies that offer the potential to improve the safety of temporary highway maintenance work zone operations, specifically truck-mounted safety accessory technologies, which could potentially reduce errant vehicle impacts with shadow vehicles in Caltrans temporary highway maintenance work zones.

Scope

The Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center conducted a search of innovative, commercially-available shadow vehicle Truck-Mounted Attenuator Accessory (TMAA) safety technology. Working with the Caltrans project advisory panel (panel), the researchers identified and procured the designated equipment and accessories for installation. These safety technologies were then to be integrated onto legacy shadow truck(s) by the Caltrans Division of Equipment (DOE) and deployed to the Caltrans Division of Maintenance (DOM) for deployment in Caltrans highway maintenance operations. The safety technology upfitted shadow trucks would then be used to evaluate the shadow truck safety products and accessories in actual Caltrans highway operations.

Due to discrepancies in product performance expectations, which were then further exacerbated by the COVID pandemic work slowdown, the product procurement timeline was severely delayed. In response, AHMCT submitted a plan that was approved by the panel to change the scope of the TMAA project enabling AHMCT to complete the research tasks by adapting the Autonomous TMA (ATMA) follower truck with the project-developed safety technologies. AHMCT then conducted safety product development, customization, and

demonstration on the ATMA follower truck platform. The panel evaluated the safety technology upfit performance and established a final shadow truck safety technology upfit package specification. The panel also decided not to expose the ATMA asset to highway traffic, so the original project task of research field deployment of the safety technology upfit package was no longer permitted. The intent by the end of the research project was AHMCT procuring additional technology upfit packages for DOE to later install on legacy shadow trucks in their fleet. Once completed, these upfitted shadow trucks would ostensibly be deployed to Caltrans DOM for field trials and general highway use. As discussed below, this final procurement was deferred per panel indications.

Background

In Caltrans highway maintenance operations, one of the most consistent safety hazards faced by highway maintenance personal are impacts from high-speed errant vehicles in highway maintenance operations. Caltrans routinely deploys shadow trucks with truck-mounted attenuators (TMAs) to help shield temporary highway maintenance operations from errant vehicle impacts. Consequently, the exposure to impact risk is inherently greatest for the shadow truck driver. TMAs attached to the rear of the shadow truck are designed and tested specifically to decelerate lighter vehicles in highway impacts with relative safety, but high-speed heavy vehicle impacts, such as loaded semi-trucks, can easily exceed TMA dynamic force design limits. Therefore, incidents involving heavy vehicles impacting a TMA shadow truck at high speed can easily cause physical injury to the shadow truck driver. Since shadow truck TMAs are mobile, they cannot be physically scaled-up to sufficiently absorb heavy vehicle impacts in temporary highway work zones. The next best mitigation strategy is to reduce the likelihood and frequency of shadow truck impacts by influencing driver behavior. Most shadow truck impacts appear to be the result of motorists not paying attention, driving too fast in the work zone, and/or not merging over out of the approaching closed work zone lane in time.

Figure 1.1: Caltrans TMA truck highway impact

This TMAA research project sought to identify, procure, install, customize, and evaluate innovative shadow truck technologies that could enhance motorist responsiveness, potentially reducing the likelihood and frequency of shadow truck impacts in Caltrans temporary highway work zones. The primary focus of this research study was on developing shadow truck equipment and accessories that could positively impact driver behavior by enhancing safe driving practices when approaching and passing through a temporary highway work zone, thereby leading to a safer highway environment for all and likely overall reduced costs.

Literature and Product Search

The literature search entailed a detailed search for innovative shadow truck impact mitigation strategy reports especially regarding existing Department of Transportation (DOT) highway work zone applications. The literature search specifically focused on intelligent work zone driver advisory technologies and related temporary work zone shadow truck safety equipment. Some of the intelligent technologies examined were driver warning systems, driver attention enhancement, and vehicle sensing systems. The project proposal suggested that the literature search may also include either a brief Request for Information (RFI) or a survey of DOTs for TMA accessory usage/experience. The approved change in project scope eliminated the opportunity and necessity for a post-safety technology deployment Caltrans user survey and the RFI effort.

The product search involved a search of available commercial off-the-shelf (COTS) TMA highway safety accessories and equipment products which exhibited the potential for improving and enhancing motorist responsiveness to TMA shadow truck highway operations, reducing the likelihood of impacts. Shadow truck equipment product categories included conflict warning systems, traffic detection devices, smart arrow boards, and work zone cameras.

Research Methodology

An advisory panel was established early in the project, and regular meetings were held with the Caltrans Project Manager (PM) and/or the panel. The proposed TMAA project methodology consisted of four distinct research phases. The initial phase was a literature and product search of commercially available innovative shadow TMA truck safety technology accessories related to enhancing driver responsiveness. The search was conducted in collaboration with Caltrans DOE and DOM to identify safety accessories of specific interest and technologies which would be compatible with Caltrans applications. The search results were then presented to the panel for selection. The second phase of research sought to create and procure a safety technology package(s) that Caltrans could use to upfit a fleet TMA shadow truck. The third research phase was to procure the shadow truck safety upfit package(s) for DOE installation on a legacy fleet shadow truck and subsequent AHMCT performance testing,

customization, and demonstration to the panel. The fourth research phase focused on Caltrans field trials and user evaluation of the AHMCT-developed technology upfit package.

Procurement problems, which occurred during the course of the research project, ultimately resulted in the panel changing the scope of the project's third and fourth research phases. The third research phase was revised to have AHMCT procure, customize, and test the upfit Technology Package on the existing ATMA follower truck platform. The fourth phase was revised to AHMCT demonstration of the shadow truck safety Technology Package to the project advisory panel to support Caltrans development of a Technology Package purchase specification. Continuing delays in communicating with Royal Mfg. combined change to outsourcing equipment upfitting, which ultimately resulted in the project panel electing to delay the task of AHMCT procuring additional Technology Packages to future projects.

Overview of Research Results and Benefits

This TMAA research succeeded in identifying, procuring, customizing, and evaluating key shadow truck safety equipment technologies that increase highway safety by enhancing motorist responsiveness when encountering temporary highway work zones. The specific technologies deployed included an innovative radar speed feedback display sign capable of displaying the absolute speed of approaching vehicles while the signboard is moving, video camera systems able to continuously record multiple views around the shadow truck, an automated highway work zone reporting system, and a shadow truck-driver activated panic/warning system. These innovative vehicle equipment accessories were combined into a safety Technology Package that can be commercially purchased to upfit a legacy shadow TMA trucks in the Caltrans fleet. AHMCT collaborated with manufacturers to specify, procure, and customize these safety features to be specifically compatible with Caltrans shadow truck highway operations in temporary highway work zones. In an effort to expedite the development and evaluation process, the Royal Technology Package purchased with the ATMA research project was utilized as the test and development platform for this project. The basic safety technology systems on the ATMA were then adapted to meet the functional goals of the current research project. The radar signboard was upgraded by the manufacturer to meet the amended Caltrans specifications for speed accuracy and multiple vehicle and distance sensing and display functions. The truck video monitoring system Digital Video Recorder (DVR) cameras were customized for Caltrans compatibility, and the video allocation options configured to support Caltrans field station transferals. Altogether new Safety Technologies features added to the ATMA test platform with the Gen 4 upgrade include a panic button incorporated into the DVR to enable the shadow truck driver to save video clips by pressing a button on the dashboard, an automated work zone reporting

module which AHMCT integrated into the arrow board, and the panic message system and a panic button message system that enables the shadow truck driver to display a panic message on the radar signboard when a potential impact situation is observed. The panic signboard message consists of flashing strobes to alert the approaching motorist and warning text urging the approaching vehicle to "Move Over".

The upgraded safety technology systems on the ATMA provided a prototype for evaluating the performance and suitability of the Caltrans customized safety technology features before satisfying the research task of procuring the additional units for installation onto Caltrans legacy shadow trucks. Ultimately, Caltrans elected not to expose the expensive ATMA asset to potential highway impacts and postponed the project field trial task until a Royal Technology Package could be installed onto a Caltrans legacy shadow truck to conduct the field trials. The procurement of additional Royal Technology Packages was also delayed to future research projects.

Chapter 2:
TMAA Safety Equipment Accessory Search and Selection

Shadow Truck Safety Equipment Search

The main focus of the TMAA research project was to identify and evaluate innovative technologies that would reduce the instance of impacts with Caltrans shadow trucks in temporary highway work zones. This research searched for COTS accessories and equipment products that enhance driver awareness when approaching temporary highway work zones and actively record video of hazardous instances. After an initial search of existing technologies, AHMCT conferred with the Caltrans panel to determine what type of products would best enhance driver awareness in Caltrans highway work zones. The result was the identification of four key technologies that could be upfit onto Caltrans legacy fleet of shadow trucks. The four technologies included a mobile radar speed sign board, a truck monitoring video recording system, an automated internet work zone reporting system, and an active panic messaging system.

Mobile Radar Speed Signboard

A popular technique of positively influencing motorist work zone awareness is to advise approaching drivers of the lowered work zone speed limit and to notify them of their current traveling speed. This common traffic safety countermeasure involves deploying a stationary roadside radar speed sign which uses a reflected radar signal to determine approaching vehicle speeds. The calculated approaching vehicle speed along with the mandated speed limit are then displayed on a signboard in large Light-Emitting Diode (LED) digits. The approaching driver notices the display because their attention is focused on the road ahead. They do not need to look down at their vehicle's speedometer to judge the appropriateness of their current traveling speed. Employing stationary radar speed signs to calm traffic speeds on roadways has become a common and effective traffic safety tactic.

One of the most efficient ways to deploy a radar speed signboard countermeasure in a highway maintenance work zone is to it attach it to the rear of the shadow truck. Since shadow trucks are often moving either periodically or continually in highway work zone operations, the radar speed sign must be capable of displaying the absolute speed of the approaching target vehicles. Common stationary radar speed signboards calculate just a

differential (relative) speed. When these stationary signboards are mounted on a moving shadow truck, the calculated approaching vehicle speeds are incorrect. To attain the correct absolute speeds, the radar speed sign must determine its own traveling speed and add it to the differential speed of the approaching vehicle to calculate the actual ground speed of the approaching vehicle.

In addition to absolute speed sensing capability, the absolute speed radar signboard must have the following physical requirements to be suitable of Caltrans highway work zone applications. The signboard must be mounted above the TMA and below the standard Caltrans arrow board on the rear of the shadow truck. The radar speed signboard should consist of a large LED lighted display which can display user-selectable customizable programed messages. Most importantly, the signboard must have the functionality to sense the speed of approaching vehicles and display this speed on both the signboard and the in-cab video display of the truck monitoring system. The radar signboard sensing range distance should be near the maximum viewing distance so drivers have sufficient time to respond when traveling at high speed. Finally, when multiple vehicles are approaching within range of the radar signboard sensing zone, the speed of the fastest vehicle should be displayed.

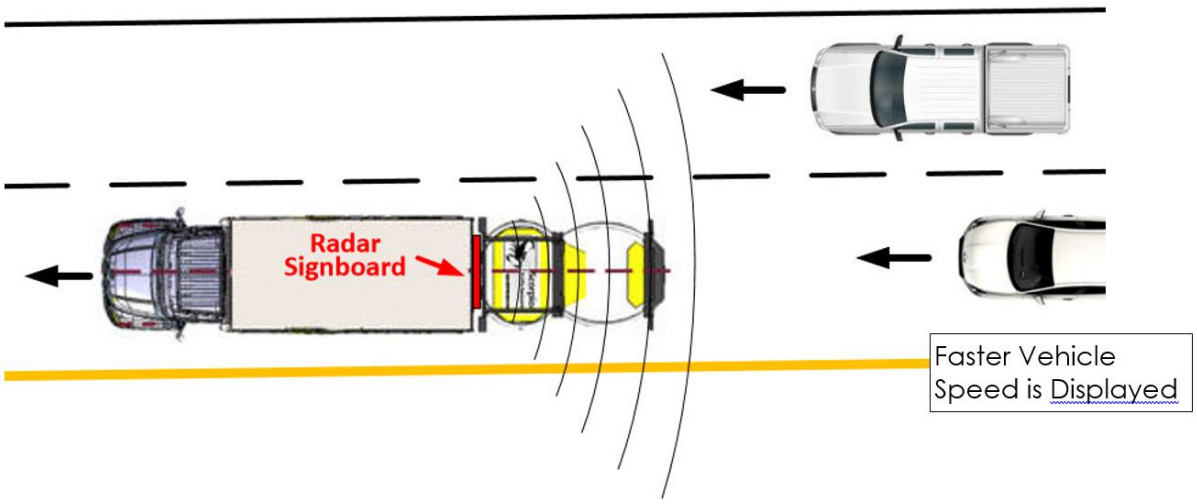


Figure 2.1: Speed sensing for multiple target vehicles

There is a large and diverse commercial market for stationary speed sign products. These stationary speed sign products can indicate a relative speed when mounted on a moving vehicle which equals the approaching vehicle speed minus the speed of the radar speed sign. Only one commercially available product was found that offered a dynamic radar speed sign capable of displaying the absolute speed by determining the radar signboard speed and adding it to the radar speed of the approaching vehicle speed. TraffiCalm was the only manufacturer identified that provides a commercially available radar signboard product that advertises an absolute speed calculation functionality.

The TraffiCalm absolute speed radar signboard is available for purchase with the Royal Technology Package.

Figure 2.2: Radar signboard speed sign message

Video Truck Monitoring System

Incorporating a video truck monitoring system onto shadow trucks provides Caltrans with several safety and legal benefits. The truck video monitoring system has an in-cab display that enables the shadow truck driver to view areas around and on the shadow truck. The most significant of these images is the image of approaching vehicles behind the shadow truck while operating in a work zone. The video truck monitoring system continuously records all the vehicle camera views surrounding the shadow truck and automatically saves video clips should an impact occur as detected using an accelerometer. The saved impact video clips provide a visual record of the incident for litigation and future training purposes.

Figure 2.3: Video truck monitoring in-cab display

The product search revealed a large and diverse commercial market for video truck monitoring systems. There are many sophisticated features offered for these projects such as live monitoring of fleet operations. The Caltrans application is relatively basic, focusing mainly on video recordings of impact incidents. Expert suppliers provide customized video systems to a customer's specifications. Royal utilizes Kohltech to supply the video truck monitoring systems for their Technology Package. Kohltech, an early DVR supplier with many years' experience providing customized truck monitoring systems, is a good choice for future Caltrans video truck monitoring systems.

Automated Work Zone Reporting

Caltrans can also use technology for early warning of a highway work zone so that the drivers are prepared to slow down and merge into unaffected traffic lanes well ahead of encountering the work zone. This information can also result in drivers selecting alternate routes, thereby reducing traffic passing a work zone. A product search identified iCone as the sole vendor that provides a commercially available automated work zone reporting product. Royal utilizes iCone to supply the automated work zone reporting system for their Technology Package.

