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

Chapter 1: Executive Summary

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Abstract

The primary goals of the CONOPS project were to: i) collect information and practices on how to safely integrate ADS-equipped CMVs into the U.S. road transportation system; ii) provide the USDOT with data; iii) demonstrate how to integrate and deploy ADS-equipped trucks in a productive and cooperative way into the existing road freight ecosystem; and iv) collaborate with a broad and diverse group that includes government entities, university and research institutes, trucking associations, and private partners. This research found that the path forward to maintain public acceptance and achieve goals of ADS-equipped CMV operational cost-effectiveness, increased freight productivity, and reduction of crashes is through human operational assurance of vehicle, automation, freight, and public safety through specification, maintenance, inspections, monitoring, insurance, metrics, roadway assessment, and secure communications, as well as continuous lifecycle performance checks

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

1. EXECUTIVE SUMMARY

Automated Driving Systems (ADS) are set to revolutionize the transportation system. In this project, we developed and documented a concept of operations (CONOPS) that informs stakeholders, decision-makers, and all interested personnel in the trucking industry on the benefits of ADS and the best practices for implementing this technology into fleet operations. The project was completed with a focus on three crucial aspects of implementation. The first focus was to demonstrate the applications of ADS technology in day-to-day truck-driving tasks to fleet personnel and the general public. The idea behind this was to provide personnel with a first-hand experience with ADS and to showcase how this technology can improve truck driving safety, support drivers, reduce human errors, and optimize fleet operations. The research team also used this opportunity to collect information on personnel expectations of ADS technology and what applications of the technology would be attractive to their operations. The second focus of the project was to document how ADS technology can be customized to support fleet operations under specific trucking use cases such as port queuing conditions, over-the-road trips, and fleet integration, and to collect data that inform policymakers on the readiness of existing infrastructure to support the implementation of ADS technology on U.S. roadways. The third focus of the project was to pool information on the existing practices of various stakeholders involved in the ADS ecosystem and use this information to provide fleets with guidelines on how to manage implementation and policy issues related to ADS technology. A high-level summary of the insights from the research activities based on these focus areas is provided here.

1.1 PUBLIC DEMONSTRATIONS OF ADS TRUCK TECHNOLOGY

The research team engaged personnel in the trucking industry at three major public events, the Intelligent Transportation Systems (ITS) America annual meeting, the Technology Maintenance Council (TMC) annual meeting, and the Commercial Vehicle Safety Alliance (CVSA) annual conference, of which many of the attendees were from the trucking industry. The first public outreach at the ITS America annual meeting, held in December 2021, featured exhibition booths, presentations, technical sessions, one-on-one question and answer sessions, and real-time displays of an ADS-equipped truck deployed in this project actively operating on U.S. roadways. Attendees were given an interactive behind-the-scenes look at ADS-equipped truck cross-country trip operations as well as the port queuing deployment use case to showcase the safe deployment of ADS technologies under real-world fleet operating conditions. Readers can go to section 2.1 of this document for more details on this outreach. Other resources can be found in the research brief summarizing activities at the meeting (https://www.vtti.vt.edu/PDFs/conops/ITS-Roadshow.pdf).

The TMC annual meeting, held in March 2022, featured similar research activities as the TMC meeting described above. However, the research team took a step further to provide on-site demonstrations of an ADS-equipped truck operating under simulated safety-critical roadway conditions such as work zone driving. The team provided attendees with the opportunity to ride along in an ADS-equipped truck to have a first-hand experience of the technology. This not only allowed the team to showcase the importance of ADS technology to fleet operations but also collect information directly from stakeholders in the trucking industry (fleet, suppliers, government personnel, maintenance/analytics personnel, manufacturers, inspection/law enforcement agents, and many others) on their expectations of the technology and potential future use case demonstrations of ADS technology. This provided crucial information on the steps towards increasing fleet interest in the technology. The team found that the existing public perception of ADS technology is generally positive. More interestingly, a before-and-after survey provided to attendees showed that the perception and acceptance of the technology improved after their first-hand experience of the technology. However, attendees who participated in the demonstration further requested future specific use case demonstrations. Sixty-two percent of the attendees requested future demonstrations on ADS application to Automated Trailer Parking, 43% requested demonstrations on Truck Platooning and on Intermodal Yard, 35% requested demonstrations on Lane Keeping Assist, 25% requested demonstrations on Exit-to-Exit, 22% requested demonstrations on Truck Teleoperation, and 14% requested demonstrations on Queueing Operation. Future work is needed to address these requests. Readers can go to section 2.2 of this document for more details on this demonstration. Other resources, including the research brief summarizing activities at the meeting (https://www.vtti.vt.edu/PDFs/conops/TMC-Roadshow.pdf), video showing the ride and drive in an ADS-equipped truck (https://youtu.be/djWIsFFWw08}, and video showing conference activities and stakeholder interviews (https://youtu.be/eBnlxkS7i_4) are also available publicly using the associated links.

