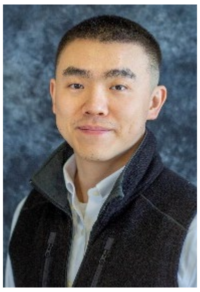
TOWARDS THE DEVELOPMENT OF A TRUCKING FLEET CONCEPT OF OPERATIONS (CONOPS) FOR MANAGING AUTOMATED DRIVING SYSTEM-EQUIPPED TRUCKS IN MIXED FLEETS





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Abstract
More than 70% of goods in the United States are delivered by truck; thus, the introduction of automated driving systems (ADSs) on heavy trucks will have a profound effect on commerce. However, existing stakeholders in the road freight ecosystem do not have a clear picture of how they will implement ADSs in daily operations. At present, technical progress is outpacing the ability of truck fleets to plan for ADS deployment. This adversely affects adoption by truck fleets and associated industries, potentially delaying the safety, productivity, and efficiency benefits of ADS-equipped trucks. To support ADS integration, current stakeholders and new entrants need a rigorous, data-driven Fleet Concept of Operations (or CONOPS). A CONOPS provides fleets, and those who work with fleets, a "how to" manual, comprised of multiple "pillars," to support the integration of ADS technology into their existing operations. This paper highlights several pillars that have not been well-researched but are critical to the success of ADSs in trucking: Installation and Maintenance, Inspection Procedures, Driver (Safety Operator) Monitoring, Insurance, Safety Metrics, Road Assessment, Data Security, and Cybersecurity. This paper will provide an overview of the project and highlight these key pillars.

Keywords: Automated, Driving, Truck, Safety, Operations, CONOPS

1. Introduction

The introduction of Automated Driving System (ADS) technology on heavy trucks (Class 8 vehicles) will profoundly affect all commerce in the U.S., as the country moves more than 70% of its goods by truck. However, existing stakeholders in the road freight ecosystem (primarily for-hire and private truck fleets, but also shippers, brokers, truck manufacturers, and service and maintenance providers) do not have a clear picture of how they will implement ADSs in their daily operations. At present, technical progress in this nascent but promising technology is outstripping the ability of truck fleets to keep up and plan for ADS deployment, which may adversely affect adoption by truck fleets and associated industries, resulting in the delayed achievement of safety, productivity, and efficiency benefits of ADS-equipped trucks. As such, the trucking industry, and those who interact with it, need guidance on *how* to safely implement, and benefit from, ADS-equipped trucks. If ADS technology is to gain traction in the U.S. trucking industry, current stakeholders and new entrants into the trucking industry and its related fields need a rigorous, data-driven Concept of Operations (CONOPS).

As we are defining the term, a CONOPS is a comprehensive document that describes ADS characteristics from the viewpoint of truck fleets, and those who interact with truck fleets, that will use the technology. As shown in Figure 1, the CONOPS includes seven key pillars: ADS Installation and Maintenance Guide, ADS Inspection Procedures, Driver-Monitor Alertness Management, Truck Fleet Guide to Insuring ADS, ADS Safety Metrics/Variables, ADS Road Assessment System, Data Security/Transfer Protocol & Cybersecurity. In addition to these seven pillars, several Operational Use Cases and Demonstrations will be conducted to highlight the implementation of ADS-equipped heavy vehicles.

Figure 1 – CONOPS is envisioned to comprise multiple pillars, each supporting a functional area in the ADS freight ecosystem.

The remainder of the paper provides context on each of the key pillars, as follows:

ADS Installation & Maintenance Guide: Procedures for installation and maintenance, including systematic maintenance, are critical before ADSs are introduced into the market. The need for systematic maintenance will be elevated for trucks that are expected to remain in motion more hours every day, well beyond the boundaries of driver hours of service.

ADS Inspection Procedures: In 2018, the Commercial Vehicle Safety Alliance (CVSA) Enforcement and Industry Modernization committee, supported by the Federal Motor Carrier Safety Administration (FMCSA), established a working group to address the inspection process of ADS-equipped trucks. The need for thorough inspections before and after ADS-equipped trucks leave their hubs and yards will be more important than ever when humans are not onboard.

