Trucking Fleet Concept of Operations for Automated Driving System-equipped Commercial Motor Vehicles

Chapter 5.2 ADS Installation and Maintenance Guide

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Abstract

Automated Driving Systems (ADS) are set to revolutionize the transportation system. In this project, the research team led by the Virginia Tech Transportation Institute developed and documented a concept of operations (CONOPS) that informs the trucking industry, government agencies, and non-government associations on the benefits of ADS and the best practices for implementing this technology into fleet operations.

The sections of Chapter 5 provide guidance on a range of topics for fleets to consider and apply when preparing to deploy ADS-equipped CMVs in their fleet. The topics cover fleet-derived specifications, ADS installation and maintenance, ADS inspection procedures, driver-monitor alertness management, insuring ADS-equipped trucks, identification of ADS safety metrics/variables, ADS road assessment, and data security/transfer protocol and cybersecurity best practices.

One of the goals of the CONOPS project is to prove the viability of an ADS in mixed fleets composed of trucks from a variety of makes and models equipped with a range of driving automation systems that assist drivers or carry full responsibility for sustained control and monitoring. This would require following efficient installation and maintenance practices for ADS equipment on these fleets. The research team developed this guide for the installation and maintenance of ADS equipment for fleets. The ADS used during the project varied based on the operational use case for deployment. These systems are examples demonstrating how ADS technologies and their assembly with the vehicle can vary based on the operational design domain (ODD) and automation functions required for operation. The chapter provides two separate installation guides and related maintenance practices for each system demonstrated in the CONOPS project. The first system was developed to support operations on public highways (as demonstrated with the port queuing cross-country deployments in the project). The second system was developed to support operations in limited geofence private yards or ports (as demonstrated with Fleet Integration in the project). It should be noted that this section is a product-focused overview of the installation process of an ADS developer, Pronto, on CMVs.

The information provided in this chapter may inform fleets on potential approaches to integrating ADS technology into their existing fleet for specific trucking operations and also provide original equipment manufacturers (OEMs) with insights on how to make provisions for ADS equipment installation during the manufacturing process. Interested ADS developers can also leverage this information to improve the software and hardware requirements for their proprietary ADS technology and possibly develop more innovative approaches to make the technology more easily adaptable to various domains, possibly streamlining the installation and maintenance process. The information may also provide law enforcement agencies with what to expect during vehicle inspection in the case of ADS-equipped CMVs. Policy- and decision-makers can also use the contents of this chapter as a primer for standardizing the installation and maintenance practices for ADS-equipped CMVs.

The following chapter has been extracted from the final report. For access to the full report, see this link: https://www.vtti.vt.edu/PDFs/conops/VTTI_ADS-Trucking_CONOPS_Final-Report.pdf

5. GUIDELINES

5.2 ADS INSTALLATION AND MAINTENANCE GUIDE

Maintenance and documentation of ADS will be a critical issue once these systems are introduced in the truck market. The VTTI team developed this guide for fleets to support the installation and maintenance of ADS equipment. One of the goals of this CONOPS is to prove the viability of an ADS in mixed fleets composed of trucks from a variety of OEM makes, models, and years equipped with a range of driving automation systems that assist drivers or carry full responsibility for sustained control and monitoring.

The ADS used during the project varied based on the operational use case for deployment. These systems are examples demonstrating how ADS technologies and their assembly with the vehicle can vary based on the ODD and automation functions required for operation. The first system was developed to support operations on public highways between hubs and exits. The second system was developed to support operations in limited geofence private yards or ports. Two separate installation guides and related maintenance practices are provided for each system.

5.2.1 Highway and Port Queueing ADS

In this section, we provide a product-focused overview of the installation process of Pronto's ADS on CMVs. The installation practices are heavily guided by Pronto's goal to provide an ADS that can be installed in a straightforward manner and swiftly validated in different CMV makes and models. Following this principle, the ADS can be conceptualized as being divided into three layers that guide the installation process:

1. Drive-by-wire (DBW)
2. ADS hardware
3. ADS software

The DBW encompasses all the electrical and electromechanical subsystems (including the ECUs required to achieve full vehicle control). These include steer-by-wire, brake-by-wire, throttle control, transmission control, and instrument cluster functions (e.g., turn signals, warning lights, headlights).

ADS hardware encompasses all essential components and sensors that the ADS software requires to run and communicate with the DBW in order to operate the CMV (for both the port queuing and highway demos of this project). Assembly and installation of Pronto's ADS hardware was designed to take advantage of modularization. Different groups of components and assemblies can be built and validated in parallel even before their installation on the target vehicle. This approach reduces CMV downtime for commercial fleets. Installation on the CMV requires minimal electrical and mechanical modifications that do not impede vehicle operations in the event that the hardware is later uninstalled.

Pronto's ADS software has three primary functions: (1) aggregate information from the vehicle sensors about the vehicle's surroundings, (2) extract contextual and semantic meaning from the

environment/surroundings, and (3) make driving decisions within a predefined scope of operations (Level 2 or Level 4 driving) that then translate to actuation commands like braking, steering, and throttle via the DBW. Installing and delivering software is relatively simple because modern software engineering provides highly reliable and scalable tools to load validated, stable versions of ADS software (more commonly known as "releases") to the artificial intelligence (AI) AV computer.

This section details the ADS hardware and software components, installation, and validation to provide a holistic understanding of the convergence required to deliver a fully functional ADS-equipped CMV. The information on DBW installation and validation is the same as that provided earlier in section 3.3 for the fleet integration use case and also in the next subsection 5.2.2 for the Port ADS. Additional information is also provided in Appendix C. Pronto's longer term goal is to deliver a fully functional system in 4 days.