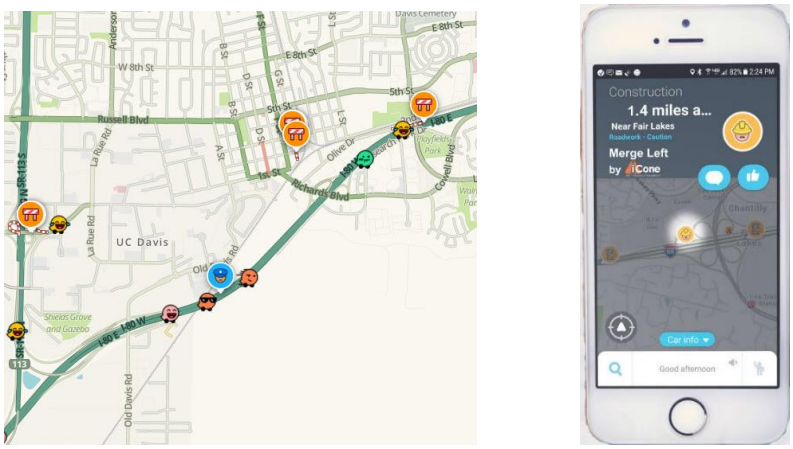


Figure 2.4: iCone automated work zone reporting

Panic Button

Caltrans gained interest in the concept of developing a panic strobe feature based on an LED panic light system developed and deployed by the Missouri Department of Transportation (MoDOT). The MoDOT system mounts six high-intensity white LED spotlights bordering a message sign on the back of a shadow truck (Figure 2.5). A manual panic switch was placed within easy reach of the shadow truck driver for quick activation when an approaching errant vehicle is observed. The flashing strobe light should gain the motorist's attention and potentially avert an impending impact. MoDOT installed several of these panic light systems on their fleet shadow trucks statewide. MoDOT has noticed a decrease of shadow truck impacts since the panic lights have been deployed. Caltrans DOM requested that a panic button feature be developed as one of the safety features in the current research.

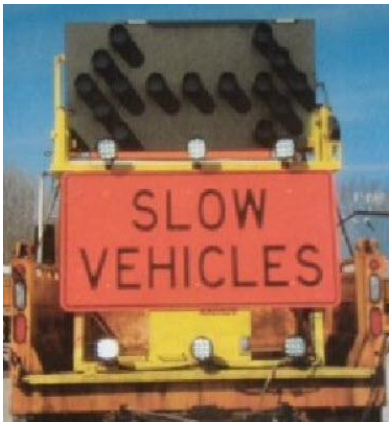


Figure 2.5: MoDOT panic strobe lights

AHMCT investigated the functional safety requirements necessary for a panic button to be safely deployed on California highways. AHMCT, working in collaboration with the project panel, determined that flashing high-intensity LED

strobes at approaching motorists on the highway could present potential legal issues. Instead, the Caltrans panel elected to employ normal-intensity orange LED strobes, which would be a more conservative first step for field trial purposes. AHMCT conducted a product search for commercially available products that provide or could be adapted to provide the desired function and would best integrate with the shadow truck and the other safety components. The search results indicated that a suitable panic button system product is not commercially available, so it had to be developed during the course of this research.

Figure 2.6: Caltrans panic button message/strobe

TMAA Safety Equipment Accessory Selection

AHMCT presented the product search results to the project panel to adopt a plan for procurement, development, and subsequent evaluation of the four innovative shadow truck safety systems. The panel chose to proceed with the purchase of the Royal Technology Package primarily to simplify the procurement and installation of future Technology Packages should Caltrans choose to further implement these features onto legacy shadow trucks. All four safety systems are products available by separate independent companies under contract with Royal. Royal creates their Technology Package by coordinating with each of these subcontractors to combine these separate system into a single package. Royal provides for installation and services for their Technology Package. Procuring the technologies from Royal enables Caltrans to deal with a single manufacturer for future procurements and service instead of having to deal with the multiple subcontractors. Additionally, selecting Royal as the main supplier expedites the process of identifying an outside installation contractor who could install the safety systems on Caltrans fleet shadow trucks should DOE decide to outsource future safety accessory installations.

Chapter 3:
ATMA Royal Technology Package Procurement and Development

ATMA Royal Technology Package Description

An early generation of the Royal Technology Package was included in the Caltrans specification for the procurement of the ATMA system. The Kratos ATMA autonomous driving control system is totally independent of the Royal Technology Package, so inclusion of the Technology Package was unnecessary for the ATMA research. The version of the Royal Technology delivered with the ATMA lacked the basic functionality needed to enable AHMCT to complete system procurement. Since the initial intent was to transfer the ATMA to the Caltrans fleet upon completion of the ATMA research evaluation, Caltrans DOE was obligated to inspect and approve all aspects of the ATMA vehicle purchase. The radar signboard was considered part of the ATMA even though it is not associated with the autonomous system. After a preliminary demonstration, Caltrans DOE rejected the functionality of the radar speed signboard and paused Technology Package payment until the radar signboard could be made to meet Caltrans performance specifications. All of this information is related to the ATMA project but is presented here because ultimately the ATMA Royal Technology Package would go on to serve as the testbed for the development and testing of the TMAA shadow truck safety accessory Technology Package. Full details of the ATMA project and the related procurement are available in the ATMA final report [1].

ATMA Royal Technology Package Procurement

The primitive version of Royal Technology Package included in the ATMA procurement included two of the four TMAA designated safety systems installed. One of these was the absolute speed radar signboard mounted on the rear of the ATMA truck and the other was a truck video monitoring system. Once the ATMA was received by AHMCT, Caltrans DOE conducted a thorough quality and performance inspection. The truck video monitoring system passed inspection, but DOE summarily rejected the radar signboard. The iCone automated work zone reporting system was included in the ATMA purchase specification, but Royal Mfg., for unknown reason, did not install the system on the ATMA.

ATMA Radar Speed Signboard Deficiency

The specification for the purchase of the absolute speed radar signboard procured with the ATMA had a single functional description that it display the absolute speed of vehicles passing through the highway work zone. The purchase specification did not specify important performance criteria such as target sensing distance, speed resolution, and/or at what distance the signboard displays the approaching vehicle speed. The purchase specifications Caltrans DOE had to base their inspection on for the ATMA absolute speed radar signboard was clearly ambiguous, but Caltrans DOE conducted a rudimentary performance test of the Royal radar signboard and determined the performance did not meet their expectations and withheld purchase acceptance. The fundamental flaw was that even though the absolute speed seemed to be correctly registering the absolute speeds, the speed was being displayed only as the approaching vehicle was passing the shadow truck, which would be too late to influence the approaching driver's behavior. The absolute speed radar signboard needed to be modified by Royal to function according to Caltrans expectations, which had not officially been defined at the time of initial procurement.

Caltrans Amended Radar Signboard Performance Specification

Caltrans DOE developed an official absolute speed radar signboard performance specification so that Royal could have a well-defined signboard specification target in which to adapt their product to attain Caltrans acceptance. Caltrans DOE determined that an existing performance specification did not exist for a moving radar signboard. Therefore, DOE created a new specification based primarily on a Caltrans stationary radar speed sign specifications (*Caltrans 12-3.32 PORTABLE CHANGEABLE MESSAGE SIGNS*), which requires an approximate 1 mph speed accuracy resolution and a 750 ft minimum sensing distance. The distance the registered speed needs to be displayed at was deduced to be 750 ft to provide maximum reaction time for an approaching driver to moderate their speed if necessary. The Caltrans specification also included a well-defined multiple car sensing requirement. The radar signboard was to display the speed of the fastest approaching vehicle, but if multiple approaching vehicles were detected, the speed of the fastest vehicle is displayed. If the faster vehicle is significantly further way, the closer vehicle speed will be displayed until the faster vehicle nears the middle of the sensing range. The radar speed sign must also be capable of registering approaching vehicle speeds while both stationary and traveling up to 10 mph.

ATMA Radar Signboard Upgrade

The amended Caltrans absolute speed radar signboard performance specification was provided to Royal to determine if the existing ATMA radar signboard could be adapted to meet the amended Caltrans requirements. Royal worked with TraffiCalm to upgrade the radar signboard to satisfy the Caltrans performance specification. The necessary system upgrades required that both the signboard and radar antenna would have to be replaced on the ATMA. Royal and TraffiCalm dispatched engineering teams that essentially replaced the entirety of the radar speed sign system and working with AHMCT, successfully conducted initialization testing.

Upgraded ATMA Radar Signboard Testing and DOE Acceptance

The upgraded absolute speed radar signboard system mounted on the ATMA was demonstrated at the Crows Landing test facility where the system could be tested at highway speeds using multiple vehicle targets. Caltrans DOE participated in the high-speed testing video and documented the many test trials and performance results. The DOE tests ultimately verified that the upgraded radar signboard performed according to the amended Caltrans absolute speed radar signboard performance specifications for single and multiple vehicle targets. Caltrans DOE granted acceptance for the Royal/TraffiCalm radar signboard and approved AHMCT to complete the ATMA Royal Technology Package procurement.

Figure 3.1: DOE radar signboard acceptance test

Chapter 4:
TMAA Safety Equipment Accessories Development

TMAA Safety Equipment Accessories Objective

AHMCT collaborated with the project panel to determine the essential features for shadow truck safety accessories which would both synchronize with Caltrans highway maintenance operations and provide a significant positive impact on worker and motorist safety. A primary constraint was that these accessories needed to be attached to Caltrans shadow trucks with a reasonable investment of cost and time. Ideally, the assortment of safety features identified would be available in a single package available from a commercial source that could provide for both installation and service. The safety accessories package would be of highway-grade quality and be consistent with Caltrans equipment standards. All equipment development was to be completed during the research stage and the refined commercial product would be readily available for Caltrans direct procurement.

TMAA Safety Equipment Accessories Development Methodology

The four safety accessories under development in the TMAA project required customized features and a greater level of interconnection not readily available in the standard commercial market. The desired functionality had to be developed specifically to meet the project panel requirements. AHMCT worked with Royal Mfg. first and then, as the complexity of the system customization increased, worked directly with the subcontractors supplying the technologies to attain the needed component performance.

The original TMAA project development methodology proposed that AHMCT purchase the designated safety accessories for Caltrans DOE to install on legacy fleet shadow trucks. Consequently, Caltrans DOM would then deploy the upfitted shadow trucks on the highway to conduct operator trials. AHMCT would solicit operator comments and conduct a formal operator field trial survey.

Unfortunately, due to delays related to the ATMA radar speed signboard rejection and subsequent modification combined with Coronavirus (COVID)-related delays, the planned TMAA research methodology became unfeasible. Consequently, AHMCT submitted a request to the project panel to change the project development methodology and pursue safety feature accessory

development on the existing ATMA platform. This new methodology would involve upgrading the Royal Technology Package on the ATMA to incorporate all of the safety accessory features designated in the TMAA project and install them on the ATMA. AHMCT would work with Royal Mfg. to specify the TMAA safety accessory functionality, which Royal Mfg. combined into a Caltrans customized version of their Technology Package that they referred to as the Royal Gen 4 Technology Package.

Royal Gen 4 Technology Package

AHMCT worked with Royal to create a customized Caltrans TMAA functionality specification for the Gen 4 upgrade for the ATMA safety accessory Technology Package. The Gen 4 accessory package was to be installed and developed on the ATMA platform. Once the Gen 4 components were functioning as required, the Gen 4 package would be evaluated by AHMCT and demonstrated to the Caltrans panel. Caltrans ultimately decided against exposing the expensive ATMA asset to potential traffic impacts in highway demonstrations during actual maintenance operations. Therefore, the project scope was reduced to evaluating the Gen 4 safety accessory package performance on closed test tracks. The field trial and Caltrans maintenance evaluation will be conducted in future projects when the Gen 4 Technology Packages are installed on fleet shadow trucks specifically intended for highway duty.

Gen 4 Absolute Speed Signboard Accessory

The Gen 4 absolute speed radar signboard was upgraded to meet the amended Caltrans operational specification and Caltrans DOE accepted the functionality for distance sensing, absolute speed resolution, and multiple vehicle sensing. The complete details of the Gen 4 performance testing is described in detail in the ATMA final report [1]. The remaining functionality that needed to be incorporated into the radar signboard was related to interconnection and support for extended safety features related to the video truck monitoring and panic button systems. These changes are discussed in detail in the following sections.

Gen 4 Video Truck Monitoring Accessory

The Caltrans customized Gen 4 video truck monitoring system provides three primary safety benefits. First it provides the shadow truck driver with live video of critical views around and on the truck while operating in the work zone. Second, the DVR continually records each camera view, so impact incidents can be obtained from the DVR for litigation and for future driver safety training resources. The third safety benefit is that it provides the shadow truck driver with the speed of approaching traffic, enabling the driver to determine when to

deploy traffic slowing countermeasures. The primary countermeasure is contacting the Maintenance Zone Enhanced Enforcement Program (MAZEEP) support for inclusion in the highway work zone and having the California Highway Patrol (CHP) run traffic breaks to slow approaching vehicle traffic.

Driver Live Video Monitoring

In the Gen 4 upgrade, to incorporate the displaying and recording of approaching vehicle(s)'s absolute speed on the video feed, the ATMA DVR needed to be replaced. The DVR included with the ATMA Royal Technology Package did not have the capabilities necessary to support the incorporation of the radar speed input. The truck video monitoring system manufacturer Kohltech determined the DVR replacement necessary to support the Gen 4 functionality was actually an older DVR version (Appendix A). This older version possessed the necessary input capabilities but unfortunately, also supports fewer camera inputs and lower camera resolution capabilities. Consequently, Royal dispatched an engineering team to replace the Kohltech DVR, but AHMCT had to relocate the cameras on the ATMA according to the project panel guidance. The current Gen 4 camera placements on the ATMA follower truck are:

1. Rear view while the TMA is up
2. Right side of truck pointing toward the rear
3. Rear view while the TMA is down (high-definition [HD] resolution)
4. Front view through windshield (HD resolution)
5. Left side of truck pointing toward the rear
6. Not currently used
7. View of truck bed surface
8. View of trailer hitch

The Royal Gen 4 video truck monitoring system includes an in-cab Kohltech MON-MDVR-7TS 7-inch high-resolution touchscreen display with push button functions mounted on the dashboard within easy sight and reach of the shadow truck driver (Appendix B). The driver can display any of the eight live camera video feeds on screen by pressing the associated numbered function buttons on the display. The driver can also select to view multiple camera views on a segmented display, but in doing so each of the camera images becomes smaller.

Figure 4.1: In-cab video monitor views

Gen 4 Video Viewing and Transfer

The truck video monitoring system continually records each of the camera views on the DVR internal hard drive, which creates a video record of the entire time the shadow truck ignition is on and a few minutes after it is turned-off. The DVR hard drive has enough space to save many days of video in memory. Eventually as the memory fills, the video storage is looped to write over the oldest videos. Special event videos are the exception in that these are permanently saved. Special event videos are automatically created by the DVR in a shadow truck upon impact. This process is triggered by on-board accelerometers and manually with the panic button described in detail in the following sections. The videos are saved on the DVR hard drive in a propriety video format so the chain of custody requirements for litigation purposes are maintained. The in-cab display provides access to all recorded videos but is password-protected. By entering the password, all system settings and video recordings are available. To watch a specific video on the in-cab display, the date and time frame of the video recording to view is entered and a video timeline is displayed. The video can be viewed on the in-cab display and a selected video clip can be exported in an open video format to a flash drive inserted in the DVR. Exporting videos in this way does not alter the video record on the DVR hard drive.