Driver-Monitor Alertness Management: As ADS technology has improved, the need to monitor against driver inaction and boredom has increased. All state-of-the-art ADS test and development programs will need to require that their test operators remain continuously attentive.

Truck Fleet Guide to Insuring ADS: To support this pillar, the Travelers Institute developed a publicly available document to guide the industry on this topic. https://www.travelers.com/travelers-institute/autonomous-vehicles/insuring-autonomy.

ADS Safety Metrics/Variables: Identifying key safety metrics for ADS operation will be instrumental to informing rulemaking and ensuring safe operation. Many parts of the commercial motor vehicle (CMV) industry today are focused on the time when ADS developers will be able to show that their vehicles can safely operate without test drivers onboard.

ADS Road Assessment System: This pillar focuses on the infrastructure characteristics most conducive to reliable ADS operation. It will consider the balance of ADS-equipped system capabilities and typical elements of good highway road design.

Data Security/Cybersecurity: Intended for everyone involved in data collection/security/storage/transfer-related tasks, this protocol will serve as a guideline to understand how data should be handled safely. The output of this task will describe how to transfer and store data safely and assist in identifying weak links in the data workflow process.

Operational Use Cases, Demonstrations: In addition to the seven pillars highlighted, three real-world ADS implementations are being conducted to demonstrate how ADSs can be integrated into a mixed-fleet operation and to generate data to support the ADS dataset, described below. These demonstrations (year) include port queuing (2021), cross-country freight corridors (2021–2022), drayage (2023), and public highway operation (2024).

2. ADS Installation and Maintenance

Today's CMV fleet equipment managers are commonly confronted with a broad range of choices when specifying new truck-tractors and trailers for purchase from manufacturers, including aerodynamic fuel-saving components, collision avoidance driver assistance safety features, and driver comfort features. After purchase, they are faced with the need to add aftermarket equipment—such as onboard monitoring systems, inspection by-pass systems, electronic driver logs, and freight tracking—to improve efficiency and safety. In the future, fleet managers may need to consider how to specify for ADS-equipped truck-tractors operating in tandem with their conventionally specified trucks.

The purpose of this CONOPS section is to inform fleets and service providers of conventional CMVs about the hardware and software components required for ADS-equipped CMVs and prepare fleets with guidance and a collection of practices that cover installation, preventative maintenance/calibration, and repair. The primary implementation for the ADS developer who partnered in this research is based on a retro-fit installation on truck-tractors after the vehicles have been manufactured and delivered to the fleet or operating authority.

From the perspective of the system installation, the ADS is divided into three layers: drive-by-wire (DBW), ADS hardware, and ADS software. The DBW includes the following vehicle–control subsystems: steer-by-wire, brake-by-wire, throttle control, transmission control, and instrument cluster functions (i.e., turn signals, warning lights, headlights, etc.). An important consideration for the DBW controls is redundancy. ADS developers and manufacturers are focusing on redundancy to ensure that if the primary control fails to complete its task, a secondary control will assist and complete the task instead. The reason for this redundancy is to ensure safe and reliable operation without humans onboard.

The ADS hardware assemblies that make up the retrofit upgrade kits are organized into modules for staggered installation to reduce the time that each fleet owned truck-tractor is out of service between transition from conventionally human- to ADS-driven operation. This is an important consideration for fleets that may have limited vehicle resources and cannot afford to order extra truck-tractors to put in reserve until they can be equipped with an ADS and rotated in for conventionally operated trucks. The ADS software serves three functions: (1) to aggregate information from the vehicle sensors about the vehicle's surroundings, (2) to extract contextual and semantic meaning from the environment/surroundings, and (3) to make driving decisions within a predefined scope of operations that are translated to DBW vehicle actuations.