The final outreach was held at the CVSA Annual Meeting in September 2023. The primary activity demonstrated how ADS developers are implementing the CVSA Enhanced CMV Inspection Program within their operational policies and procedures. The Virginia Tech Transportation Institute (VTTI) sponsored a CONOPS booth in the exhibit hall that was staffed by project personnel for the duration of the conference to support the Enhanced CMV Inspection Program demonstration. Project personnel spoke to attendees who visited the booth about the CONOPS project and how the CVSA Enhanced CMV Inspection Program and Electronic Roadside Communication activities supported the CONOPS goals. VTTI drove their newly refurbished Peterbilt truck and the CONOPS trailer to Texas and showcased it in the CVSA exhibit hall for the demonstration. VTTI also partnered with Kodiak Robotics to demonstrate their procedures for implementing the Enhanced CMV Inspection Program within their fleet and daily operations. This allowed attendees to consider questions they may want to address to better understand the program. The second element of the outreach included a joint partner presentation to give ADS developers, OEMs, and fleets an opportunity to share their experiences with the Enhanced CMV Inspection Program and certification and training process. Readers can refer to section 2.3 of this report for a full report on this outreach event. Additional information can also be found using the following links: research brief summarizing ADS-equipped truck's inspection procedures (https://www.vtti.vt.edu/PDFs/conops/ADS-CVSA-Brief.pdf) and video showing the ADS-equipped truck's inspection procedure and interviews (https://youtu.be/rcgJYd_gDnA).

Feedback on lessons learned from these events was also distributed on a rolling basis at various other academic conferences. The VTTI team attended over 20 conference sessions, sharing information about the project as it was obtained.

1.2 ADS-EQUIPPED TRUCK DEPLOYMENT FOR FLEET OPERATIONAL USE CASES AND DATA COLLECTION

As part of the CONOPS effort, ADS-equipped trucks were deployed for three operational use cases. This research effort is detailed in section 3.1. The aim was to explore and showcase how ADS-equipped trucks can be customized for specific fleet use cases and to collect data on the readiness of existing infrastructure on U.S. roadways to support ADS implementation. The fleet use cases were port queuing, cross-country trips (similar to over-the-road operations), and fleet integration.

The port queuing use case was deployed at the Port of Oakland in California. This use case focused on refining ADS technology for loading and unloading operations in port queuing operations. During this use case the research team collaborated with Pronto, an ADS technology developer, to refine their driving algorithms to account for the unconventional behaviors of other drivers (such as speeding and cut-ins) at ports. Pronto modified the ADS behavior to include reduction in transition time (from being stationary to reinitiating motion when the queue resumed), maintaining tighter gaps with preceding vehicles, and improving object detection and tracking to prevent collision during aggressive low-speed cut-ins from surrounding vehicles. Following fine-tuning, the research team operated and showcased the ADS-equipped truck delivering containers for five days. A live stream was provided to attendees at public events as reported in the previous section. During this deployment period, over 50 GB of data was generated. This part of the research effort is detailed in section 3.1. The data is publicly available on the CONOPS Dataverse developed for this project by VTTI. Interested readers can find more details on this use case using the following links to access the port queuing operations data (https://dataverse.vtti.vt.edu/dataset.xhtml?persistentId=doi:10.15787/VTT1/ZYMSEM), video showing the queuing demonstration (https://www.youtube.com/watch?v=DCs8uGJAuks), and a research brief summarizing the port queuing activities (https://www.vtti.vt.edu/PDFs/conops/Port-Queuing-Brief.pdf).