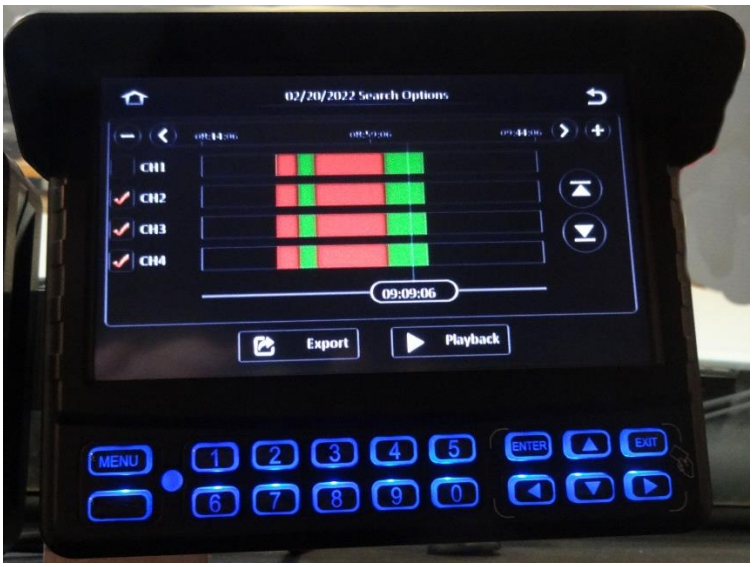


Figure 4.2: In-cab touchscreen display video timeline

Navigating and viewing recorded videos on the relatively small in-cab screen is cumbersome. Consequently, Kohltech provides interface software that enables videos to be viewed on a Windows PC. Kohltech provides several methods for linking this viewing software to the DVR video record on the shadow truck. The most basic is Secure Digital (SD) card memory. The Kohltech R8 model DVR has an SD memory card installed which acts like the hard drive but with a much smaller memory capacity. Only a few days of recorded video can be saved before being over-written. This SD card can be physically removed from the DVR and inserted into a PC computer. The SD card memory then appears in the directory of the Kohltech viewing software where videos can be selected for viewing. Selected video clips can then be saved in either propriety or open-source video formats. Changes on the SD card do not alter the DVR hard drive record. Should the SD card not be replaced, the DVR will continue to record videos on the DVR hard drive.

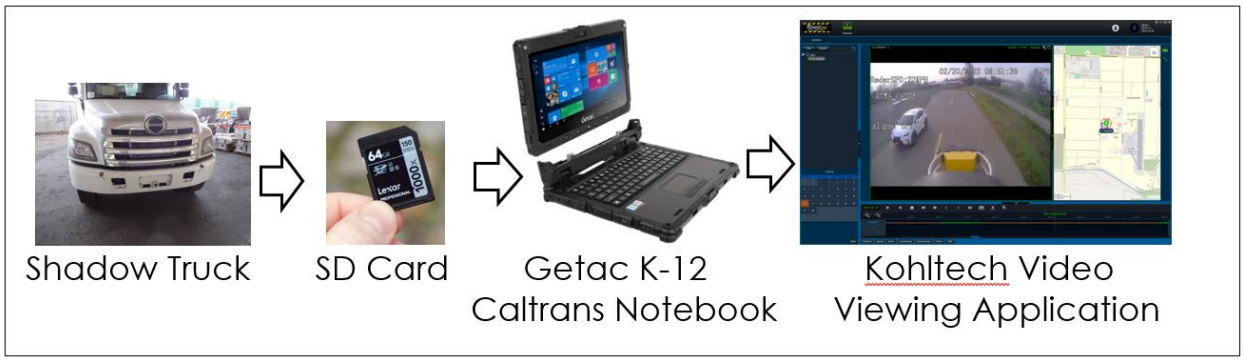


Figure 4.3: SD card recorded video transfer method

A second method of accessing the DVR hard drive video memory is with a wireless cellular link. The Gen 4 DVR has a wireless cellular card installed that enables a PC tablet computer with a cellular card installed to link wirelessly to the DVR hard drive in the shadow truck. Caltrans assigns Getac K-120 tablet computers to several Maintenance field supervisors. These tablets have the necessary cellular hardware to make the wireless link, and AHMCT is seeking approval from Caltrans Information Technology (IT) to install the Kohltech video software program on these computers. The Caltrans project panel expressed a preference for the cellular transfer method should the software installation approval be granted. Once the cellular link is established, the recorded video on the DVR hard drive appears in the directory of the Kohltech viewing software where it can be selected for viewing and selected video clips can be saved in either propriety or open-source video formats.

Figure 4.4: Wireless cellular recorded video transfer method

A third method of accessing the DVR hard drive video memory is to physically remove the hard drive from the DVR and use a special cable adapter to directly connect it to a PC. The hard drive can be accessed using the Kohltech viewing software. This direct connection allows the hard drive memory to be edited or erased.

The Kohltech DVR has many system settings and video recording options that can be used to optimize the Caltrans video recording application. Continued DVR setting customization will most certainly occur in the near future as the Gen 4 safety Technology Packages are installed on Caltrans shadow trucks and deployed on the highway in support of Caltrans maintenance operations.

Gen 4 ATMA In-Cab Approaching Vehicle Speed Display

One of the important duties of the shadow truck driver in a Caltrans highway maintenance operation is to monitor the traffic safety conditions in the work zone and using the radio, manage both the Caltrans traffic closure taper vehicles and the MAZEEP traffic control resource(s). The innovative Gen 4 function of displaying the absolute speed of the approaching vehicle(s) on the in-cab video display provides the shadow truck driver with the exact speed of approaching traffic from a long distance away. Without this feature, shadow

truck drivers have a difficult time judging passing vehicle speeds and no sense of approaching traffic speeds because a rearview mirror view is all that is available. Providing the shadow truck driver with the exact approaching vehicle speeds keeps them better advised of ever changing traffic conditions and the exposure risk of the work vehicles in the highway work zone.

Figure 4.5: In-cab display of approaching vehicle speed

While operating in a highway work zone, the shadow truck driver has the ability to select a single camera view, or multiple views if they prefer, to display on the in-cab screen using the function buttons. The Gen 4 radar speed sign displays and records the absolute speed of approaching vehicles and the speed of the shadow truck on all camera images.

Gen 4 Panic Button Accessory

One of the key shadow truck safety accessories identified by the Caltrans project advisory panel to be developed in this research project was the panic button. The panic button is an innovative concept where a manual panic switch is placed within easy reach of the shadow truck driver so that the driver can activate a panic message to be displayed on the radar signboard. The flashing strobe lights and warning message seek to gain the motorist's attention and potentially avert, or at least minimize, an impending impact. This function was not a feature of the initial Royal Technology Package, so AHMCT had to collaborate with Royal and their subcontractors TraffiCalm and Kohltech to specify the function of the panic button for inclusion with the Royal Gen 4 Technology Package upgrade on the ATMA.

Working with the project advisory panel, AHMCT was able to establish a panic button performance specification that both achieved Caltrans DM needs and was suitable for upgrading the existing Royal Technology hardware. The adopted panic button performance specification calls for the strobes to be four

inch square segments of amber LED lights in each of the four corners of the radar signboard display panel mounted on the rear of shadow truck. These amber LED light patches will flash and a user-selectable text message will appear on the radar signboard when the panic button in the cab is pressed by the shadow truck driver. The panic message/strobe message on the signboard is maintained until the driver releases the panic button and the radar signboard returns back to the speed sign message. Pressing the panic button also triggers the truck monitoring video system to save a video clip of the event. The saved video clip has a user-defined pre-event time interval and a user-defined clip length.

The panic button safety accessory feature was an altogether new feature developed at the request of the Caltrans, so Royal needed to work with their subcontractors to engineer this additional feature into their Gen 4 Technology Package. Since the panic button specification requires different functionality from two different systems, Royal Mfg. worked with each subcontractor separately to achieve the necessary performance. The two subcontractors were Kohltech, which provided the video truck monitoring system panic button video clip saving feature, and TraffiCalm, which provided the signboard panic message display feature. Since Royal tasked each of these subcontractors to adapt their respective systems independently to accomplish the specific function, the result was a unique panic button to activate the panic function for each of these systems.

Kohltech Alertor Panic Button Description

The Gen 4 Kohltech DVR has a physical panic button switch input mounted on the truck dashboard called an Alertor. It is a serial-activated device, but has the look of a classic red button emergency switch. The shadow truck driver simply presses the Alertor red button mounted on the dashboard to save a video clip. The camera views are recorded with the video beginning an interval before the button was pressed, and the overall recording length of the saved clip are all user-customizable settings. When the shadow truck is impacted in the work zone, the video clip is automatically saved as an event. The Kohltech panic button is most useful when the shadow truck driver witnesses a near miss, a traffic accident in the work zone involving other vehicles, illegal driving activities of approaching vehicles, etc. and wants to save a video clip of the event.

Figure 4.6: Alertor panic button

The truck video monitoring system records all the camera views while the shadow truck ignition is on. This makes finding an event at a later date very difficult to identify, especially if the exact recording times of the events were not noted. The key advantage of the driver pressing the Kohltech panic button is that the video clip is then saved as an event. The Kohltech video viewing software setting feature filters out only triggered video events to be displayed and their associated camera views on the video timeline. This feature greatly simplifies finding, viewing, and transferring specific recorded events. The video event feature is a benefit either when using the in-cab display or the Kohltech computer viewer software to find event triggered videos. Recorded events are color-coded by type on the calendar view, indicating which days recordings were created. When clicking on event days, color-coded, recorded events are displayed on the daily timeline in the day view window. The panic button saving of event videos is a convenient way of marking specific recorded events in the immense DVR video memory.

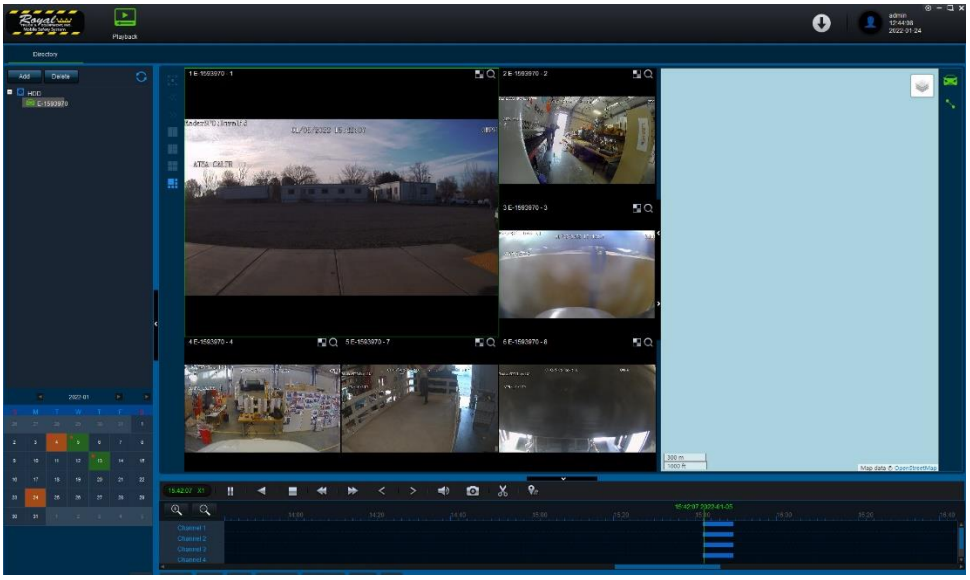


Figure 4.7: Kohltech video recording viewer application

TraffiCalm Panic Button Description

The Gen 4 TraffiCalm panic button feature simply toggles between two messages being displayed on the speed signboard mounted on the rear of the shadow truck. Accomplishing this simple functionality involved quite a significant engineering development effort and the addition of technical hardware. The primary TraffiCalm device addition to the Gen 4 package was the inclusion of the TC Commander. The TC Commander is a rudimentary touchscreen computer device mounted on the truck dashboard that wirelessly connects to the radar signboard. The TC Commander allows a user to customize the messages that are displayed on the signboard. To create the panic function, TraffiCalm programed a large graphical "Start Panic Message" button on the TC Commander touchscreen. This button, when pressed, toggles the signboard message between the normal work zone absolute speed sign message and the panic message. Graphical dropdown boxes enable the text for both messages to be customized by the user from inside the truck cab. For the normal work zone absolute speed sign message, a work zone speed limit can be selected and a preprogramed line of text below the speed text values can be changed to read "Move Left", "Move Right", or "Lane Closed". To assist the user with programing text messages, a window on the TC Commander shows a graphical display of the current message configuration to be displayed on the signboard. Physical buttons on the signboard itself can also be used to configure the signboard message text by cycling through the various available text message options.

Figure 4.8: TC Commander – In normal speed sign mode

Figure 4.9: Radar signboard – In normal speed sign mode

During work zone operation, the shadow truck driver can press the panic button on the TC Commander mounted on the truck dashboard to toggle from the normal work zone operation speed sign message to the panic message on the radar signboard. The panic message consists of a user-selectable text display accompanied by flashing amber LED strobe patches that appear at each of the four corners of the signboard. The text displayed on the panic message is "Move Over", which was the text suggested by the project panel, but this text can be customized should the need arise. The panic message remains until the user toggles the signboard message back to the normal speed sign message once the hazard has cleared.

Figure 4.10: TC Commander – In panic mode

Figure 4.11: Panic message

Panic Button Combination

Caltrans requested that the possibility of consolidating the current two separate panic buttons into a single panic button be explored. AHMCT is working directly with TraffiCalm and KohlTech to determine if engineering a consolidated panic button is possible.

Gen 4 Automated Work Zone Reporting Accessory

Caltrans could also use technology to provide early warning of a highway work zone to have drivers prepared to slow down and merge into unaffected traffic lanes well ahead of encountering the work zone. This information could also result in drivers selecting alternate routes, thereby reducing the amount of traffic passing a work zone. A product search identified only a single vendor which provides a commercially available product. The iCone module has been utilized for many years and has a proven functional and deployment record.

The iCone automated work zone reporting module connects to the shadow truck arrow board. The operating manual for the ATMA arrow board is included in Appendix C. The iCone module connects to specific arrow board indicator lights on the arrow board display to indicate when a left arrow, right arrow, or single closed lane chevron is being displayed (Appendix D). The iCone module utilizes a cellular link to upload the arrow signboard information to the Waze application, which then displays an iCone on the Waze navigation app advising drivers of the work zone and to change their route or steer into the open lanes.

Chapter 5:
TMAA Gen 4 Technology Package Testing

The course of the TMAA shadow truck safety accessories research and development did not follow the proposed project research plan. Unexpected events in the separate ATMA research project ultimately resulted in major alterations in the scope of the TMAA project. A key safety accessory component was rejected by Caltrans DOE for performance deficiencies in the ATMA project. Consequently, progress in the TMAA project was effectively blocked while AHMCT worked with Royal to resolve the component deficiency on the ATMA. This situation inexorably linked the ATMA project to the TMAA project and altered the progression of TMAA project development, prompting modification of project tasks, timeline, and final deliverables.

TMAA Gen 4 Technology Package Test Plan

In an effort to deliver as much safety accessory technology development for Caltrans as possible during the ATMA signboard delay, AHMCT proposed a change in TMAA project scope. The project panel approved the plan of AHMCT developing and evaluating the Royal Technology Package performance on the ATMA system and conducting performance evaluations on closed test tracks for each of the four specific safety accessory components. The evaluation could be used to finalize a Caltrans customized shadow truck safety accessory Technology Package specification for future procurement and deployment. AHMCT adapted the initial TMAA test plan for testing each of the procured items separately, because each of these components became operational on the ATMA at different points in the project.

Gen 4 Radar Signboard Test Plan

The bulk of the radar signboard testing was conducted during the process of achieving DOE acceptance in completing the purchase of the Royal Technology Package part of the ATMA procurement. Caltrans DOE devised a series of radar signboard tests that could logically be divided into three classifications: moving signboard with single approaching target vehicle, moving radar signboard with multiple approaching target vehicles, and stationary radar signboard with a single approaching target vehicle. Since the intended use of the radar signboard is sensing vehicles potentially traveling at high speeds, AHMCT wanted to run radar signboard at high speeds up to

70 mph. The signboard test was conducted at an abandoned NASA airfield containing multiple long expanses of wide, paved runways.

Moving Radar Signboard with a Single Target Vehicle Testing

The first Caltrans DOE test scenario had the shadow truck traveling in a straight line at 10 mph. The single target vehicle started accelerating up to 70 mph once the shadow truck was 1,500 ft or more away. The observers in the target vehicle recorded the distance where the radar signboard began displaying a speed and compared the displayed absolute target speed to the speedometer speed of the target vehicle.