- Day 1: DBW installation and validation
- Day 2: ADS hardware installation and validation
- Day 3: ADS software configuration and validation
- Day 4: Initial operational integration test

5.2.1.1 ADS Installation Guide – Hardware

ADS hardware encompasses all the necessary components, sensors, and connectivity devices that the ADS software requires to run. It was designed and built with a modular approach that packages most components in a single assembly referred to as the "Longhorn" to facilitate propagating the technology to many CMVs. The Longhorn is a roof rack attachment that can be installed with minimal engineering and can be quickly modified to meet any height or width restrictions. To deliver a holistic understanding of ADS hardware installation practices, this section will cover the components of the Longhorn and its ancillaries, sensors, and HMIs, as well as their installation and validation processes.

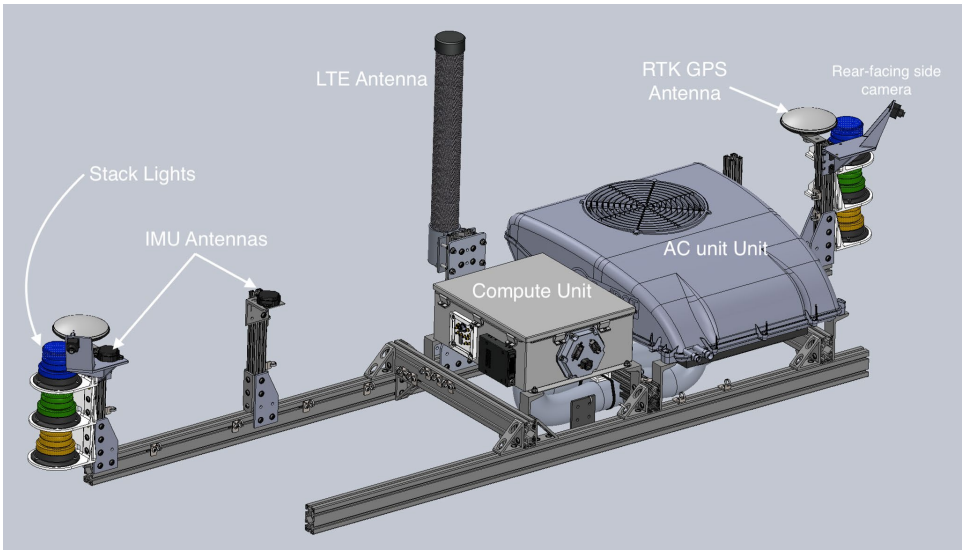

Figure 1. Diagram. Longhorn assembly.

Figure 2. Photo. Longhorn mounted on roof rack.

Longhorn: The core of the Pronto's ADS hardware is the Longhorn assembly pictured in Figure 34 and Figure 35. The Longhorn is built with an 80/20 T-slot system that provides incredible flexibility for installation onto different models of CMVs and adding new components. It contains the compute unit, the compute unit cooling system, antennas, rear-facing cameras, and antennas. The compute unit (Figure 34) is a shoebox-sized National Electrical Manufacturers Association-rated enclosure that contains the "brain" of Pronto's ADS:

- AI-ready compute module
- IMU
- Real-time kinematic (RTK) Global Navigation Satellite System (GNSS)/GPS modules

- LTE module
- Dedicated Short Range Communications (DSRC) module
- Camera processing module – supports up to six cameras via Gigabit Multimedia Serial Link (GMSL)
- Integrated CAN bus
- General purpose Input/Output (IO)
- Power conditioning and management unit
- 4-TB logging hard drive

The compute unit also contains two plates from which connections for antennas, CAN, power management, and cameras are aggregated and managed (Figure 36 and Figure 37).

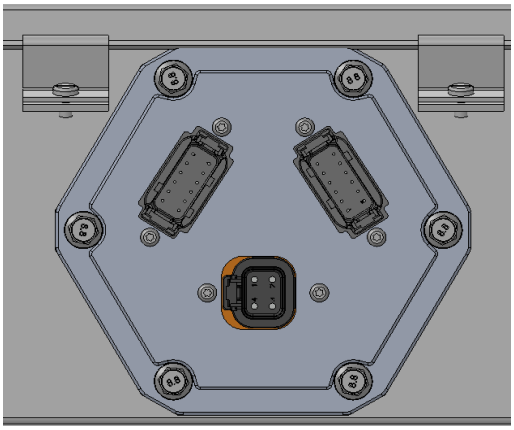

Figure 3. Diagram. Power and CAN Interface Plate.

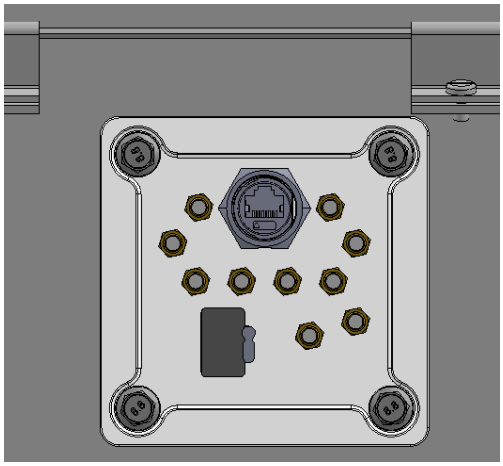

Figure 4. Diagram. Communications Interface Plate.

The Power and CAN Interface Plate is composed of two Deutsch DTM 12-way connectors and one Deutsch DTP 4-way connector. The DTM connector at the top left manages the Pronto DBW CAN bus, radar CAN bus and power, and SAE vehicle J1939 bus. The DTM connector at

the top right manages IO for the stack lights (discussed in a further section), HMI CAN bus, and power control for the air conditioning (AC) unit fan and clutch. The DTM connectors are keyed to prevent installation errors. The DTP connector supplies power to the power conditioning and management unit inside the compute unit.

The Communications Interface Plate is composed of five pairs of SMA connectors for antennas, an all-weather Ethernet port for engineering and troubleshooting, and a key-shaped hole where camera GMSL cables are routed. Although not visible in Figure 37, the SMA connector pairs correspond to the antennas for the following devices:

- IMU GNSS/GPS – for accurate positioning of the vehicle using RTK
- RTK GNSS/GPS
- LTE – for vehicle-to-vehicle and vehicle-to-server/cloud communication
- DSRC

All the antennas, with the exception of the DSRCs, are labeled in Figure 34.