This section also identifies specifications of conventional truck components that may support smoother retrofit integration with ADS hardware. Finally, this portion of the CONOPS provides information on practices to calibrate and maintain ADS components. To support the collection of information, a literature review of Engineering and Maintenance Practices from the American Trucking Associations' (ATA's) Technology and Maintenance Council (TMC) and SAE Recommended Practices was performed. Included in this review were recommended practices that cover specifications and processes for installation, specification, and maintenance or repair of sub-systems, assemblies, and components of existing conventionally controlled vehicles that interface with ADS equipment on CMV.

3. ADS Inspection Procedures

ADS-equipped CMVs transfer the burden of operational safety away from human drivers and onto the equipment and its responsible carrier department of transportation (DOT) authority in a number of ways. This is true in many aspects in addition to just driving responsibility. Among conventionally equipped truck-tractors and their coupled trailers, the responsibility for the state of the equipment is spread across the truck-tractor carrier, trailer carrier, and the driver. Cases of owner-operators who drive and maintain sole DOT authority stand in contrast from large fleets with dedicated repair and maintenance programs, staff, and facilities. Whatever the CMV operation type of conventionally equipped trucks, it is up to the onboard human driver to decide if the truck–tractor and trailer combination is fit for duty before operating on public roads. Furthermore, it is the role of CVSA-trained inspectors to check the CMVs at roadside to identify if the truck-tractor and trailer is violating any design or maintenance requirements, or even worse, out-of-service criteria requiring immediate repair before returning to service.

However, it is anticipated that ADS-equipped CMVs will not be subject to roadside inspections so as to avoid risks of interactions with pedestrian inspectors and other unpredictable roadside scenarios. Therefore, another model is needed to ensure the equipment is well maintained and will not pose a risk to other traffic while operating on highways and between off-highway hubs. To answer this need, in September 2018, the CVSA Enforcement and Industry Modernization Committee, in cooperation with FMCSA, established an Automated CMV Working Group to address the inspection process for ADS-equipped trucks. Later, the ATA proposed the creation of a new task force to examine the inspection of ADS-equipped vehicles. This task force drew from the fleet maintenance, component supplier, and ADS provider communities within ATA's TMC and partnered with CVSA's Automated CMV Working Group to create a report exploring consensus-based approaches to inspection and enforcement.

The result is an Industry Enhanced Inspection program where representatives from the operators of ADS-equipped CMVs are trained to certify and ensure defect-free operations at dispatch and at in-transit vehicle fuel or service stops. This defect free self-certify inspection model is built upon existing industry practices: pre-trip driver inspections across 23 component zones of the CMV, parking lot dispatch and in-transit inspections of motorcoaches, the highest federal inspection standard criteria in North America (i.e., Canadian regulations), and CVSA roadside inspector-level training and testing for identifying CMV regulatory defects.

The CONOPS research team will explore this program to identify the latest recommendations for the self-certification training. The research team will also be monitoring how industry and government coordinate the inspection of non-conventional equipment like sensors and onboard fault systems on ADS-equipped vehicles. Another inspection issue that will be tracked by the research team involves the electronic messaging to roadside stations about the inspection status, load, and health of the ADS. Finally, the team will consider the future of enforcement interactions where safe ADS operation will need to include a process whereby enforcement agents can safely signal and pull over an ADS-equipped CMV for emergency reasons.

4. Driver-Monitor Alertness Management

As higher-level ADS-equipped CMVs are tested on public roadways, the need for safety operators who can quickly react to takeover requests, mechanical malfunctions, or other safety-critical events becomes imperative. Safety operators must remain attentive even as the ADS controls all vehicle operations. As this technology improves further, and fewer takeovers are required, the need to monitor these safety operators for inattention, hypovigilance, and boredom increases. Driver state monitoring (DSM) systems are an opportunity to monitor these operators to ensure their attention is on the monitoring task and/or that their physical/mental state is conducive for a high vigilance task. However, common metrics for many DSM systems are vehicle-based and determine a driver's state based on driving performance (i.e., lane departures, speed variation, etc.). In higher-level automated vehicles, the vehicle is assumed to have control over longitudinal and lateral functions; therefore, these functions would not be influenced by driver state. For this reason, DSM system capabilities need to be investigated to understand their future integration with ADS-equipped vehicles and their ability to effectively monitor a safety operator without vehicle-based metrics.