For the cross-country trips, the team deployed ADS-equipped trucks on select routes to collect data on the readiness of the existing infrastructure to support ADS technology. The five routes were selected to cover states across the country with various roadway classifications, terrains, weather conditions, and times of day. The first trip was a round trip from California to Texas, the second was from Calgary, Canada, to California, the third was a round trip from California to Florida, the fourth was a nationwide cross-country loop, and the final trip traversed routes that linked California, Oregon, Washington, Idaho, Montana, Wyoming, Utah, Arizona, Nevada, and back to California, in that order. This part of the research effort is detailed in section 3.2. The team deployed various sensors on the ADS-equipped truck to collect real-time data on the infrastructure required for the technology to function optimally, such as lane marking quality, Global Positioning System (GPS) strength, availability of cellular connectivity, and road condition. Data from this deployment was used to develop a road readiness rating system that provides a detailed evaluation of the infrastructure required to support ADS trucks on each roadway section traversed. This is especially useful for government agencies and decision makers, both at State and Federal levels, that are interested in utilizing truck automation technologies. The data is publicly available on the VTTI CONOPS Dataverse (https://dataverse.vtti.vt.edu/dataset.xhtml?persistentId=doi:10.15787/VTT1/ZYMSEM). Interested readers can find more details including the cross-country deployment data (https://dataverse.vtti.vt.edu/dataset.xhtml?persistentId=doi:10.15787/VTT1/ZYMSEM), video showing the cross-country deployments (https://www.youtube.com/watch?v=DCs8uGJAuks), and a research brief summarizing the cross-country deployments (https://www.vtti.vt.edu/PDFs/conops/Cross-Country.pdf) using the associated links.

The fleet integration use case was conducted at the Whittier port in Alaska. The goal of this task was to thoroughly define the organizational elements as they exist at an operational level to better understand the implications of introducing ADS into an intermodal fleet operating heavy trucks for repetitive driving actions on a private yard—in this case between a barge and rail cars. This goal was accomplished by collecting relevant observational and interview data and using those data to perform various task, risk, and organizational systems analyses. The objective for the approach was to establish a baseline evaluation of the organization at the operational level for future use in identifying the impacts of incorporating automated vehicles (AVs). The analyses address both organization- and person-level elements and relate those across a macrocognitive model for human involvement within their tasks and roles. This part of the research effort is detailed in section 3.3.

1.3 GUIDELINES ON IMPLEMENTATION AND POLICY ISSUES FOR ADS-EQUIPPED TRUCKS

To develop a comprehensive understanding of the present practices regarding ADS implementation and policy issues for fleets, the research team consulted with various stakeholders involved in ADS technology development. This included technology developers, insurance agencies, commercial motor vehicle (CMV) safety agencies, inspection agencies, and cybersecurity experts. Information was pooled from these sources to provide fleets with guidelines on how to navigate each of these issues. The CONOPS includes eight key sections: Fleet Specifications, Installation and Maintenance, Inspection Procedures, Driver State Monitoring, Insuring ADS-Equipped Trucks, ADS Safety Metrics/Variables, Road Readiness Rating System, and Data Transfer and Cybersecurity. Below, we provide a high-level description of the focus of each section. Each of these is documented in detail in chapter 5 of this report. It is recommended that readers treat each section as a stand-alone guide that addresses different aspects of ADS implementation and policy concerns.

The ***Fleet Specifications*** guidelines are provided in section 5.1. Considering that the adoption of ADS technology by fleets is more likely to be a gradual process rather than a one-time, full-scale adoption, the research team took an industry-first approach and conducted discussions with truck industry partners regarding the use cases that have the most appeal to truck fleets. The goal of this task was to identify the most desirable set of use case specifications for fleet users to support the development of the fleet ADS. This was to ensure that truck fleets specified their needs as a function of their real-world operational experiences and that guidelines provided on integrating ADS would meet those needs. Based on the discussions held by VTTI with fleets, three use cases were identified and research was conducted to understand stakeholder expectations of ADS technology in these use cases. Further, various systems such as safety equipment, electrical components, batteries, sensors, controls, and displays on conventional trucks that may require special consideration towards the integration of ADS technology for these use cases were outlined and practices on how these are handled were provided.