The AI-ready computer can generate significant heat when running the multiple neural networks at the core of the ADS software. In order to keep the unit running at safe temperatures, an after-market AC unit, labeled in Figure 34, was integrated to circulate air from the bottom of the compute unit. The AC unit contains all components for an entire AC system loop except for the compressor.

In the most up-to-date revision of the Longhorn, stack lights and two wide-angle cameras pointing backwards, have been added for port queueing operations (Figure 38).

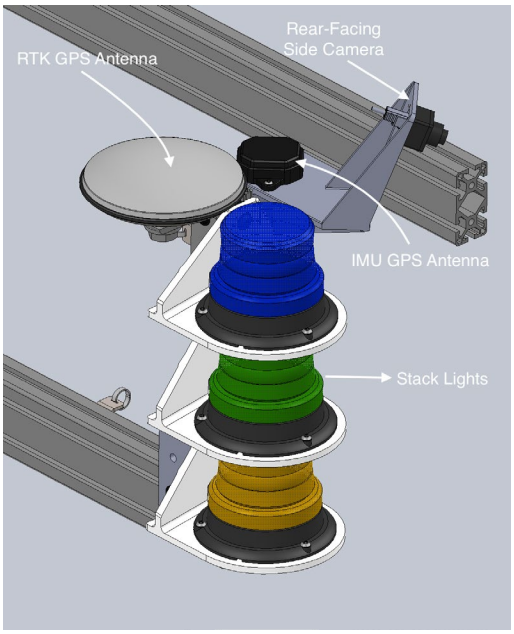

Figure 5. Diagram. Stack light and side cameras.

The stack light is composed of three colors:

- Blue when the CMV operates in automated operation.
- Green when the CMV operates in manual operation.
- Orange when the parking brake is applied.

Operators should not approach the vehicle unless they are following proper lockout procedures.

Longhorn Ancillaries: Although the Longhorn packages most of the ADS hardware, additional components are needed to securely mount it to the vehicle, power it, and connect it to the Pronto DBW and vehicle CAN buses. These can be grouped in the following categories:

- Mechanical mounts
- Power components
- Wire harnesses
- Cooling components

The Longhorn requires a series of mounting brackets attached to the vehicle's body to secure it in place. The goal was to make the Longhorn quickly removable for maintenance and repairs. Engineering work specific to the CMV is done to build and install mounting brackets.

Power for the Longhorn and all other components is sourced from the vehicle's 12-V system. The components to supply power safely and reliably are:

- ~10 AWG wire
- Battery disconnect switch
- Ignition switch contactor
- Fuse sized for expected current draw
- Power distribution wiring harness connector

Power flows from the 12-V battery through the battery disconnect switch into a fuse and ignition switch contactor. The contactor supplies power to the rest of the system through the power distribution wiring harness when the ignition switch is in the ON position.

Wiring harnesses supply power and data connections between the vehicle and the Longhorn. Power is sourced from the vehicle's 12-V battery system to the compute unit through the Deutsch DTP connector and to the AC unit's power supply. Data connections link CAN bus lines, Ethernet, and GMSL camera cables from the compute unit's Deutsch DTMS 12-way connectors to the vehicle's cabin where the front-facing camera, ECUs, and CAN bus devices live. A short list of components includes:

- Power distribution wiring harness
- Data wiring harness

- Radar wiring harness extension

Wiring harnesses are secured to the vehicle's cab and routed to the exterior components through a single through hole. Depending on the model of the CMV, a through hole must be created for the wiring harnesses.

The AC unit mounted on the Longhorn needs to be tied to the truck's AC compressor. This needs to be done both electrically, by wiring the AC compressor clutch to the compute unit's power conditioning and management board, and mechanically, by connecting the refrigerant lines to the compressor. The list of components to support this includes:

- AC compressor hoses – from compressor to AC unit
- AC hose fittings – compressor
- Refrigerant
- Relay sized for the current draw of the truck's compressor

Cameras and Radar: The Pronto ADS's primary sensors are the forward-facing camera and the front-facing radar. More details about these can be found in Appendix C. The front-facing camera is mounted inside the cabin and attached to the windshield. The radar is typically mounted at the center of the front bumper. The mount for each sensor was designed and manufactured in-house by Pronto to be versatile across CMVs. An additional driver-facing camera can be installed for driver monitoring functions. Figure 39 and Figure 40 show the front-facing camera and radar mounted onto one of the CMVs in the project's test fleet. Note that in Figure 39 there are two camera mounts (for testing), but operation of the ADS only requires one.

Figure 6. Photo. Front-facing camera.

Figure 7. Photo. Front-facing radar.

HMI: Pronto has developed its own human-machine hardware to operate the vehicle in both queueing and highway operations. A prototype version of the HMI box, pictured in Figure 41, provides tactile and responsive feedback to safety operators. It is the primary form of ADS control used during testing. The HMI is mounted to an easily accessible location on the vehicle fascia and communicates with the ADS software through the CAN bus. In addition, there is also a companion phone app that provides more detailed information and control of the vehicle with the intention to be the primary form of operator-to-vehicle communication during unmanned operations.

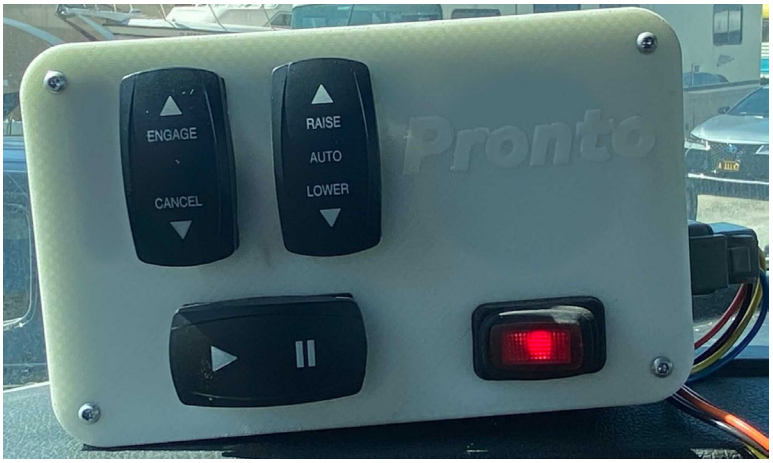

Figure 8. Photo. Cabin HMI prototype.