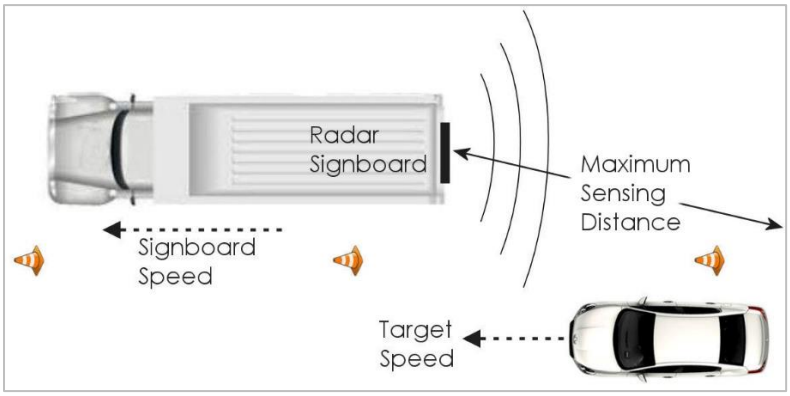


Figure 5.1: Single vehicle absolute speed sensing test

After running four trials at highway speeds, DOE accepted that the Gen 4 signboard performance was within the required 1 mph speed sensing resolution. The sensing distance was also well over the 750 ft in the Caltrans performance specification. The radar signboard began reading the target vehicle speed at approximately 900 ft, which is right near the visual sight limit of the approaching driver.

Moving Radar Signboard with a Multiple Target Vehicles Testing

The second DOE test scenario had the shadow truck traveling in a straight line at 10 mph. Two target vehicles were stationary until the shadow truck was 1,500 ft or more away then the first target vehicle started accelerating up to a constant 35 mph. Once the radar signboard began to display the 35 mph absolute speed of the first target vehicle, the second target vehicle accelerated up to a constant 70 mph. The observer in the second vehicle observed when the displayed speed on the radar signboard changed from 35 mph to 70 mph. This test was designed to verify the sensing logic performance of the radar signboard that Caltrans specified to display the fastest approaching vehicle when multiple approaching vehicles are within the radar speed signboard sensing range.

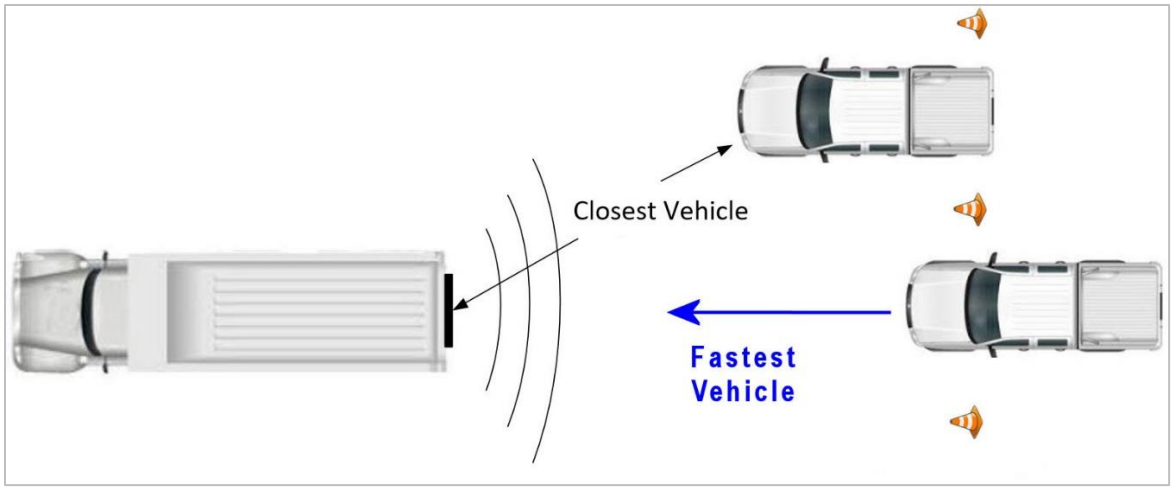


Figure 5.2: Multiple vehicle absolute speed sensing test

After running multiple trials at these speeds, Caltrans DOE accepted that the Gen 4 signboard performance was within the required 1 mph speed sensing resolution with a sensing distance well over the Caltrans mandated 750 ft minimum sensing distance requirement. The radar signboard actually began reading the target vehicle speed at approximately 900 ft, which is right near the visual sight limit of the approaching driver. DOE deemed the multiple vehicle radar signboard test to be a success.

Stationary Radar Signboard with a Single Target Vehicle Testing

Caltrans DOE also tested the Gen 4 radar signboard while the shadow truck was stationary. The results in testing were not satisfactory with the approaching speed sometimes not being displayed. AHMCT worked with TraffiCalm to mitigate the problem. After much development and system testing, acceptable stationary radar signboard performance was consistently achieved. AHMCT subsequently conducted a demonstration for Caltrans DOE to verify just the stationary radar signboard aspect of performance. AHMCT collaborated with DOE to drive a target vehicle past a stationary radar signboard on the AHMCT test track. The radar signboard displayed the target vehicle speed each time in several trial runs. Upon the successful completion of this stationary test, Caltrans DOE formally granted full acceptance of the Gen 4 radar signboard, which allowed AHMCT to finalize the purchase of the Royal Technology Package as part of the ATMA procurement contract.

Gen 4 Truck Monitoring Video System Testing

AHMCT tested multiple operational and performance features of the Gen 4 Kohltech truck monitoring video system. The basic system functions of displaying camera views around the shadow truck and onboard was visually examined and adjusted to maximize the available field of view. The original DVR on the ATMA had twelve cameras that provided a 360-degree view around the

shadow truck and several onboard views as well. The upgrade to the Gen 4 Technology Package required an older version Kohltech DVR to be installed to support speed inputs. The replaced DVR supports only eight cameras. AHMCT reconfigured the cameras on the ATMA and was able to achieve a nearly 300-degree view around the shadow truck with the blank sections being the areas out from the truck front quarter panels. Camera views of the truck bed and trailer hitch were maintained. The camera views are readily visible and configurable to the shadow truck driver while the ignition is on. The camera views are visible in both light and dark lighting conditions on the in-cab display, but headlights of approaching vehicles at night tend to oversaturate the image and reduce image resolution. The Kohltech R-8 DVR records all the configured camera views to both an SD memory card and a large hard drive continually when the truck ignition is on. AHMCT specifically tested the safety features related directly to Caltrans shadow truck operations application and the truck monitoring features that would provide the near-tern safety benefits to Caltrans highway maintenance operations. These features are the display of approaching speeds to the shadow truck driver and the ability to transfer wanted video clips of interest off the DVR for remote viewing.

Display Vehicle Speeds in Video

The new feature added to the Gen 4 truck video monitoring accessory was to display the speed sensed by the radar speed sign on the in-cab display. AHMCT conducted trials where the shadow truck was moving and a target vehicle approached and overtook the shadow truck at a higher speed. The trials were observed and recorded by the shadow truck driver on the in-cab display. The speeds displayed were compared to the actual speeds and as expected based on the radar signboard testing, were accurate to 1 mph resolution. The primary goal of this testing was to ensure the speeds sensed by the radar signboard were being displayed correctly on the in-cab display and recorded on the DVR. After the trials were complete, the video record was examined to confirm that the recorded speeds did indeed show up on the video recording of the trials on the DVR recordings.

Figure 5.3: In-cab display speed viewing and recording

Video Viewing and Transfer Testing - In-Cab Display Method

All functions of the truck video monitoring system can be controlled with the in-cab touchscreen display and function buttons. Only some basic operator view setting are freely accessible on the in-cab display. Access to the DVR video recordings and most of the recording settings are password protected. The most direct method of viewing and transferring recorded video is through the in-cab display access. Once the password is entered, a series of functional categories are made available for selection (Figure 5.4). These include recording settings, communication settings, and the video recording timeline. By selecting the REC Search menu item, a calendar appears, indicating on which days videos were recorded (Figure 5.5). Selecting one of the dates changes the screen to show a timeline of the full day and the times when videos were recorded.

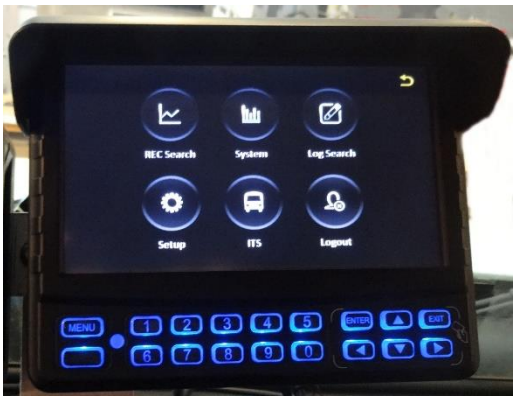


Figure 5.4: In-cab display menu

Figure 5.5: Video recording calendar

The daily video timeline screen provides tools to watch videos of the different camera views and export recorded videos to a flash drive on the DVR (Figure 5.6). The videos can be exported as a file in either a proprietary or open video format. An on-screen linear cursor selects the time of day to start viewing the video recording (Figure 5.7). The different colored bars indicate the video type recorded: locked, alarm, or normal. To export a recording, the linear cursor enables the user to select the start time and end time of the exported video clip on the video timeline. Exporting recorded videos does not alter the DVR recording memory.

Figure 5.6: Video recording timeline

Figure 5.7: Video recording playback

AHMCT was able to successfully access all of the videos recorded on the Gen 4 truck monitoring system during operational testing using the in-cab touchscreen display. Specific videos were searched for viewing and several videos were exported onto a flash drive in an open video format and viewed on a separate computer. Conducting video searches for playback and exporting on the in-cab touchscreen display is somewhat physically awkward, but full functionality was confirmed.

Videos Viewing and Transfer Testing – SD Memory Card Method

The SD card slot is located on the front of the Gen 4 DVR, which is mounted below the passenger seat in the truck cab (Figure 5.8). A locking door covers the SD card slot. To open the door, a key must be inserted and turned a quarter turn. Then the hard drive needs to be at least partially removed to clear a tab on the door and allow it to fully open. All SD cards are released by pushing in and releasing. The SD card will spring partially out and can then be pulled free. The SD card is then inserted either directly or with an SD card reader accessory into the computer.

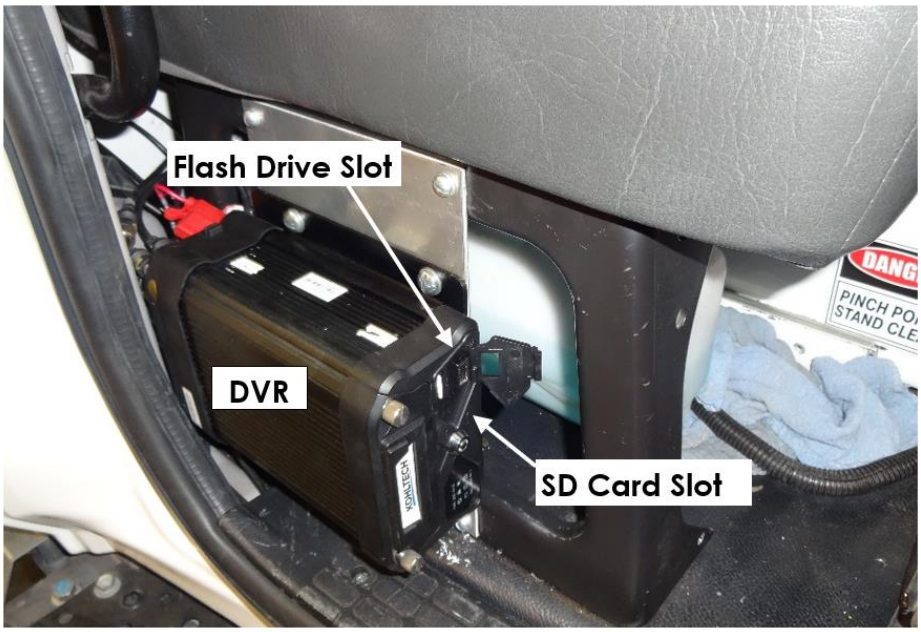


Figure 5.8: Reviewing video recordings from SD card

Once the SD is inserted into a PC computer running the Kohltech video viewing software application, the SD memory appears in the Directory window. Clicking on the SD card icon will cause the video memory to be displayed in both a calendar and a daily timeline format. The viewing application has many functions, settings, and tools to both view videos and transfer video clips of user-selected camera views and time segments for transfer into external files saved in either proprietary or open source video formats.

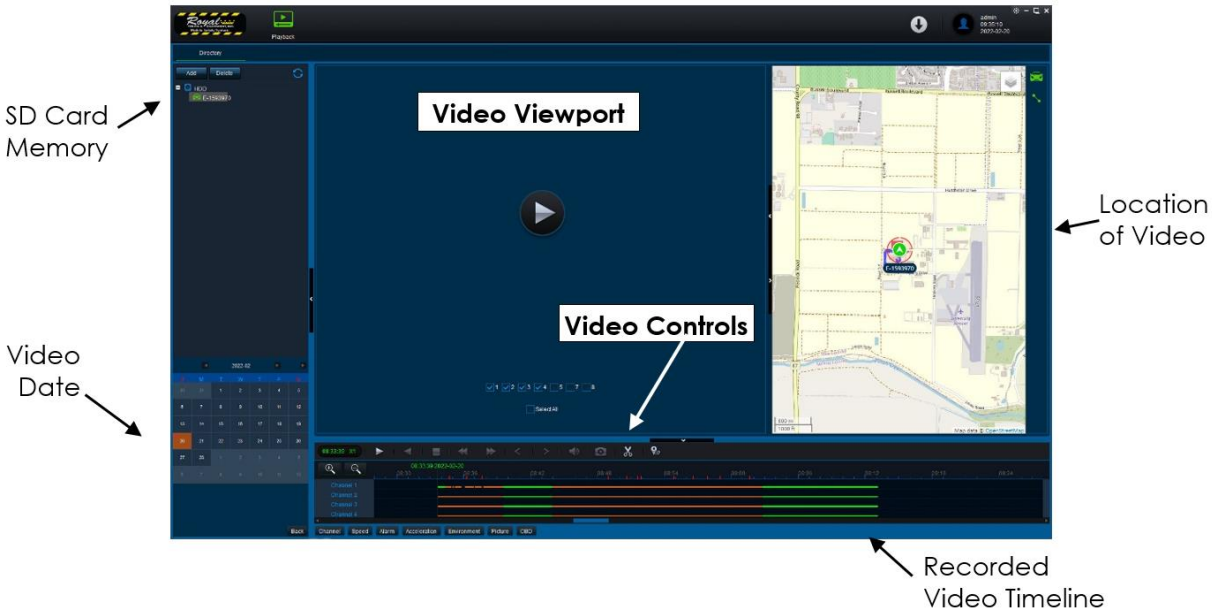


Figure 5.9: Video viewer software

AHMCT was able to use the SD card method to successfully transfer the recorded video record from the ATMA DVR to a laptop computer. Using the Kohltech video viewer software application, AHMCT was able to successfully access all the videos recorded on the Gen 4 truck monitoring system during operational testing. Specific videos were searched for viewing, and several video files were saved in an open video format and viewed on a separate computer. The Kohltech video viewing application is much quicker and easier to use than the in-cab touchscreen display video access method.

Gen 4 Panic Button Testing

The AHMCT testing of the Gen 4 panic button functionality was inextricably integrated with its functional development. AHMCT evaluated the Royal Gen 4 installation on the ATMA and then had to work directly with Kohltech and TraffiCalm to bring the functionality of these panic system components up to the level of Caltrans expectations. This process involved several rounds of development and testing until the necessary Caltrans customized functionality was established. Once completed, the final AHMCT testing simply involved separately verifying the functionality of each of the two individual panic systems.