For ADSs to gain acceptance in the U.S. trucking industry, it is critical to understand the impacts of safety operators and the way their performance is monitored. The purpose of this section is to define the capabilities of DSM systems to give stakeholders in ADS and DSM technologies an understanding of the role DSM systems can play in ADS-equipped CMVs. Additionally, it serves to examine whether state-of-the-art DSM technology can effectively monitor a safety operator given the operator's specific responsibilities.

To assess these capabilities, a three-phase study approach was used. Firstly, an information collection phase, leveraging a literature review and technology scan of DSM systems, was conducted. The resulting report outlined relevant metrics of DSM technologies in the context of supporting ADS applications such as driver state metrics (i.e., drowsiness, distraction, substance impairment, etc.) and evaluation criteria for an effective DSM system.

The second phase involved interviews with ADS developers and DSM technology providers as well as a survey sent to carriers. DSM technology provider interviews allowed an understanding of the potential benefits and challenges with integration such as technology capability, future features of the systems, and barriers to implementation. The ADS developer interviews gave insight to the role of the safety operator being monitored, as it is unclear whether current features of DSM systems appropriately monitor these individuals. The carrier surveys showed how carrier representatives currently manage DSM systems and how they look to future integration with ADS-equipped CMVs.

The final phase consists of a test-track experiment to evaluate a state-of-the-art DSM system identified in the information collection phase. The technology will be evaluated for its ability to accurately detect operator state, robustness to illumination changes, and calibration requirements in an ADS-equipped CMV. The outcome of these phases is a view of how DSM systems can support ADS technologies and their stakeholders by determining whether DSM technologies currently meet standards necessary to integrate with ADS technology and accurately assessing the state of a safety operator.

5. Truck Fleet Guide to Insuring ADSs

Truck fleets face a number of challenges and unknowns regarding insurance and policy questions for ADS trucks. To assist fleets in navigating these complex issues, the CONOPS team partner, Travelers Insurance, developed an insurance and policy guide for truck fleets (Insuring Autonomy, 2021). A 2018 position paper from Travelers Institute that focused on insuring autonomous passenger vehicles informed this recent 2021 report, as truck fleets face similar issues. Furthermore, the body of knowledge surrounding autonomous vehicles has expanded considerably over the past 5 years and this is reflected in Traveler's insurance and policy guide for fleets to address the following critical and evolving questions:

- What is/are the current state of the ADS-equipped truck market, projections for future development, and early policy responses?
- What will truck insurance look like in an ADS world?
- What are specific insurance recommendations for a legal and regulatory structure?

6. ADS Safety Metrics

The introduction of ADSs into the transportation industry warrants a close and continuous investigation into what it means to safely implement these technologies. Although the deployment strategies vary across ADS developers and partner or client fleets, each entity must maintain a focus on safety throughout the integration of ADS technologies into fleet operations. While there are several other metrics to consider when evaluating the utility or efficiency of ADSs (e.g., return on investment, personnel needs, productivity of systems, maintenance needs, etc.), the primary responsibility of ADS users is to ensure the safety of all individuals across whichever deployment strategy is employed.

Rates of safety metrics describe the combination of two elements: the exposure characteristics and the measured safety element. Traditionally, the exposure in epidemiologic crash data captures hundreds of millions of miles to quantify crash characteristics, given the rarity of the events. As such, the first iterations of safety metrics used in describing the safety of automated vehicle deployment referred to the rate of crashes per million miles (Blanco et al., 2016). These crashes are lagging indicators and measure ADS "incidents" in the form of prior safety statistics. As lagging indicators, these are a poor measure of preventing safety incidents. Crash rates alone are ineffective at providing information to developers and fleets looking to implement automation systems within their own operations. Leading indicators must be used within any assessments of the technology instead.