Installation and Validation: Pronto's goal is to deliver an ADS that can be installed with minimal support. All components and assemblies are validated at Pronto's facilities in San Francisco, California.

The installation of the ADS hardware can be divided into three phases:

1. Mechanical installation and validation
2. Electrical installation and validation
3. ADS hardware/software cross-validation

The mechanical installation requires mounting and securing the components to the vehicle's body and connecting the AC unit to the vehicle's compressor. The electrical installation involves wiring harnesses and all other modifications to connect the compute unit (which distributes power to most of the components) to the vehicle's 12-V power system and route and connect all data wiring harnesses to their endpoints. It is important to note the interdependence between the ADS software and the hardware. The ADS hardware/software cross-validation is performed by executing a series of tools developed by Pronto. Those custom tools are installed on the onboard computer and check that all ADS hardware components and Pronto's DBW communicate and behave as expected. These checks are discussed further in section 5.2.1.2 (Software and Hardware Cross Validation).

5.2.1.2 ADS Installation Guide – Software

The installation procedure for the ADS software is relatively simple and straightforward. Modern software engineering best practices provide highly reliable and repeatable tools to load stable and validated versions of the software (a.k.a. "releases") over-the-air (wirelessly) to the AI-ready computer. In this iteration of the document, the firmware will be excluded, as it pertains to the Pronto DBW system. For robotics systems like the Pronto ADS, software installation includes additional steps because the ADS software is highly interdependent with the hardware platform and, as a result, must be fully integrated with the operations of the target customer. These additional steps can be summarized as follows:

- Software and hardware cross-validation
- Configuration
- Camera calibration
- Controls tuning
- Connectivity
- Operational validation

Software and Hardware Cross Validation: Once the ADS hardware is installed, the Pronto ADS can be turned on by switching the battery disconnect and ignition switch to ON. The onboard computer, already preloaded with the latest release of ADS software, has built-in diagnostic tools that are used to check that it is communicating correctly with all the necessary hardware components. The built-in software checks include:

- Antenna installation (correctly connected to their corresponding SMA connector)
- LTE connectivity

- Radar configuration and output
- Camera streams
- IMU initialization
- Stack lights
- HMI buttons (correctly mapped to their corresponding actions)
- Communications with the DBW
- J1939 bus information
- Camera intrinsics (correctly loaded)
- Logging system

To supplement these tools, the phone app developed by Pronto can also be used to check the results of the diagnostics. In addition, the app can be used to visualize all video streams to confirm correct placement of the cameras.

Configuration: Before the Pronto ADS-equipped vehicle can start driving, the operational mode and lever arms have to be configured and validated by a qualified technician or engineer. Operational mode refers to the ADS's two functional modes: highway mode and port queueing operations. Lever arms are measurements of the sensor locations relative to a predefined coordinate system.

Operational mode is an important feature to highlight, as the two functional modes of Pronto ADS-equipped trucks have two fundamentally different safety recovery mechanisms. The e-stop system, part of the Pronto DBW, is able to switch between the modes in an assured and reliable way. When in queueing operation with a remote operator, an emergency stop must disable actuation to the truck while also ensuring that the brakes come on to prevent a runaway vehicle. However, in highway operation with a safety operator, it is critical that the truck remain in motion.

Lever arms are a fundamental part of the configuration because all vehicles share the same sensors and components but with varying placements. In order to construct a unified and accurate geometrical representation of what the perception stack "sees," a coordinate system must be defined from which each sensor location is measured. It is highly important for these to be right for correct placement of objects relative to the vehicle and accurate localization for path navigation. For the Pronto ADS, the origin of the coordinate system is at the bottom center of the compute unit installed on the Longhorn, which is also the location of the IMU. This was chosen intentionally to hedge measurement errors. The following lever arms must be measured before the ADS software is ready to operate:

- Front radar
- Front camera
- RTK GPS antenna receivers
- IMU GPS antenna receivers

At the moment, an engineer must input and validate those measurements. These lever arms are tightly coupled with vehicle controls. More details about validating these will be provided in the following subsections.

Calibration: Pronto's ADS core technology is powered by vision-based machine learning algorithms, making cameras the primary mode of perception. Just as the lever arms must be measured, camera extrinsic and intrinsic parameters must be obtained to understand the placement of objects relative to the vehicle position. Extrinsic camera parameters describe where the camera is located relative to a predefined coordinate frame (level arm from section 5.2.1.2 [Configuration]) as well as its orientation (yaw-pitch-roll). Camera intrinsic parameters describe how world points map to the image plane and also describe distortion introduced by camera lenses.

The intrinsic calibration procedure of each camera installed in a system occurs at Pronto's facility in San Francisco, and values are loaded onto the ADS onboard computer. If the calibration has not already happened at Pronto's offices, it can be done on-site. Camera extrinsic parameters are measured along with the lever arms of other sensors and antennas. The initial orientation measurement is obtained by manually driving the vehicle and using the built-in calibration tool, which uses computer vision techniques, to derive them from motion. The ADS software periodically checks and updates the orientation of the camera. No human intervention is required unless the camera has been drastically displaced from its initial location.

Controls Tuning and Validation

The Pronto ADS controls were designed to function with CMVs of different makes and models, each with its own vehicle dynamics. To quickly fine-tune the algorithms to the specific vehicle, each can be described by a set of discrete characteristics that can be measured and loaded into the ADS software. These include:

- Vehicle wheelbase
- Steering ratio
- Maximum steering wheel angle
- Compute unit location relative to the first non-steering axle
- Brake pressure calibration

All of these are part of the Pronto DBW, and these parameters will live in the ADS software and ECU firmware. More details will be provided in later revisions of this document.