DVR Panic Button Testing

The AHMCT test plan for the DVR panic button feature focused on how Caltrans would be expected to utilize this feature in deployment. The shadow truck driver would press the Alertor panic button on the dashboard to save a video clip of a highway hazard or event. Later, the video clip could be transferred off from the shadow truck to an independent file. AHMCT tested the DVR panic button feature by staging shadow truck operations and pressing the Alertor panic button. AHMCT was then able to search both on the in-cab touchscreen display and with the SD card transfer method, to find and view the saved video clips. AHMCT also tested transferring these saved video clips to independent files in a common video format on a separate computer.

Signboard Panic Button Testing

Pressing the panic button on the TC Commander causes the signboard display to toggle between the normal speed sign message and the panic message. AHMCT repeatedly verified that the TC Commander panic button successfully toggled between the speed sign message and the panic message in closed test track trials.

AHMCT also tested the changing of the text options displayed on both the speed sign and panic messages. The in-cab TC Commander screen has dropdown menus that provide the easiest method of changing text on the signboard messages. The user can select a work zone speed limit value, which are displayed in 5 mph increments. For the panic message, the user selects from

a list of preprogrammed warning text messages to display. AHMCT was able to easily and successfully change the displayed message text. The most important of these choices is the "Move Right" or "Move Left" text on the speed sign message. The shadow truck signboard must be consistent with the direction of the lane closure to redirect traffic. The Gen 4 signboard also has manual buttons mounted on the back of the signboard to change the speed sign message, and another button to change the work zone speed limit value as shown in Figure 5.10. AHMCT successfully tested this manual method of changing the signboard speed sign message text as well. The manual method is more difficult to use because one person cannot press the button and see the displayed message at the same time. Including a second person is the most efficient approach when using the manual buttons.

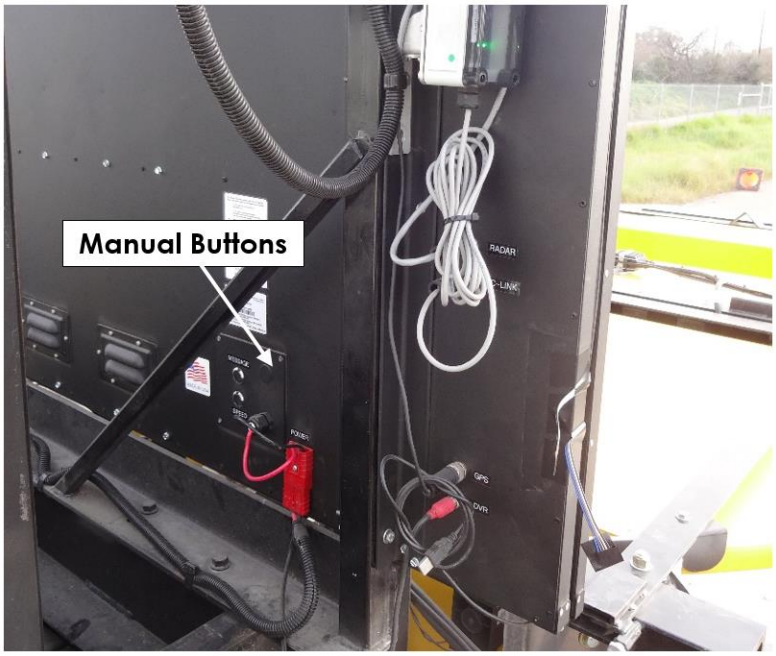
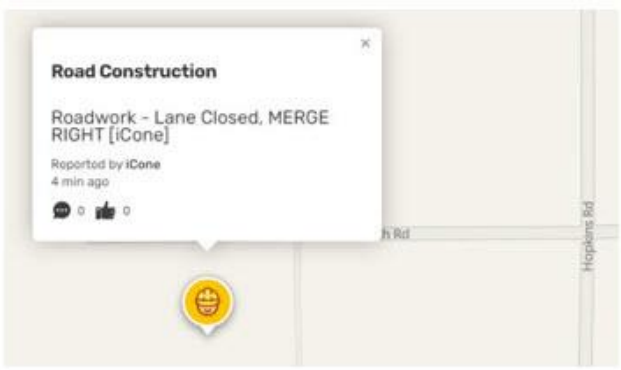


Figure 5.10: Manual buttons for modifying speed sign message

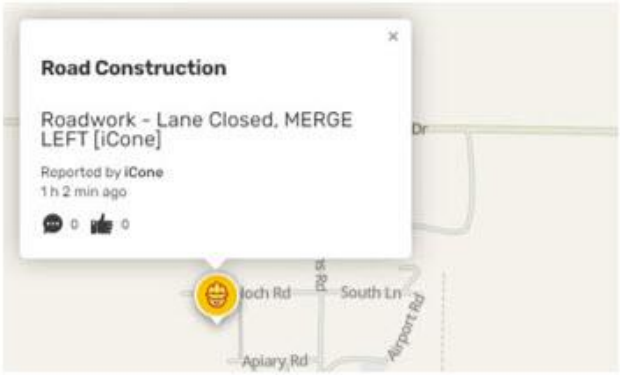
Automated Work Zone Reporting Testing

The iCone automated work zone reporting system was purchased from Royal, but AHMCT installed and integrated it onto the ATMA arrow board. The arrow board mounted on the ATMA is not the standard arrow board that Royal uses, but instead a Caltrans standard National Signal arrow board which is not pre-wired for iCone installation. Therefore, AHMCT had to work with iCone to get installation instructions, commission the system, and initialize service. Royal provided three years of iCone service with the ATMA purchase. AHMCT could not get an estimate from iCone as to the cost of service, because the initial service contract is through Royal.

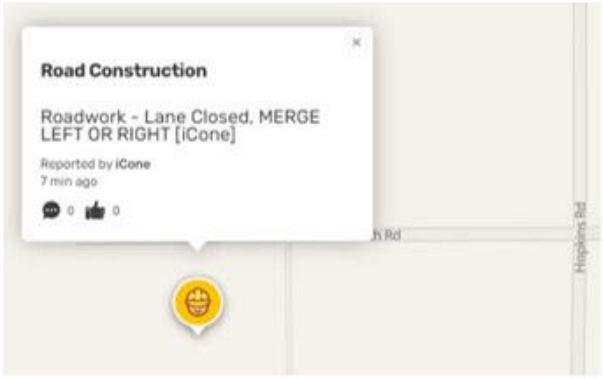
The iCone automated work zone reporting system powers on with the arrow board and automatically monitors the display of the arrow board. Any display on the arrow board appears as a road construction icon on the Waze map (Fig 5.11). During AHMCT testing, it was determined that the Waze notifications will appear on the map anywhere the arrow board is located. These notifications would not affect the Waze route planning algorithm unless the work zone is located on a roadway.



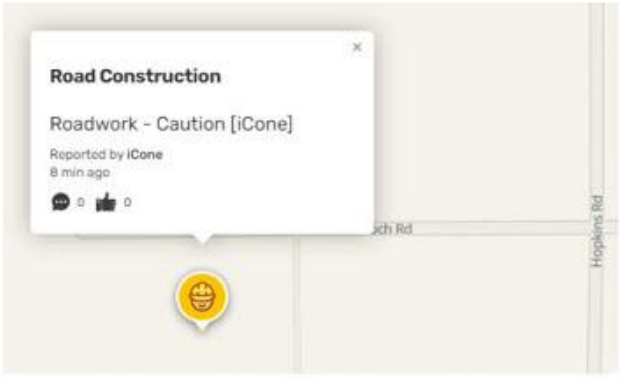
Arrow Board Right Arrow



Arrow Board Left Arrow



Arrow Board Double Arrows



All Arrow Board Cautions

Figure 5.11: Waze Notifications

Chapter 6:
Conclusions and Recommendations

The research conducted in developing innovative new shadow truck safety accessory technologies for Caltrans deployment did not progress as planned. Commercially available safety accessory technologies needed to be both adapted and functionalities extended to ensure that the research project deliverable of shadow truck integrated safety accessory system technologies were Caltrans compliant and deployable. The Caltrans project panel adapted the project research plan as commercial safety system technologies were extended and customized to satisfy Caltrans requirements. The resulting research plan had AHMCT develop a Caltrans-specific collection of safety technologies appropriate for Caltrans shadow truck highway maintenance operations. The resulting Gen 4 Technology Package is comprised of four Caltrans safety system accessories that act together to increase highway safety by enhancing motorist responsiveness to temporary highway work zones. The Gen 4 Technology Package was developed, integrated, and evaluated by AHMCT on the ATMA shadow truck platform.

Final Safety Accessories Technologies

Four specific safety technologies comprise the Gen 4 Technology Package: an innovative radar speed feedback display sign capable of displaying the absolute speed of approaching vehicles while the signboard is moving, video camera systems able to continuously record multiple views around the shadow truck, an automated highway work zone reporting system, and a shadow truck driver-activated panic/warning system. Each of these innovative vehicle equipment accessories was developed and tested according to Caltrans specifications. The resulting systems were integrated onto the ATMA and demonstrated to the Caltrans project panel for review and comments. The Caltrans demonstration findings were integrated with the AHMCT research findings to develop a Gen 4 Technology Package specification recommendation, which would ultimately become the primary research deliverable. The Caltrans customized Gen 4 Technology Package specification could be used in the future to guide additional Gen 4 Technology Package procurement by Caltrans for installation on Caltrans shadow trucks to be used in deployment trials in Caltrans highway maintenance operation work zones.

Safety Accessories Procurement and Installation Recommendations

Throughout the course of this research, communications with Royal Mfg. were inconsistent. Much of this inconsistency can be attributed to COVID-mandated closures. Royal has ultimately adapted their Technology Package to Caltrans performance specification and upgraded the ATMA with the Caltrans customized Gen 4 revision. AHMCT has also directly collaborated with the subcontractors providing each of the four safety accessories. AHMCT has assisted each of the subcontractors in development of their technologies on the ATMA to attain necessary Caltrans required functionality. AHMCT working directly with the subcontractors expedited the development process since Royal was not involved as an intermediary. The result is a fully functional Caltrans safety accessory Gen 4 Technology Package integrated on the ATMA. Royal has remained committed to being the supplier of the Caltrans customized Gen 4 Technology Package. AHMCT maintains that the choice of purchasing these four safety accessories together from Royal is a far better option than the alternative of purchasing each of these products separately and leaving Caltrans with the responsibility of integrating the separate systems together and inheriting the duty of maintaining and servicing these systems.

The initial research project methodology had Caltrans DOE installing the Royal Technology Packages on legacy Caltrans fleet shadow trucks. Based on the AHMCT Gen 4 development experiences, AHMCT recommends that Caltrans DOE work directly with Royal Mfg. to develop an all-inclusive installation plan and quote that covers all aspects of the Gen 4 Technology Package installs on Caltrans shadow trucks. The plan should specifically highlight that Caltrans legacy shadow trucks typically have an Energy Absorption Level 2 TMA installed, while Royal Mfg. installs their Gen 4 Technology Packages on shadow trucks with a Level 3 folding Scorpion TMA. The ATMA was configured with the Scorpion TMA and has custom hydraulic telescoping mounting to lower the arrow board to retract the Scorpion TMA (Figure 6.1). Consequently, the plan to install the Gen 4 Technology Package on Caltrans legacy shadow trucks may involve engineering an altogether new arrow board mounting, which would likely incur additional cost and development time. Caltrans DOE would be far better suited than AHMCT to directly work with Royal to determine the best option available to deploy additional Gen 4 Technology Packages on shadow trucks for future Caltrans deployments and meeting Caltrans DOE requirements.

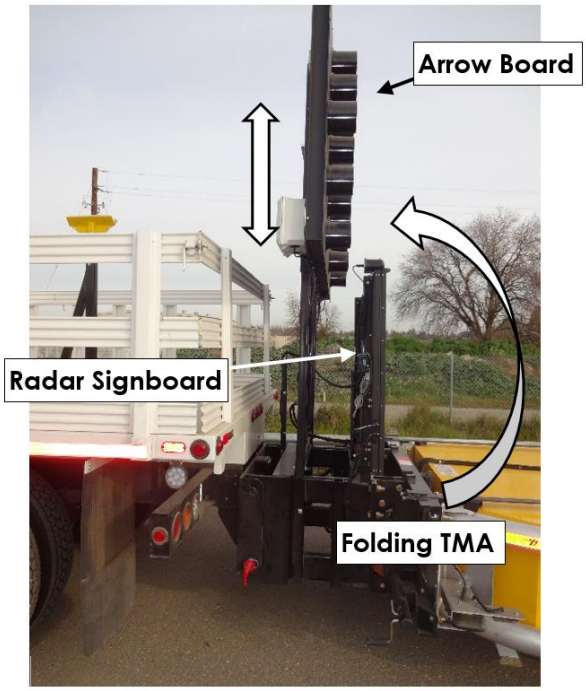


Figure 6.1: Signboard telescoping mounting for Scorpion TMA

Gen 4 Specification Recommendation

Royal Gen 4 Specification

The specifications for the original version of the Royal Technology Package procured with the ATMA purchase were insufficient and ultimately rejected by Caltrans DOE during initial purchase acceptance testing. AHMCT worked with Caltrans to develop an amended safety accessories technologies performance specification. AHMCT then collaborated with Royal Mfg. to develop an updated Gen 4 Technology Package, which provided the necessary functionality to achieve the Caltrans performance specification. Royal provided a quote for dispatching an engineering team to upgrade the ATMA with the Gen 4 Royal Technology Package. In addition Royal provided a Gen 4 specification and price quote for the purchase of additional Royal Gen 4 Technology Packages (Appendix E).

When Royal completed the Gen 4 Technology Package upgrade installation on the ATMA, several outstanding issues still remained that AHMCT needed to resolve. As of the end of this research project, a few outstanding safety accessory issues remain to be resolved, Caltrans customizations finalized, and future Gen 4 Technology Package installation procedures to be defined. Therefore, the final AHMCT research task of developing a Caltrans Gen 4 Technology Package specification will consist of the Royal Gen 4 specification and a list of AHMCT specification recommendations focused on resolving

outstanding functional issues needed to better satisfy Caltrans performance requirements.

The following list is a series of tasks that AHMCT recommends be conducted on the current Gen 4 safety accessory systems on the ATMA:

1) Gain Caltrans IT approval for installing the Kohltech video viewing software on Caltrans Getac K-12 tablet computers.
2) Verify the wireless cellular link connection between the shadow truck-mounted DVR and the Getac computer to transfer video recordings.
3) Investigate if the Caltrans Traffic Management Center (TMC) could use the iCone automated work zone reporting data.

AHMCT Gen 4 Recommendations

The final specification for the Caltrans customized shadow truck safety accessories developed in this research project is a combination of the Royal Gen 4 specification with the following AHMCT recommendations outlining additional features not completed in this research and new functionality to enhance safety and performance benefits.

AHMCT recommends the following modifications to the Royal Gen 4 system specification:

1) Combine panic buttons to use the Alertor serial button mounted on the dashboard.
2) Obtain 360-degree video coverage. The forward-pointing side cameras should be specified to obtain full surrounding video coverage. This can be easily accomplished by attaching a forward-facing side camera to the one unused camera input currently available and by replacing the hitch camera with the other side camera.
3) Caltrans should plan on installing the Gen 4 Technology Packages on shadow trucks fitted with Scorpion TMA units, because Royal Mfg. has already engineered a working design for shadow trucks with a Scorpion TMA. The process of designing a different mount to accommodate a different TMA would most certainly incur additional engineering development time and result in higher installation costs.