ADS Installation and Maintenance guidelines are provided in section 5.2. 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 makes and models equipped with a range of driving automation systems that assist drivers or carry full responsibility for sustained control and monitoring. The research team developed this section to serve as a 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. This section provides two separate installation guides and related maintenance practices for each system demonstrated in this project. The first system was developed to support operations on public highways (as demonstrated with the port queuing cross-country deployments). The second system was developed to support operations in limited geofence private yards or ports (as demonstrated with Fleet Integration). The section gives a product-focused overview of the installation process of an ADS developer, Pronto, 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 validated in different CMV makes and models.

ADS Inspection Procedure guidelines are provided in section 5.3. The development of vehicle automation and ADS show potential for significant safety improvements. However, there will be a need to inspect the vehicle and its systems that operate without a driver onboard to ensure proper performance and safety. This creates a challenge for the National Highway Traffic Safety Administration (NHTSA), Federal Motor Carrier Safety Administration (FMCSA), and the CVSA to create policy and inspection procedures to ensure the safety of both CMVs and the motoring public. VTTI reviewed the Federal Motor Carrier Safety Regulations (FMCSRs) and the existing research literature to better understand the current state of practice regarding truck inspections and the implications of driverless vehicles. In conducting the literature review, the study team searched various terms related to truck inspections—roadside, pre-trip, Driver Vehicle Inspection Report (DVIR), periodic, and the link between mechanical failures and truck crashes. Additionally, the VTTI study team interviewed nine experts involved in motor carrier enforcement, motor carrier safety, and ADS technology development to better understand the challenges that ADS-equipped vehicles pose to existing truck inspection processes, to identify the changes needed in the FMCSRs, and to identify alternative truck inspection procedures. The section also provides insights into the enhanced CMV Inspection Program by CVSA specifically for ADS-equipped trucks. Lastly, recommendations, next steps, and future areas to consider are highlighted.

Driver State Monitoring guidelines are provided in section 5.4. Safety operators (or safety drivers) supervise the performance of prototype Level 4 (L4) ADS-operated vehicles in on-road traffic for testing purposes. Their role is to respond to unexpected events in case an ADS, on rare occasions, executes an incorrect or unsafe driving maneuver. Hence, ensuring the driver is actively engaged with the vehicle operations while the ADS is active is of utmost importance. Present practices involve implementing in-vehicle technologies that monitor driver states in real time and can nudge a driver when alertness or attention to the ADS is compromised. In this section, we document the state-of-practice on driver state monitoring (DSM). DSM systems are designed to track metrics (i.e., physical, physiological, psychological, and/or behavioral variables) that may be indicative of driver inattention or inability to react appropriately. First, we document some of the performance indicators used for monitoring driver states, including distraction, impairment, drowsiness, mental workload, and emotions. Then, we conducted a technology scan to identify commercially available DSM technologies that could be used to assess the ability of a safety operator to take over control of an ADS-equipped CMV during a planned or unplanned ADS disengagement. This technology scan established what DSM technologies and systems are available and their functions, capabilities, limitations, and use cases when integrated and applied with ADS operations. Further, the research team conducted interviews with personnel from two critical sectors involved with ADS technology: ADS developers and DSM technology providers. The interviews gathered information about the integration of DSM into ADS-equipped CMVs through questions about barriers to integration, roles of a safety operator, and current use of DSM technology. Finally, a pilot study was conducted to explore the capabilities of two DSM systems by documenting possible shortcomings and by exploring how effectively a state-of-the-art DSM system meets the needs of safety operator monitoring. Findings in this section inform stakeholders on the existing practices and capabilities of DSM systems and identifies future research directions.