Once all of these have been configured, a safety operator and an engineer will perform a closed-circuit test to confirm that the controls are behaving as intended and refine them as needed. In addition, safety failure cases will be tested to validate safety systems and procedures. Once completed for both operational modes, it is safe for the safety operator to test the system in a real-world environment.

Connectivity and Operational Validation: Once control tuning and validation have been completed for the ADS-equipped CMV, it is ready for operation. The ADS-equipped CMV will most likely be integrated into fleet management and dispatch software and will enter a regular maintenance schedule. The goal is to provide an easy-to-manage asset with high uptime and low maintenance requirements. In order to achieve this, connectivity and operational flexibility are of the utmost importance.

Connectivity is highly important for both maintenance and productivity; therefore, part of the validation process is to make sure that communications—LTE, Wi-Fi mesh networking, radio, and DSRC—are stable and highly reliable across the intended operation zone. This ensures that the individual in charge of managing the assets can quickly react to business and maintenance needs. The ADS software diagnostics (currently under development) can alert different stakeholders to evolving issues in real time, which we anticipate will prove to be key to realistic operations.

In addition, the ADS companion phone app can be used to manage the truck from any location, and technicians can use it to perform diagnostics. Part of the validation process includes verifying that the local Wi-Fi and local area networks are working, as they provide redundancy for quickly accessing and diagnosing the CMV if the primary form of communication were to fail.

5.2.1.3 ADS Maintenance Guide

Properly maintaining and routinely inspecting ADS-equipped vehicles is an important part of a fleet's ADS adoption process and is key to preventing crashes and related losses. Pronto has, from the outset of their vehicle testing program, defined and updated maintenance guidelines for ADS use that build upon the Driver Pre-trip Inspection Checklists required by the FMCSA for CMVs. Pronto has expanded these checklists to include the practical realities of operating Pronto ADS-equipped vehicles (for both highway and port queueing operations). This section summarizes the maintenance practices used in Pronto's Fleet Safety Program. This information is an example of the maintenance information that is constantly being updated to remain current with periodic changes in hardware and software.

Pronto focuses on three distinct maintenance programs: preventative maintenance, demand maintenance, and crisis maintenance. While all three have an important role in a fleet safety program, the most cost-effective is preventative maintenance. Before defining the scope of each, it is important to discuss the pillars of an effective maintenance program.

An effective and well-rounded maintenance program for ADS-equipped CMVs should include the following:

- A review of the manufacturer's specifications and recommendations for periodic preventative maintenance integrated with the actual experience of the vehicles;
- Clearly defined mileage-based service intervals consistent with manufacturer's recommendations;
- Thorough quarterly inspection by a Pronto-trained ADS technician;

- Robust analog and digital documentation practices; and
- A culture of accountability.

Pronto is committed to following a rigid, daily inspection program carried out by the drivers of highway products and vehicle operators for port queueing applications. Any losses resulting from a failure to inspect the equipment are considered grounds for disciplinary action, including termination. Mandatory inspections occur at the beginning and end of each shift. All drivers/operators must perform a pre-trip inspection prior to ADS-equipped vehicle operations.

Inspection and maintenance programs are only as good as record-keeping procedures. Drivers, operators, mechanics, and technicians need to forward all vehicle maintenance and repair records for record-keeping. Vehicle service history and inspection documentation will be stored electronically using fleet management software.

Preventative Maintenance: Preventative maintenance (PM) is performed daily and on a mileage and time basis. Typical PM inspections and services are the same for an ADS-equipped vehicle as a manual one and include fluids, filters, brakes, tires, suspension, general powertrain, and drivetrain. All regular vehicle maintenance is performed by a Pronto-trained professional mechanic or Pronto's Vehicle Maintenance Team. This includes oil changes, suspension alignment, brake service, tire service, OEM parts replacement, plus any component related to the ADS DBW and hardware platform. Only Automotive Service Excellence (ASE)-certified technicians may perform engine or transmission repair work. Only Pronto-approved technicians can perform work to the ADS DBW and hardware. The maintenance manager ensures that all technicians hold current valid ASE certifications. In addition, the maintenance manager will track manufacturer Technical Service Bulletins (TSBs) and recalls, including those issued by NHTSA. TSB and recall service is performed by the applicable manufacturer dealership or authorized service center.

Pronto drivers/operators are the first line of defense for any vehicle defects. Maintenance concerns are to be reported directly to the assigned program administrator. Drivers use a third-party app at the beginning and end of their driving shift to inspect the vehicle. Drivers also use Pronto's phone app to get feedback from the ADS's system diagnostics tools. Each vehicle has a maintenance schedule based on the manufacturer's guidelines. These intervals are traced electronically through third-party management software. In short, the PM for an ADS-equipped vehicle is almost identical to that for a traditional vehicle, and the ADS DBW and hardware do not require any specialized skills to be inspected (although they do require Pronto-approved technicians to perform maintenance work on those components). This is key for commercial fleets to be able to readily adopt ADS trucks in a mixed-fleet environment without requiring burdensome additional manpower or employee training.

Driver Pre-trip Inspection: A properly performed and thorough pre-trip inspection must be conducted by each driver/operator prior to operating an ADS-equipped CMV. For port queuing operations, the inspection should occur before the vehicle is set to autonomous mode and marked as available for work in the fleet management software. The pre-trip inspection is the same for highway and port queuing modes, as they currently use the same hardware platform. Any mode-specific item will be clearly noted in the pre-trip inspection checklist. The following steps must

be completed for each pre-trip inspection. If anything potentially unsafe is discovered during the inspection, it must be fixed immediately and verified by the assigned authority.