References

1. Duane Bennett and Ty A. Lasky, Evaluation of Autonomous TMA Trucks for use in Caltrans' Operations (http://ahmct.ucdavis.edu/pdf/UCD-ARR-21-12-31-03.pdf), AHMCT Research Center, UC Davis Dept. of Mechanical & Aerospace Engineering, UCD-ARR-21-12-31-03, November 2021

Appendix A:
Kohltech R8-Mobile DVR Manual

KEY FEATURES

- Up to 8 Channels of 1080p Video
- Solid State Design: SD + SSD Based Storage
- Mirror Recording: SD + SSD
- GPS Module and Accelerometer
- Supports 4G LTE for Live Viewing and Remote Management
- 3-Axis Internal

Total Visibility

KOHLTECH FLEET SAFETY SYSTEM

ACCESS IS A TOUCH AWAY

Our Rugged 7" Touch Screen Monitor allows instant camera and view changes. Search, play and export video in seconds without the need for a remote.

CONNECTED

Monitor incidents live or retrieve video and GPS history from the hard drive over the air. Optional 4G LTE and Wi-Fi provide instant real-time access to video on the road or in the yard.

MONITOR, MANAGE, TRACK

Available fleet software provides the ultimate in fleet monitoring, tracking and management. Real time alerts of vehicle impacts. Speed or location violations, and camera or DVR tampering.

User Manual

R8

Mobile Digital Video Recorder

1-12 For more information, please visit our website **www.kohltechnology.com**

Notice

The information in this manual was current when published. The manufacturer reserves the right to revise and improve its products. All specifications are therefore subject to change without any notice.

The purpose of this manual is to kindly aid the user for the operation for our MDVR. The user should have a basic understanding of computer operation and basic knowledge of how to connect peripherals and make some settings.

Copyright

Guarantee & Warnings

1) Electrical Apparatus Safety
   All installation and operation should comply with local electrical safety norms.

2) Transportation
   In the process of transportation, storage and installation, please avoid heavy stress, violent vibration, impact and water splashing.

3) Installation
   Install the equipment in accordance with the requirements, handle carefully. Do not heavily press the equipment before the MDVR installation is finished.

4) Requirements on Engineers & Technicians
   All the work of checking and maintenance should be done by qualified technicians and engineers.

We do not undertake any responsibility caused by unauthorized modifications.

5) Requirements on Environment

The equipment should be installed and stored in a cool and dry place, away from direct sunlight, flammable or explosive substances, etc. Keep gaps not less than 3cm around the device to facilitate ventilation for cooling.

6) Accessories

Make sure to use accessories from the manufacturer recommended in the attachment.

Insulate circuit ground and metal shell for all the peripherals.

Before installation, please open the package and ensure that all parts are included.

If there are any problems, please contact us as soon as possible.

1. Product Characteristics

1.1. Overview

KOHLTECH's R8 is a functional Mobile Digital Video Recorder specially designed for vehicle video surveillance and remote monitoring. It has a high-speed processor and embedded operating system, combining with the most advanced H.265 video compression / decompression technology, 3G/4G network, GPS positioning technology, as well as WIFI. It supports not only video recording in 108OP, 720P, WD1, WHD1, WCIF, D1, HD1 and CIF formats, but also vehicle travel information recording and wireless data upload. With center software it also achieves alarm linkage central monitoring, remote management and playback analysis. It is easy to use with simple design, multi-functions, superior anti-vibration, anti-electromagnetic interference, radiation protection, hard disk storage, SD backup, flexible installation, and high reliability.

1.2. Specifications

Technical Items	Technical Indicators
Product Model	R8
Function Overview	Preview, Recording, Playback, Network, Locating

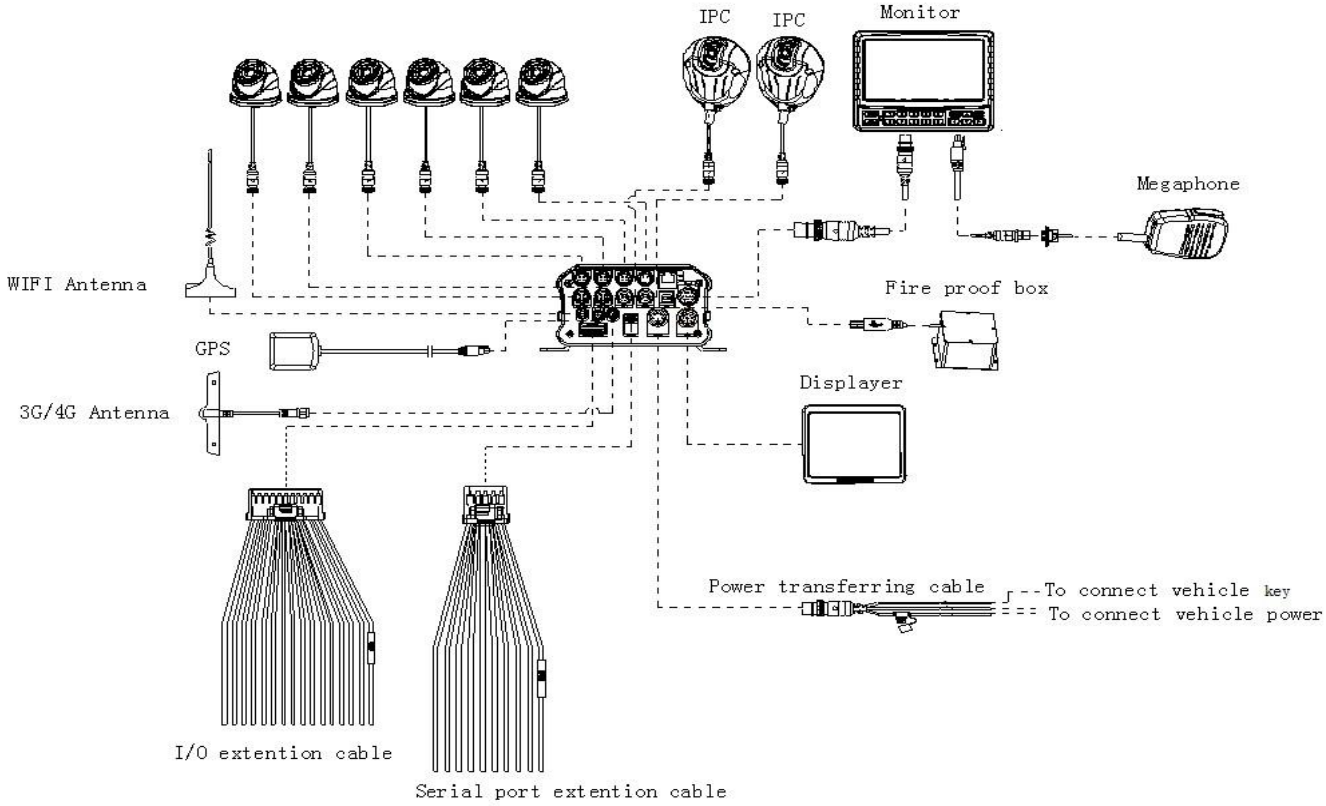
System	Operating System	Linux
	Control Mode	CP4, mouse, EasyCheck, network(3G/4G/WIFI)
Video	Input	AHD*6+IPC*2
	Output	2 CH (CP4+VGA)
	Total Resource	PAL: 6*720P@15fps(AHD)+2*1080P@30fps(IPC) or4*1080P@10fps(AHD)+2*1080P@30fps(IPC) or4*720P@25fps(AHD)+2*1080P@30fps(IPC) NTSC : 6*720P@15fps(AHD)+2*1080P@30fps(IPC) or4*1080P@12fps(AHD)+2*1080P@30fps(IPC) or4*720P@30fps(AHD)+2*1080P@30fps(IPC)
	Video Signal Standard	Electrical level: 1Vpp Impedance: 75Ω NTSC/PAL Optional
Audio	Input	8 CH (AHD*6+IPC*2)
	Output	1 CH
	Audio Signal Standard	Electrical level: 2Vpp Input impedance: 4.7kΩ

Display	Display Split	1/4/9 Image display	
	OSD	GPS, Alarm, Vehicle plate, Speed, Time, etc.	
	Operation Interface	Semi-transparent GUI	
Recording	Video/Audio Compression	Video	H.264/H.265
		Audio	ADPCM, G.711A G.711U
	Image Resolution Note: If analog channel (AHD) 1 or channel 2 are connected to 1080P, there will be no video image for channel 5 and channel 6.	PAL: 1080P(1920X1080), 720P(1280X720), WD1(928X576), WHD1(928X288), WCIF(464X288), D1(704X576), HD1(704x288), CIF(352x288) NTSC: 1080P(1920X1080), 720P(1280X720), WD1(928X480), WHD1(928X240), WCIF(464X240), D1(704x480), HD1(704x240),CIF(352x240);	

		Digital: 1080P(1920X1080), 720P(1280X720)
	Image Quality	8 Levels adjustable (Level 1 is the best)
	Recording Mode	Schedule/Alarm(sensor trigger, speed, acceleration, video loss, temperature)
	Pre-recording	0-60min
	Post-recording	0-30min
Playback	Playback Channel	1/4 channel by local playback, supports WEB 1/4/8 channel by local playback
	Search Mode	Date/time, channel, event
Network	3G/4G	EVDO/TD-SCDMA/WCDMA/TDD-LTE/FDD-LTE optional
	WIFI	802.11b/g/n
	Ethernet	RJ45 x 1(10/100M)
	IPC Ethernet	2 x 6-pin DIN JACK (10/100M PON port, power supply) 2 x 6-pin DIN JACK (10/100M Network port, no power supply)
Locating	GPS	Location tracking, speed detection and time sync
Sensor	G-Sensor	Built-in 6-axis inertial sensor
Storage	HDD/SSD	1 x2.5"SATA HDD or SSD, thickness 7mm/9.5mm/15mm, supports hard disk heating
	SD	Support SDXC 32GB/64GB/128GB/256GB, plug and play
Interface	USB	1 x USB2.0(Type A)+ 1 x USB2.0(Type B), hot swap

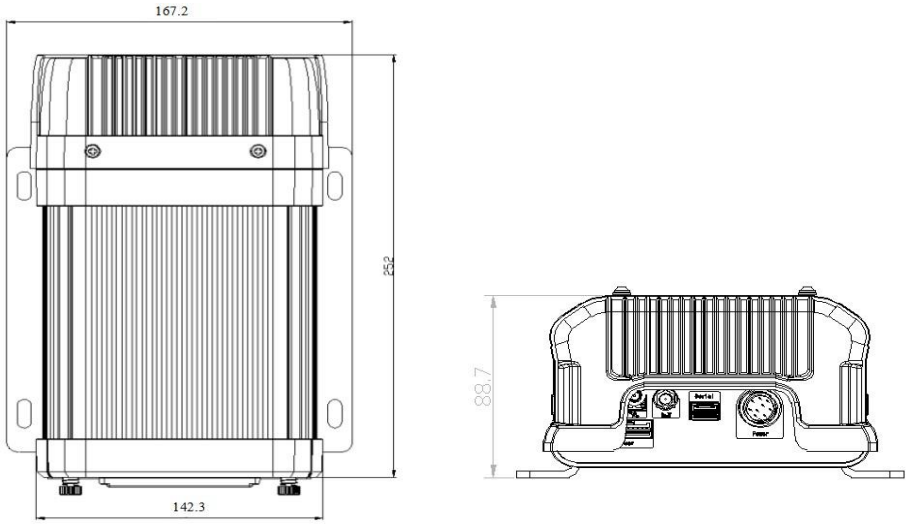
	SD	1 x SD slot
	SIM	1 x SIM slot
	Serial	2 x RS232, 1 x RS485, 1 x CAN
	I/O	8 inputs, 2 outputs
	Speed	1 channel pulse speed detection
	Control Panel	CP4
	Intercommunication	1 MIC port(CP4)
Power	Input	DC 8~36V, ACC
	Output	5V@500mA & 12V@500mA
	Max Power Consumption	46W
	Standby Power Consumption	≈0W
Physical characteristics	Dimension(mm)	252x167.2x88.7 (with bracket and rear shield)
	Weight(KG)	2.2KG (not include HDD)
Environment	Operating Temperature	-40℃~+70℃(with heating and no HDD)
	Operating Humidity	8%-95%(No condensation)

1.3. System Diagram

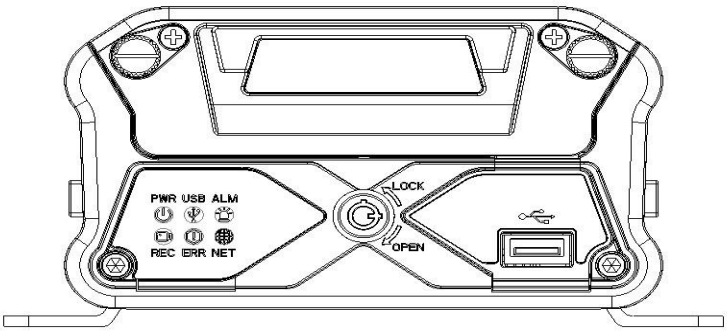


1.4. External interface

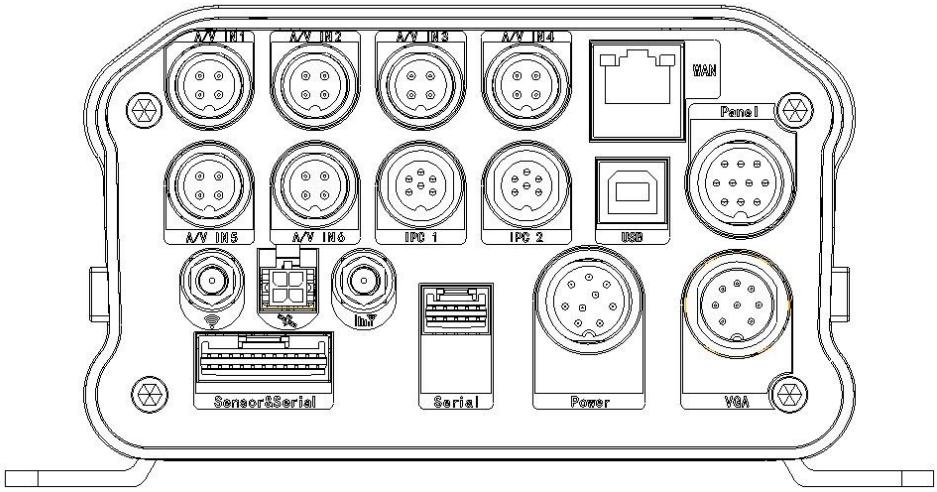
Dimension (Unit: mm)