Guidelines on ***Insuring ADS-Equipped Trucks*** are provided in section 5.5. In this section, we focus on insurance practices involving AVs in general, with specific consideration for heavy vehicles. The section was to answer questions on what the current and future AV trends are, how auto insurance will meet society's needs in an AV world, and what the critical insurance-related components for AV regulation are. A comprehensive review of publicly available information on insurance policies for AVs was conducted. The materials reviewed were based on resources from the Travelers Institute, an education and public policy division of The Travelers Indemnity Company, a home, vehicle, valuables, and business insurance provider. Most of the information herein was released in a position paper published by Travelers in January 2021 titled, "Insuring Autonomy: How Auto Insurance Will Lead Through Changing Risks." We examined the discussions in the paper and modified the findings and conclusions to focus on trucking fleets. We also provided insights based on a technical session hosted by the S.18 Automated Vehicles Study Group at the TMC annual meeting on February 28, 2023. It should be noted that the information and positions stated in this section are shared to inform the developing conversation about insuring AVs. The information is based on the publicly available resources mentioned and is not necessarily representative of positions held by VTTI or the U.S. Department of Transportation.

Guidelines on ***Identifying Truck Safety Metric/Variables*** are provided in section 5.6. Traditional safety metrics, such as crashes and moving violations, may be inadequate for monitoring the performance of ADS-equipped trucks once they are deployed or for convincing the public of the safety of these technologies. In this section, we conducted an extensive literature review to identify potential variables that might be used by fleet decision-makers and the public to evaluate the safety of the ADS. We also examined the data required to assess the safety of an ADS before implementing ADS-equipped vehicles into their operations and to monitor ADS performance when deployed. Our findings revealed two major categories of safety metrics: lagging metrics and leading metrics. The lagging metrics, such as incidents per vehicle counts, year-over-year number of vehicle crashes, and incidents per million miles, are often used to measure system safety performance after deployment. They measure incidents based on the continuous operation of the ADS. Hence, they are poor measures for preventing safety incidents. On the other hand, the leading metrics (such as near-crash events, disengagements, traffic violations, and safety envelope violation) are good indicators for future events and they measure activities carried out to prevent and control safety incidents. These metrics are proactive and provide information on how the ADS is performing on a regular basis. We identified the application of both categories of safety metrics and how it can be used to inform policy making.

ADS Road Readiness Assessment guidelines are provided in section 5.7. In this section, we developed and documented a basic road readiness assessment system for ADS-equipped trucks using the cross-country deployment datasets. The idea is to use this system to distinguish roadways that are suitable for the operation of ADS-equipped trucks from roads that are not, in which case intervention by a human operator may be needed. The system was developed using a combination of roadway infrastructure data and the ADS-equipped vehicle's perception of the roadway conditions based on its kinematics. Understanding that the operation of ADS technology across various developers is not homogeneous and may differ in terms of the systems and algorithms used to develop them, an advanced road readiness system was also designed to be flexible enough such that future applications are adaptable to specific ADS developers' proprietary algorithms. This advanced system was designed as a variation of the basic road readiness system. The section further demonstrated how the systems can be applied to U.S. interstate highway systems using the data collected by Pronto, an ADS developer. As a first step towards ADS implementation, government agencies can also evaluate their State roadway system using the road readiness system developed in this section. Recommendations and next steps are also provided to stakeholders on preparing U.S. roadways for ADS trucking operations.

Data Transfer and Cybersecurity guidelines are provided in section 5.8. Like many new technologies, ADS development continues to evolve at a rapid pace, especially regarding cybersecurity. This section provides detailed information on data transfer and cybersecurity topics that are directly relevant to end users who adopt ADS technologies. More specifically, the focus is on cybersecurity from the point of view of an ADS-equipped CMV fleet as opposed to an ADS developer. General guidelines for understanding cybersecurity, how mixed fleets (both conventional and automated trucks) and cybersecurity relate to each other, and how fleets should tailor these guidelines to meet their specific systems are provided. The section addresses cybersecurity topics from a unique angle that has not previously been studied in detail and is continuously evolving. As such, this section does not focus on technical details for implementation. Rather, it is best viewed as a starting point for CMV fleets and other audiences with a general interest in the practical, real-world implementation of cybersecurity measures in ADS deployment. The section goes into more detail on various possible vulnerabilities in an ADS environment, potential security challenges for ADS-equipped CMVs, and challenges of mixed fleets. We also discuss various security aspects to consider such exposure, access, security assurance, failure and recovery, emergency action plan, life cycle, and those involving data transfer such as storage, processing, sharing, logging, and auditioning. We wrap up the section with insights on best practices for fleet cybersecurity to protect their ADS technology from various potential sources of cyberattacks.