1. **Review Last Vehicle Inspection Report** – The driver must review the last DVIR to verify that any needed repairs were made to the vehicle. If an authorized signature certifies that defects were corrected or that correction was unnecessary, the driver may continue with the pre-trip inspection. If the defects noted were not acknowledged by an authorized signature, the driver shall not drive the vehicle until the defects are corrected.
2. **Vehicle Documentation** – The driver must verify that vehicle registration, insurance cards, and the emergency procedures document are in his or her possession (if applicable). These are to be stored in the center console.
3. **Vehicle Overview** – A general condition review of the vehicle is required. The driver will:
    - Look for damage or unusual wear to the vehicle.
    - Look under the vehicle for fresh oil, coolant, grease, or fuel leaks.
    - Check the tires for punctures, pressure leaks, and damage.
    - Verify that illumination and signal lights function as intended.
    - Verify that the fuel level is above one-quarter of a tank.
    - Verify that sensors are securely fastened.
    - Verify that the exterior is reasonably clean.
4. **ADS Hardware Overview** – A general condition review of the accessible ADS hardware components. The driver will check that:
    - The front radar is securely in place with no obvious damage.
    - The front-facing camera is still securely attached to the windshield.
    - The Longhorn and its components are securely attached and with no obvious damage.
    - The wire harnesses (from Longhorn to the interior of the cab) show no obvious damage.
    - All antennas are still in place:
        - 1 × LTE
        - 2 × RTK GNSS
        - 2 × IMU GPS
    - Stack lights are secured and show no obvious damage.
    - The rear-facing cameras are still in place with no damage.
    - The compressor hoses to the Longhorn's AC unit are connected and free of visible damage.
    - The vehicle is clean, especially since there is no buildup of excessive grime on components and sensors.

5. **Start Engine and Inspect Inside the Vehicle** – The driver will verify that the parking brake is set, start the engine, listen for unusual noises, and then check the following:
    - Gauges (oil, ammeter/voltmeter, coolant temperature, engine oil temperature, warning lights and buzzers).
    - Condition of controls. Look for looseness, sticking, damage, or improper settings (steering wheel, accelerator, brake controls windshield wiper/washer, and lights [headlights, turn signals, emergency flashers, and brake lights].
    - Condition of mirrors, the windshield, and windows.
    - Location of emergency equipment (three red triangles, first aid kit, emergency phone number list, and emergency procedures).
    - Maintenance required and check engine light.
    - Vehicle cleanliness:
        - Sensor surfaces are clean.
        - The driver will clean all lights, reflectors, and glass as needed.
6. **ADS Software Verification** – The driver will use the Pronto-supplied phone application to initiate diagnostic checks. The diagnostics run software/hardware cross-validation and report if the system is ready for operation. Any critical system that does not pass diagnostics will have to be verified by a qualified technician before the system is unblocked for use. The granularity of the diagnostics information will be filtered based on the role of the person running the inspection. The ADS software diagnostics tool will check that:
    - All required sensors and antennas are connected and in optimal condition.
    - The AC unit is running and keeping the system at a safe operating temperature.
    - All software subsystems (as described in the ADS Technology Specification document) are running.
    - The system is logging data.
    - (*In Development*) J1939 is being used to report OEM diagnostics information.
    - Connectivity is established with Pronto's servers (only required for the port queueing operations).
    - While the system is locked out and the parking brake is applied, the stack lights illuminate properly.
7. **Test Methods of ADS Disengagement** – While the vehicle is stopped, the driver will engage and then disengage the ADS using each method of disengagement and verify that the e-stop mechanism of the intended mode of operation is executed.
8. **During a Trip** – Once on the road for highway operations, the driver must examine the vehicle:
    - Before they begin driving after any stop
    - After driving for 3 hours
    - After driving 250 miles

If a problem is found, the driver must either have the necessary repairs or adjustments made prior to operating the vehicle or safely travel to the nearest repair facility. During each stop, the driver will check the following items:

- Tires, wheels, and rims
- External mounted sensors (if any)
- Lights and reflectors

For port queueing operations, the ADS will self-report problems to the fleet management system. Depending on the issue, the vehicle will stop or return to the maintenance area. If the vehicle cannot safely proceed, the appropriate person will have to be alerted and will have to lock out the vehicle, enter and disengage the system, and drive it manually to the maintenance area to be diagnosed, fixed, and validated before returning to operation.

9. **Post-Trip Inspection and Report –** Each driver is required to complete a written report on each vehicle's condition at the end of the day, or when they finish driving the vehicle for that day. The report must be completed in its entirety and the driver must note any defects to the following:
    - Parking brake
    - Steering mechanism
    - Lighting devices
    - Tires
    - Horn
    - Windshield wipers
    - Windshield and windows
    - Rear-view mirrors
    - Wheels and rims
    - Brakes and throttle
    - Emergency equipment
    - ADS hardware

The driver must also note any other defects that could affect the safe operation of the vehicle or result in its mechanical breakdown. The report must also indicate whether no defects are found. A copy of the inspection report and certification of repairs will be retained electronically. The inspection reports on which defects were noted and the certification of repairs will be retained for 3 months.

Quarterly Assessments: In addition to the periodic maintenance assessments dictated by the OEM, Pronto requires an in-depth inspection of all DBW and ADS hardware components on a quarterly schedule. The quarterly ADS hardware assessment includes the following tasks:

- Check that the bolts and screws holding the Longhorn assembly and mounts together are present and properly torqued.

- Replace the Longhorn AC unit air filter.
- Check that the compute unit is properly secured.
- Check antennas for wear and tear.
- Check that all antenna cables and connections are secure.
- Inspect the inside of the compute unit for any loose or broken parts.
- Verify the health of all data and power harnesses.
- Inspect connections to the vehicle's 12-V system for corrosion or damage.
- Verify that all camera mounts have not been damaged or displaced. If damage is found, the mount has to be replaced and the camera has to be recalibrated.
- Run built-in hardware diagnostic checks included with the ADS software.

Once the assessment is complete. The operator must test that the ADS engagement works and complete a test lap. Documentation records must be kept, and a service sticker must be placed on the vehicle's windshield with the date of the next assessment.

Demand Maintenance: Demand maintenance is performed only when the need arises. Some vehicle parts are replaced only when they actually fail. These include light bulbs, window glass, wiring, etc. Other "demand maintenance" items involve vehicle components that are worn based on information from the vehicle condition report. These include tires, engines, transmissions, universal joints, bushings, batteries, etc. Since these situations are identified through periodic vehicle inspection, they can actually be classified within the PM program. All ADS hardware components will follow the same guidelines and there is nothing unique about an ADS-equipped vehicle from a maintenance perspective.