Front Panel



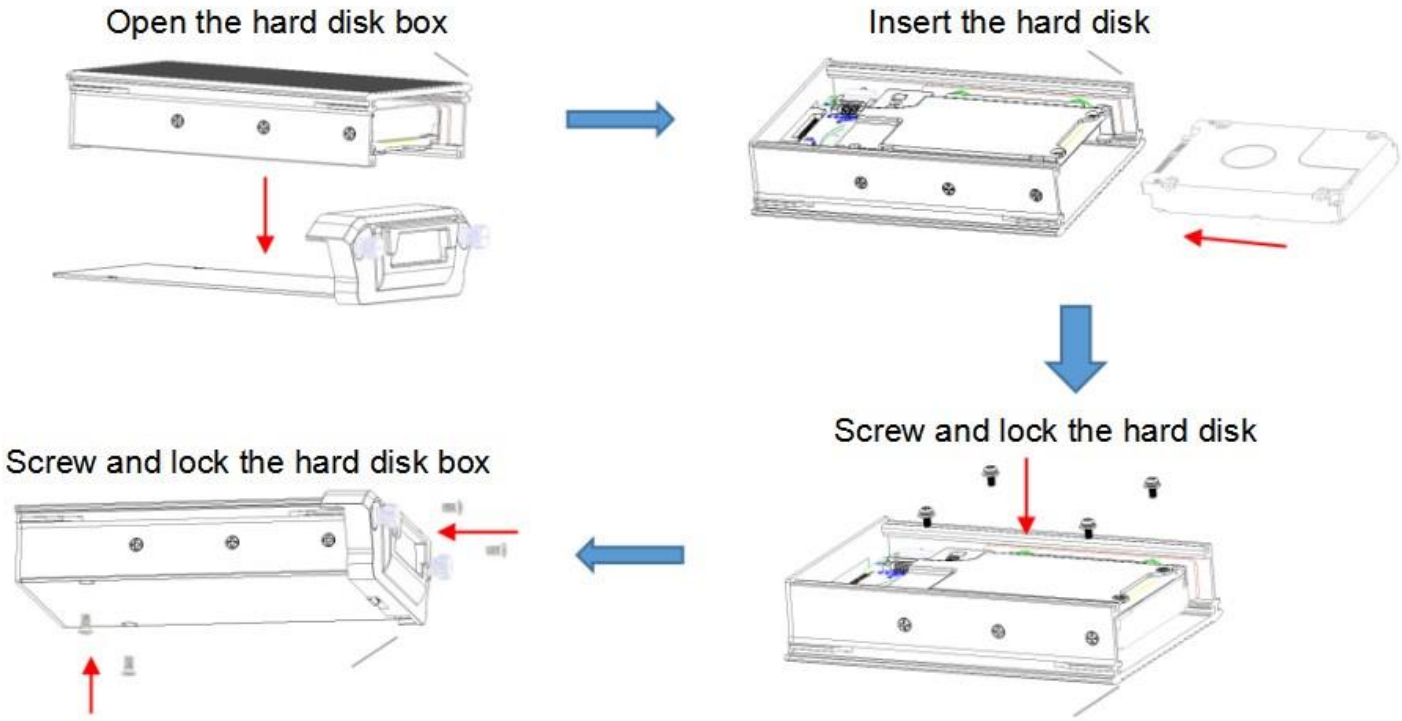
Rear Panel



Serial No.	Print	Description
1	A/V IN1~6	Analog audio/video input 1~6
2	IPC1~2	IPC A/V input 1~2
3	VGA	VGA video interface
4	WAN	100Mbps network interface
5	USB	USB 2.0 interface (Type B)
6		3G/4G antenna interface
7		GPS antenna interface
8		WIFI antenna interface
9	Sensor&Serial	Sensor & serial interface
10	Serial	Serial interface
11	Panel	Control panel interface(CP4)
12	Power	DC8-36V power input

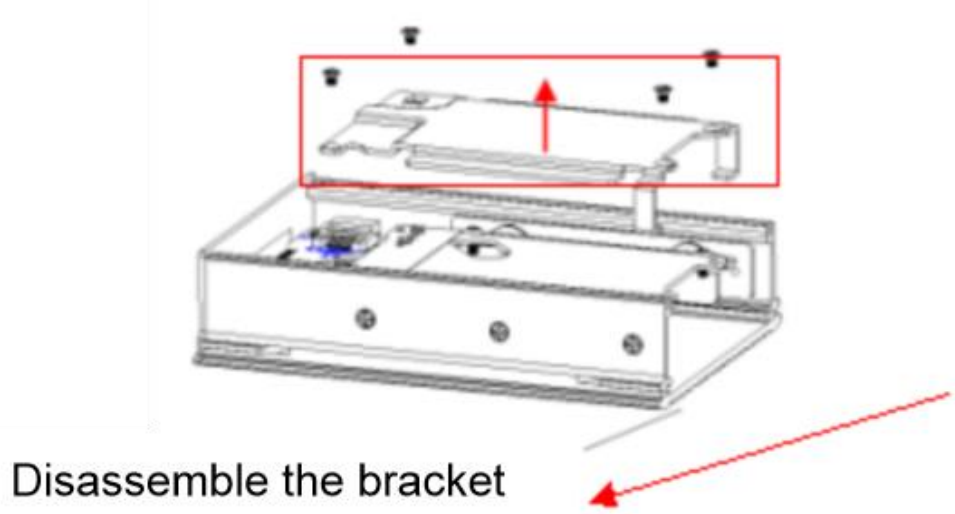
1.5. Hard disk installation

The procedure to install the hard disk of 9.5mm/7.5mm



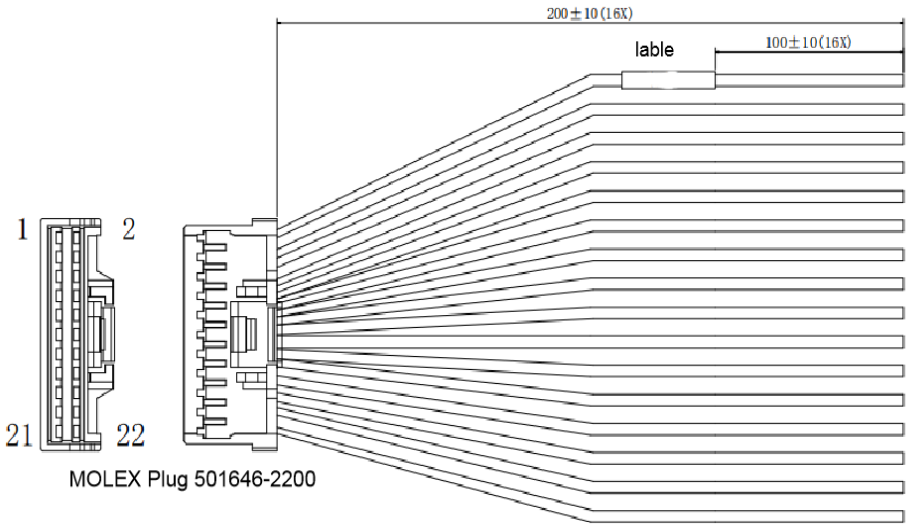
The procedure to install the hard disk of 15mm

To install the hard disk of 15mm, user needs to disassemble the brackets, and then insert it.



1.6. Definition and pictures of external cables

Alarm cable definition

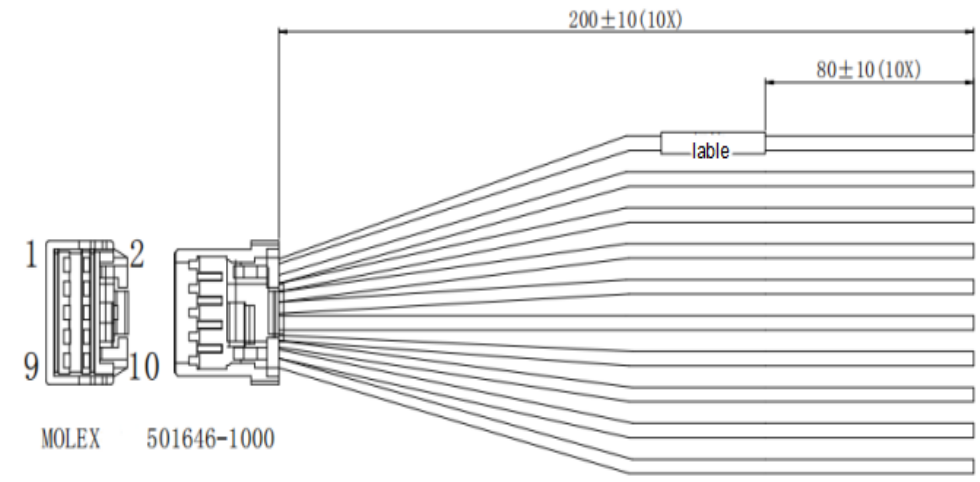


Diagram

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

Serial port definition



diagram

501646-1200

1	white&yellow	232TX-1
2	green&yellow	232RX-1
3	white&black	CAN-H
4	green&black	CAN-L
5	red	+5V
6	black	GND
7	black	GND
8	red	+12V
9	white&blue	485A-1
10	green&blue	485B-1

2. FAQ

1) The system can’t start?

Usually this problem results from the incorrect power connection. Please follow below steps to check the power connection:

1. Check the input power, whether the power wire is connected correctly, whether the ground wire is connected back to the battery, and whether the fuse on the power wire is in good condition.
2. Check whether the ACC signal wire input to the power is with voltage higher than 7 V.
3. Check whether the device key is closed.

2) The MDVR restarts uninterruptedly?

Please follow below steps to check it:

1. Check whether the voltage of MDVR is insufficient. If the voltage is less than the start-up voltage of the device, the device would always restart.
2. The problem in hard disk/SD card may cause the failure to start. Take off the storage part and check whether it is broken down.

3) The device can't record?

Usually this problem results from the storage disk or camera. Please follow below steps to check it:

1. Check whether the storage disk is installed, whether it is in good contact, and whether the disk can be read normally in computer.
2. Check whether the storage disk is formatted. The storage disk should be formatted before normally storing record files.
3. Check whether there is video signal input into the device from camera, and whether there is video/image on the screen.

4) There is no voice in record file?

Please follow below steps to check it:

1. Check whether there is an external pickup, or whether the camera features with the function of audio collection.
2. Access to Video Channel Settings, check if Audio is set on.
3. There must be video input into the channel for recording and it must record normally.

5) The GPS works abnormally?

Please follow below steps to check it:

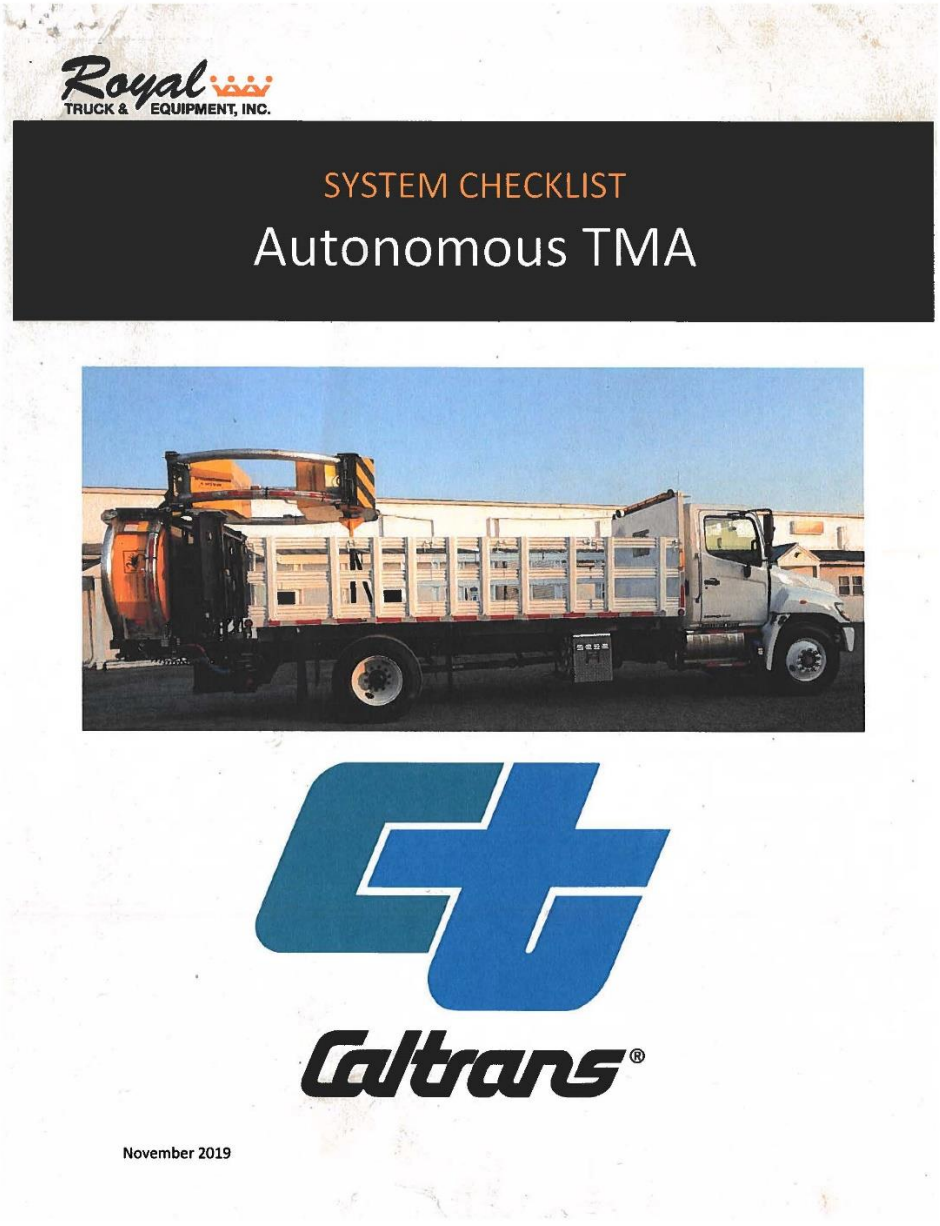
1. Check whether the GPS antenna is installed correctly. There is a silk print logo on the GPS antenna holder behind the host device.
2. Check whether the antenna receiver is sheltered. It should not be covered by any stuff, which may cause it not to receive signals.
3. Environmental influence such as tree shades, being inside tunnel, driving near tall building or elevated roads, thunderstorms or other weather influence, etc. can also cause signal loss or receiving wrong signals.

6) The device can't shutdown in ignition switch mode?

1. Check if the ACC line connection mode is correct; and check whether there is voltage on ACC yellow line when the key is turned off.
2. If the device has been set with schedule recording, it can't shutdown if it is still during recording time of the task table.

Appendix B:
Royal DVR System Manual

Appendix B describes the operation of the truck video monitoring system as taken from the ATMA operational manual provided by Royal Truck & Equipment Inc.