Crisis Maintenance: Crisis maintenance involves a vehicle breakdown while on the road. While situations of this type may happen regardless of the quality of a PM program, it is an expensive alternative to not having an effective PM program at all. Crisis maintenance situations should be minimized through proper PM procedures.

In the event of a vehicle breakdown, the driver is to park the vehicle in a safe location and notify the fleet dispatcher immediately. The dispatcher and driver will coordinate with the maintenance manager to determine if a tow truck should be dispatched, if it is safe to drive the vehicle to a repair facility, or if the vehicle can be driven back to base. In the event of a vehicle breakdown, the ADS must no longer be used until the problem is fixed even if the breakdown is wholly unrelated to the ADS features.

Software Maintenance: To ensure proper ADS operation, a series of tests are performed to ensure that the ADS software is operating and updated properly.

5.2.1.4 Initial Operation at a New Deployment

After the ADS is set up, tuned and calibrated for a new deployment for the first time (see section 5.2.1.2 of this guide), the ADS must pass a series of commissioning tests to ensure that the software is performing as expected before it can be put into operation for a customer. Pronto's

practices are to first complete the commissioning tests "internally," meaning that only Pronto personnel are involved with the tests. After successful completion, the tests are then repeated with the customer representative present. During the "customer commissioning" tests, a representative of the ADS end-user fills out test notes, observations, results, and signs confirmations that the commissioning tests were successfully completed.

Pronto's commissioning tests focus on safety-critical operations of the software. They cover, among other things:

- Camera-based tests
  - Detection and proper interaction with other vehicles at different view angles for both front- and rear-facing cameras
  - Correct detection and projection of the intended path of travel for the ADS-equipped vehicle (both forward and reverse)
- Safety-system tests
  - Ensure that a command to stop ADS operations works and that the ADS cannot re-engage. This test also covers tests to ensure that the ADS-equipped vehicle is "safe to approach" by drivers or other personnel.
  - Check emergency stop operations by injecting faults into the software and ensuring the system stops properly.
  - Check a series of fault conditions (by disengaging/crashing certain software functions, hardware connections, and CAN interfaces) to ensure that the ADS properly responds to each "failure." The failures tested include, among others, a loss of GPS precision, loss of computer power, loss of camera feed(s), driving off the intended path of travel, loss of communications with a device that can order an emergency stop remotely, and broader loss of communications.
- Driving tests
  - Brake commands tests (service brakes)
  - Steer command tests
  - Path tracking tests
  - Parking brake tests
  - AEB tests

5.2.1.5 Software Updates and New Releases

Like all other software, the ADS software needs to occasionally be updated to improve performance or patch vulnerabilities. Before new versions are rolled out to ADS-equipped vehicles operated by customers, the Pronto software team first compiles all the changes/updates to be rolled out into internal release notes. The engineering team reviews the release notes and the new/updated features. They then discuss any additional tests that may be needed for this software update specifically or more generally for all future releases.

The Pronto engineering team then completes a full software "release test" at its private truck testing grounds. Notes and results are compiled in internally managed release test reports. This

ensures that the new (or improved) functionality of the ADS works as intended and, just as importantly, that the new release has not somehow unintentionally degraded other performance/functionality of the prior software release. The release tests are similar to the commissioning tests described above and have an additional focus on the newly updated features.

After successful internal completion of the release tests, the software is updated at each customer site and all of the ADS-equipped trucks operating at customer sites undergo release update testing. These are a subset of the internal release tests that cover the core safety features of the ADS software.

Although there are not yet industry-standard tests that cover ADS software performance, there are more general automotive safety system tests that can be referenced and leveraged to validate ADS performance. In developing its internal commissioning and software release/update tests, Pronto referenced and adapted several such industry standards and tests, including:

- ISO 3450, part 6, performance tests of brakes
- ISO 5010, part 6, performance tests for steering
- The United Nations Economic Commission for Europe (UNECE) and International Organization of Motor Vehicle Manufacturers (OICA) working group on advanced and autonomous emergency braking (AEB) standards and test protocols
- The European New Car Assessment Program (Euro NCAP) Test Protocols for AEB
- The Euro NCAP Test Protocols for AEB for Vulnerable Road User (VRU) protection
- The New Car Assessment Program for Southeast Asian Countries (ASEAN NCAP) Test Protocol for AEB Systems
- The Insurance Institute for Highway Safety (IIHS) Pedestrian Autonomous Emergency Braking Test Protocol (Version II)

5.2.2 Port ADS

The installation and maintenance guide in the previous section gives an overview of Pronto's approach to installing and maintaining ADS on their trucks specifically for highway systems. Considering that vehicle operations at ports can differ significantly from those on typical highways (for example, port operations may involve more queueing conditions, more turning movements, lower speed, vehicle cut-ins, more reverse maneuvers, and more interaction with non-vehicular objects), Pronto's ADS equipment was first refined to match these conditions before deployment. This ensures equipment integrity, as there are potentially more moving parts and more demand on the equipment due to the tougher or irregular operating conditions at ports. The refinement also facilitates traceability when troubleshooting, service, or repair is needed at ports. This section covers the installation and maintenance of ADS equipment including the DBW system, the RF cables and connections, cameras, seals, harness, steering, and braking systems, specifically for port operations.

5.2.2.1 Port ADS Installation Guide

Before the installation begins, the entire kit is fully bench-tested. The kit is assembled on a rolling cart with each part that will eventually be installed on the truck, including RF cables and harnesses. This allows the bring-up time for each truck to be much faster than previous installations as full system checks can be completed except for anything that requires communication with the base truck. The steps for the installation of the Pronto kit have been broken down into 18 installation guides plus a master guide, the "Global Installation Instructions." A different set of guides is required for each supported truck. These guides cover the entire installation and are as decoupled as possible, meaning that jumping between guides is kept to an absolute minimum. However, due to the current design and the nature of the complex systems that are installed, some sections require jumping between guides. A summary of the installation follows.