4. DVR System

4.1. DVR System

- Use the key provided to unlock the DVR and access the SD or SSD
- Lights are described below:

Display	Description	When illuminated...
PWR	Power	the power is ON
REC	Record	the device is recording
USB	Universal Serial Bus	a USB device is connected to the DVR
ERR	Error	one of the hard drives is not working properly
ALM	Alarm	one of the cameras is not plugged in OR a storage device is missing (hard drive, SSD or SD)
NET	Internet	the DVR is connected to the internet *Applies only to trucks with a data plan (additional)

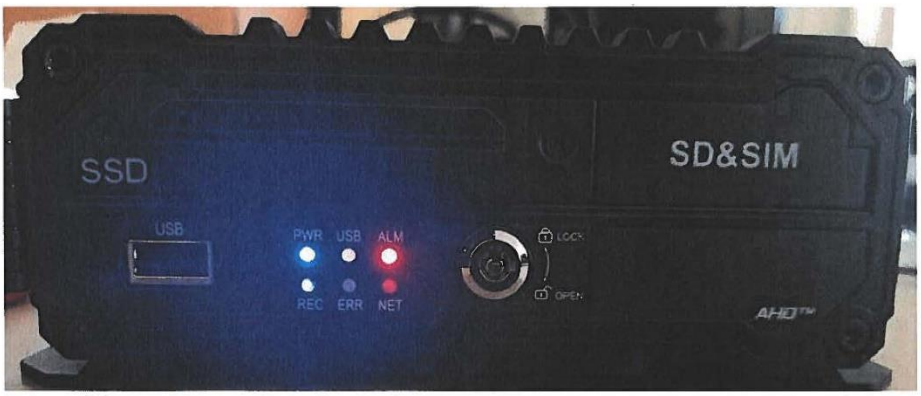


Figure 20: DVR Indicator Lights

4.2. Monitor

Figure 21: Monitor

- Ensure monitor turns on with the key in the on position
- Push numbers 1 through 9 to select a camera for full screen (depending on the number of cameras on your truck, some options may not be available)
- Push the MENU button or the blank button beneath it to log into the DVR
- Push the EXIT button for the sub-menu
    - This allows the user to select the view
    - The below button brings up the log in screen
    - The default password is 222 or 222777. After logging in you can change the password in the settings menu

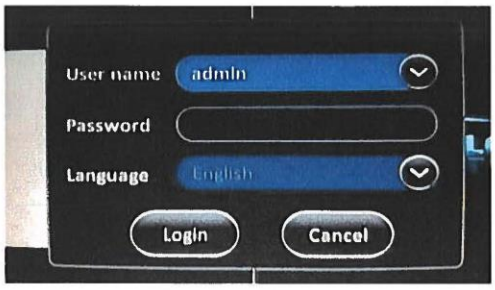


Figure 22: DVR Login Screens

4.3. Playback Function

- This function allows you to view recorded events from within the truck
- There are 2 ways to watch playback on the monitor
  - Bring up the sub-menu by pressing the EXIT button and select Playback
    - This will start the playback from the most recent recording
    - You can fast forward, rewind and change cameras from this screen
    - You can also change the time of recording by dragging the top bar
  - Log in from the menu
    - After logging in, select REC Search from the below screen

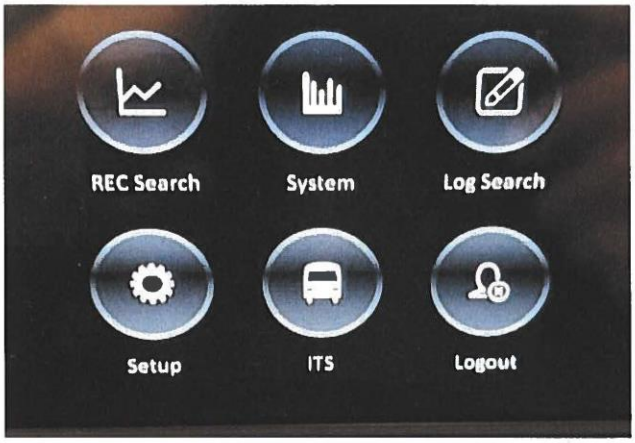


Figure 23: DVR Menu Screen

- Select the Date you want to search and press Next

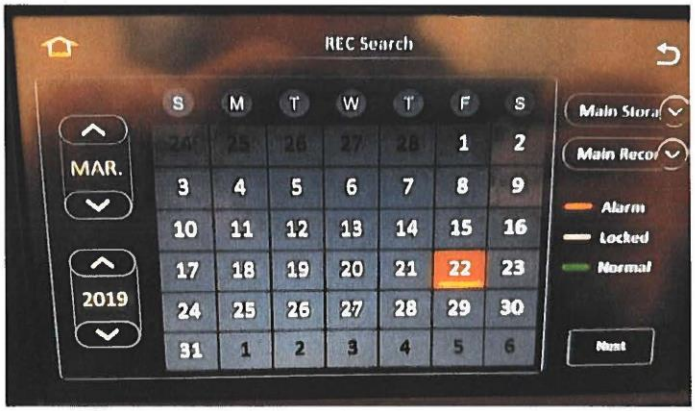


Figure 24: DVR Date Search

- Select the Channels you want to preview and then press Next

Figure 25: DVR Channel Search

- After selecting channels, you have the option to select Export or Playback. Press the Playback button

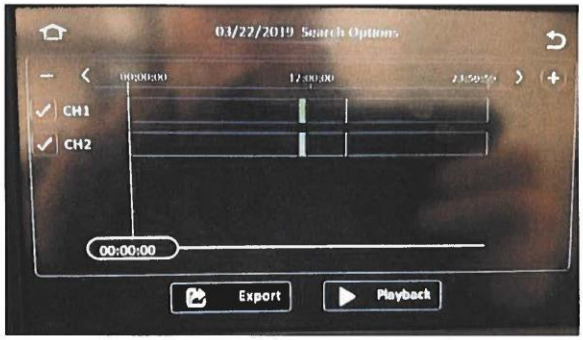


Figure 26: DVR Playback Screen

- Use the arrows on the right side of the screen to change cameras

Figure 27: DVR Playback Navigation

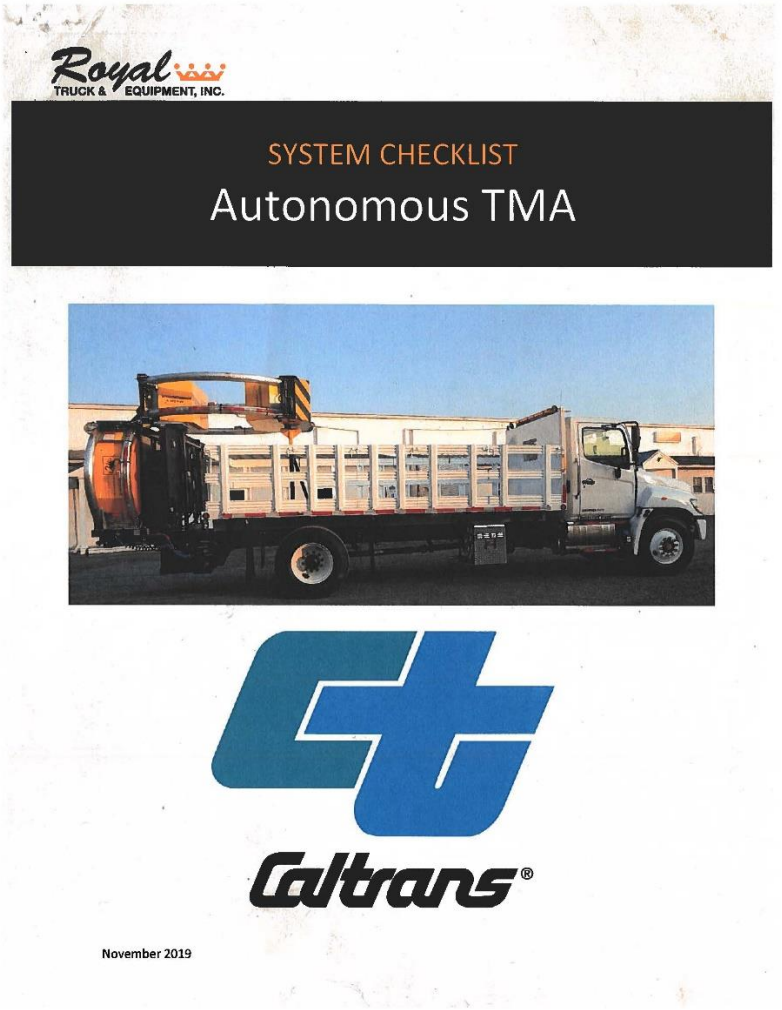
- Use the buttons along the bottom of the screen to control the speed of the playback
- Use the volume buttons on the left side to adjust the playback volume
- Drag the dot at the top of the screen to control the playback time

4.4. Cameras

- 10 Cameras in total
  - Driver facing
  - Forward facing
    - Both are in the cab
  - Bed facing
  - Rear facing on top of arrow board
    - Back up camera with attenuator deployed
    - Hit camera
  - Rear facing under attenuator D module
    - Back up camera with attenuator stowed
  - 2 Bullet cameras on each side (4 total)
- Clean the lenses to ensure clear visibility

Appendix C:
Royal Technology Package Arrow Board Manual

Appendix C describes the operation of the arrow board as taken from the ATMA operational manual provided by Royal Truck & Equipment Inc.



2. Arrow Board

Figure 13: Arrow Board

2.1. Operation

- The arrow board will raise and lower **together** with the attenuator using the two-button controller

- Press and hold the DOWN button to 1) lower the attenuator and 2) raise the arrow board
- Press and hold the UP button to 1) lower the arrow board and 2) raise the attenuator to the stow position
- Releasing the button will **immediately** stop the movement

Figure 14: Two-Button Controller

- Always ensure the arrow board is fully raised and fully lowered
- The arrow board should be stowed fully to ensure the attenuator does not hit it up on raising

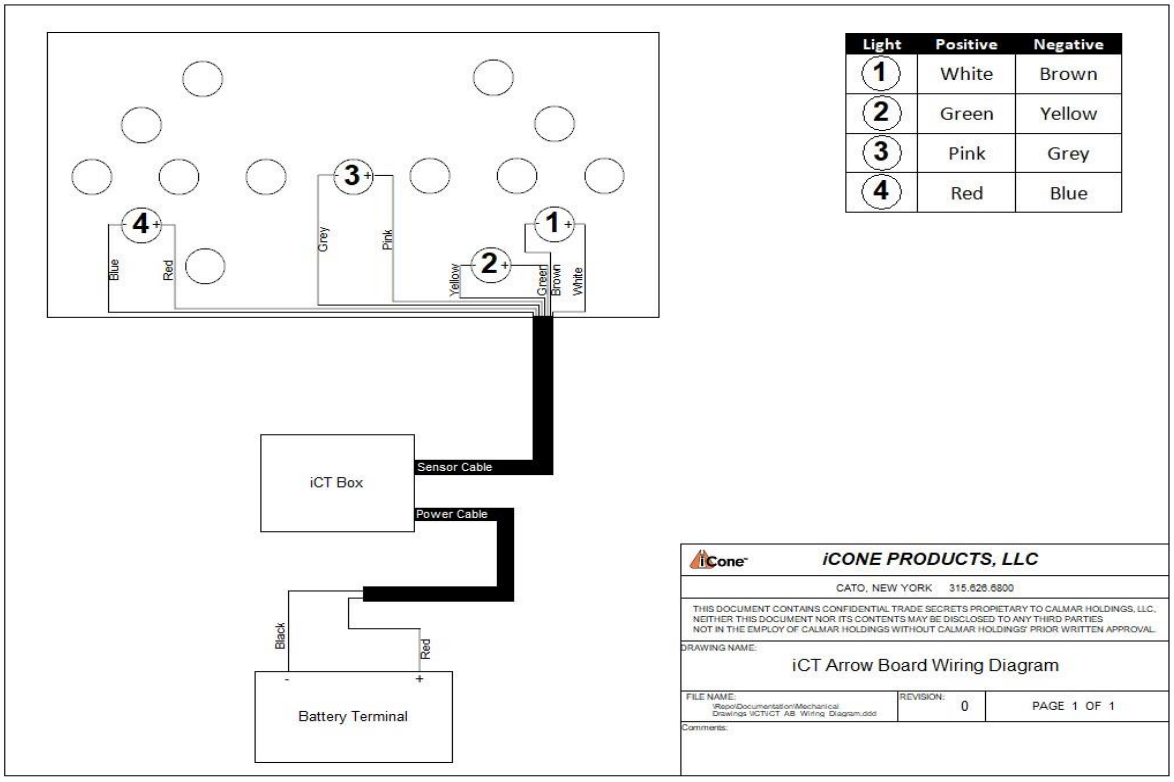
Figure 15: Stowing the Arrow Board

2.2. Arrow Board Lights & Patterns

- Check all of the lights on the arrow board to ensure they are all working properly
- Turn on the arrow board control with the switch on the dashboard and then on the controller
- Cycle to the double arrow and caution bar. These two patterns will operate all of the lights on the arrow board

Appendix D:
iCone Module Installation Diagram

ICone Wiring Diagram to arrow board



Appendix E:
Royal Gen 4 Purchase Specification

Royal TRUCK & EQUIPMENT INC.

Quotation
6910 PA-309, Coopersburg, PA 18036
Phone: 610-282-4090
Fax: 610-282-8986

Quote

Quote Number:	657	**Date:**	03/30/2021 1:19 PM
		Sales Person:	CK Madeira
			cmadeira@royaltruckequip.com
Valid Until:	2021-04-25	Payment Terms	

Bill To	Ship To
California Department Of Transportation (Caltrans) 1120 N St Sacramento, CA, 95814 USA	California Department Of Transportation (Caltrans) 1120 N St Sacramento, CA, 95814 USA

Vehicle Information

Stock #	
Year:	
Make:	
Model:	
VIN:	

Qty	PN	Quoted Line Item	Unit Price	Ext. Price
1.00	L4T	Level 4 Technology Package All items are in addition or an upgrade to the Royal Standard Camera System Included with the TMA Package 8 Channel 1080p MDVR (500GB SSD + 256GB Industrial SD) w/Integrated GPS, Inertia Sensors, Black Box Recording System w/Impact Resistant Solid State Hard Drive enclosed in a locking metal case with fan. Avail 4G and Wi-Fi (2) High Definition 1080p wide angle 130 FoV Camera w/Audio and IR Illumination - (Bed and TMA Cam) (1) 720p Wide Angel 130FoV Cam w/Audio and No IR 3.6mm (110) - (Backup Cam) (1) 720p Mini Cam - (Interior driver facing cam) (1) 1080P Mini Cam 9 Forward Facing) 7" Touch Screen MDVR Monitor - Includes Bracket and 5m cable 5m 4 Pin Waterproof Audio/Video Cable - HD 15M 4 Pin Waterproof Audio/Video Cable - HD Truck Mounted 36x60 Full Matrix CMS with Radar Vehicle detection and GPS Speed Correction Built in data fields to display the speed limit and corrected vehicle speed accounting for the truck speed. Programmable messages and graphics. Up to 9 internal or custom programmed frames can be selected for view in a repeating sequence using TraffiCalm's CMS software. Sign is configured to transmit the corrected speed to another device to be recorded overlaid on video to be recorded by DVR TC Commander SNAP Network Connection Controller for message selection and programming, and for diagnostics. Durable Aluminum frame and poly carbonate window. Display modules are encapsulated in chemical resistant material to enhance vibration and shock resistance, and provide an environmental	$24,985.00	$24,985.00

1 / 3

		seal. Maximum speed the sign can measure is 140 MPH in ½ MPH increments. It is accurate to +/- 1 MPH and never needs calibration over the lifetime of the sign. The sign can receive firmware code updates through the Bluetooth connection. While Traveling The range is 750 feet with the truck moving at 55 MPH. At a distance of 400 feet or more, three lanes come into view. This decreases as the approaching vehicle gets closer to the truck. The following vehicle must be moving +/- 3MPH faster or slower than the truck to be seen. The Board is capable or displaying either the vehicle closest or moving the fastest. Radar is capable of detecting multiple lanes; the lane directly behind and each lane to either side Safety Zone Rear Alert The safety alert mode (with the truck stopped) can measure vehicle speeds from 5 to 90 MPH at more than 1200 Feet giving the truck operator 9 to 16 seconds of warning about an approaching vehicle. An alert can be provided to the approaching driver by automatic activation of the emergency flash message on the message board. The Safety Alert Mode can also be activated manually from the TC Commander . Royals Level 4 Technology Package also includes a G force sensor which enables the DVR to segment and save any recording in which a TMA impact or similar G-force event has occurred. This technology also allows for communication of the Full Matrix CMS with Radar Vehicle detection and GPS Speed Correction with the DVR rerecording sysyem to lock in and overlay onto the recording the speed at which the object was traveling prior to striking the TMA.		
1.00	CTA	ICONE Arrow board add-on which sends live work zone status updates to popular navigation systems. Includes Hardware and 3 Year Data Subscription	$1,495.00	$1,495.00
1.00	CTPT	CalTrans Tech package swap travel Travel , Accommodation and labor for a 1Royal and 1 Trafficalm Representaive to remove original tech package and replace with L4T	$6,000.00	$6,000.00
1.00	Tech Credit	Gen 2 Tech Package Credit	$-18,972.00	$-18,972.00
			Subtotal:	$13,508.00

Grand Total

Currency:	USD	Subtotal:	$13,508.00
		Discount:	$0.00
		Discounted Subtotal:	$13,508.00