The DBW can be broken down into two categories. Included in the first category are actions that are only actuatable with a physical signal. That is, they are not controllable with an electronic signal. For example, the brake pedal pushes on a pneumatic valve. The pneumatic valve controls the air pressure to the braking system. There are no electronics in the loop. The second category includes everything that is controllable with an electrical signal. For example, the throttle pedal is connected to a sensor that outputs the position. This position signal is what the engine responds to. The Pronto kit needs to control things in both categories. The steering, service braking, parking, and parking brake all fall into the first category and therefore need a physical actuator added. The throttle, gear shifter, and horn are in the second category and can be controlled by the electronic signal, without the need for a mechanical actuator.

Steer-by-wire: The steer-by-wire kit affects the steering system by actuating the hydraulic steering gear. Critically, this system does not break the physical link between the steering wheel and the wheels on the ground, allowing for normal operation whenever the Pronto system is disconnected. Relevant installation guides are "2: Pronto Steer-by-wire Installation," "4: Floor Pass Through Installation," "5: Exterior Harness Installation," and "13: Internal Harness Installation."

Brake-by-wire: The brake-by-wire kit actuates a second treadle valve in parallel with the manufacturer's brakes, which, similarly to the steering kit, does not interrupt the normal operation of the truck. The brake-by-wire kit is installed inside the cab on a Pronto-designed bracket. Relevant installation guides are "4: Floor Pass Through Installation," "6: Exterior Brake Hose Installation," "16: Parking Brake Installation," and "18: Brake Box Installation."

Squid : The electronically controllable signals are intercepted by the Pronto system through the Squid, a custom ECU with a tentacle-like topology. The installation consists of mounting the ECU to a Pronto-designed bracket in the cab, routing the wiring harness to each system that is controlled, and then connecting to the base truck at each of those systems. Relevant installation guides are "4: Floor Pass Through Installation," "5: Exterior Harness Installation," "13: Internal Harness Installation," and "18: Brake Box Installation."

5.2.2.2 Port ADS Maintenance Guide

After the Installation: To facilitate traceability, we implemented as-built forms. This form documents each installation with very specific photos. It will be designed to capture any deviation from the standard procedure to inform any future maintenance or troubleshooting. The system is designed to reduce the regular maintenance that is required. For instance, thread locker and proper torque for screws are called for in the initial installation. However, there are a few items that should be serviced regularly.

RF Connections: Over time, the RF connections may come loose even though they have been installed with thread locker and torqued appropriately. Check these connections every shift by hand. If any have become loose, retighten to the recommended torque (0.6 Nm for SMA connections, 2.2 Nm for N-type connections). Note that a special torque screwdriver and crows foot attachment must be used. Overtightening can permanently damage the connector and therefore the cable. Note that the RF connections at the GPS cable should also be checked. Relevant installation guides are "8: Front Camera Installation," "9: Rear Camera Installation," "12: RF Harness Installation," and "17: Compute Box And Mount Installation."

Cameras: The front camera is placed such that the windshield wipers will clean the glass in front of the camera lens. However, the rear camera is not. The rear windshield should be cleaned as often as needed to keep a clear view in front of the camera. This should happen at least once a shift but as often as necessary. If the front camera design does not have a baffle, then the glass on the lens itself should be cleaned periodically. For example, the front camera on the day cab trucks does not have a baffle. To clean the lens, use any glass cleaning wipe. Relevant installation guides are "8: Front Camera Installation" and "9: Rear Camera Installation."

Seals: The polymer seals that are used should be checked every 6 months. For example, on the GPS and LTE antenna installation on the 579 Day Cabs, sealant is required on some of the bolts into the roof of the cab. Relevant installation guides are "10: GPS & LTE Mount Installation" and "11: Snorkel Installation."

Harness Routing: With proper installation, the harnesses should be relatively maintenance free. To ensure proper installation, after 4 weeks of operation, the harness routing should be checked for any signs of damage from rubbing components, heat, or exposure. Replace, reroute, and protect as necessary. There are a couple of items which may need replacing after 6–12 months of operation. Specifically, check the adhesive zip tie mounts on the roof and back of the cab used to secure the RF and SVD cables respectively. Relevant installation guides are "5: Exterior Harness Installation," "12: RF Harness Installation," and "13: Internal Harness Installation."

Steering: As part of the installation, wedgelock washers (name brand Nordlock) are used on safety-critical and/or high-vibration bolted connections. The steer-by-wire installation uses these washers on the mounting points to the bracket. As part of the pre-trip inspection, the pinch bolts on the shaft (using deformed thread lock nuts) and the bolts connecting the actuator to the bracket should be visually inspected. Torque stripe is used after torquing the bolt to the appropriate torque. This allows for a quick visual inspection to see if any bolts have loosened. Relevant installation guide is "2: Pronto Steer-By-Wire Installation."

Braking: The brake-by-wire system requires greasing at two different locations inside the brake-by-wire enclosure. The plunger that contacts the treadle valve slides through a bronze bearing. White lithium grease should be used every 3 months on this sliding joint. With the plunger fully retracted, apply a pea-sized amount of grease (Loctite® LB 8042 White Lithium Grease) to the plunger with a gloved finger. Smooth out over the cylindrical surface. Additionally, the ball screw jack also requires regular greasing. There is a zerk fitting accessible once the brake enclosure is opened. Use Mobilgrease XHP222 every 6 months. The maintenance intervals for this item are still being fine-tuned, so this may change. Relevant installation guides are “6: Exterior Brake Hose Installation,” “16: Parking Brake Installation,” and “18: Brake Box Installation.”

RF Cables: RF cables are used in some of the most critical components of the Pronto system. Care must be taken during the installation process to not kink any of the cables. If any cable is suspected to have been damaged during operation (pinched, kinked, abraded, etc.) then the cable must be replaced. Regular maintenance is not required. Relevant installation guide is “12: RF Harness Installation.”