As such, safety metrics in the ADS-space have since evolved into more granular and informative outputs, and a more proactive means of identifying behavioral competencies of automated vehicles, along with higher specificity of exposure rates, are being used to take a more meaningful look into the safe implementation of ADSs in mixed fleet operations. The outcomes of these behaviors can be referred to as the aforementioned leading indicators. These indicators precede or indicate a future event and measure activities carried out to prevent and control safety incidents. Current iterations of safety metrics include evaluating leading indicators to show the automated vehicle is operating safely in situ.

Fleet personnel should utilize available data on the safety of an ADS before implementing ADS-equipped vehicles into their operations. Once implemented, data will be required to monitor how the ADS performs while deployed in fleet operations. Identifying which metrics can be calculated within a fleet's collected data, or working towards a standardized process to store and record data to calculate safety metrics, will be an important step during ADS integration. The current collection of safety metrics can be used for various purposes when implementing ADS technologies, including internal tracking, external reporting, and safety improvement.

There will not be any single safety metric that can be used for all purposes in reporting or tracking the safe operation of vehicles. Internally, fleets can use combinations of metrics to determine if an ADS is safe to deploy. Further, the safety evaluation of an ADS should not be considered a one-time event (e.g., ADS certification), but will rather be a continual process given there will be new software upgrades, vehicle platforms, and targeted operational design domains (ODDs).

7. ADS Data and Road Assessment

Enabling ADS-equipped vehicles on the road requires infrastructure improvements and adjustments based on the needs of the technologies (Manivasakan et al., 2021). The road infrastructure is designed for human drivers, and it may require more work to integrate automated vehicles entirely on public roads. Thus, authorities and agencies need to understand the readiness of road infrastructure for safe ADS operations. Unfortunately, the literature related to this subject area is very scarce.

The current road maintenance and assessment practices involve manual surveys, which transportation agencies perform. These are often time-consuming, inefficient, and need more accuracy (Suliman et al., 2019). At the same time, an ADS's onboard computer system can process the data collected and perform necessary maneuvers like stopping, steering, reacting to traffic signs (Gouda et al., 2021). An ADS can even recognize road features like lane markings and collect information about the built environment.

This project section aims to develop a system to assess road readiness with a specific ADS technology under a specific ODD. The objective is to assess the interaction between roadway features, ADS technology, and ODD requirements for an ADS-equipped vehicle. The research will identify roadway attributes critical to effective ADS operations, such as pavement markings, lane markings, and intersections. The final outcome will be developing a tool that highway agencies could use to see where it may be possible to permit ADS operation. Likewise, fleet operators could use the tool to assess which roads might be used for ADS operations. The road assessment system will also be critical for ADS developers to demonstrate their system's usefulness on portions of the roadway.

The other effort undertaken by the research team to understand road readiness for ADS integration involves cross-country drives that demonstrate the safe integration of ADS-equipped trucks into the U.S. on-road transportation system. The purpose is to collect detailed inventories of ADS perception of sensory data on roadway features and the quality of supporting communications and location data. Currently, no public dataset is available that includes infrastructure metrics required for ADS-equipped trucks on interstates. Through these deployments, the research team will develop a national dataset of the infrastructure and ADS performance metrics required for autonomous operations. Key infrastructure metrics include (1) cellular LTE connectivity, (2) lane marking quality, (3) road bumpiness, and (4) GPS satellite coverage. These infrastructure metrics are quantified by *variables* as follows:

- Cellular LTE Connectivity (Signal Strength %): Better connectivity is needed for autonomous deployments. Connectivity is measured as the received signal strength percentage for LTE Modems.
- Lane Marking Quality (Lane Score of Road %): Measured as a score between 0 and 1, indicating a neural network's ability to detect lane lines.
- Road Bumpiness (Smooth or Bumpy): Measured as a binary (0, 1) variable as to whether the road is "bumpy" or "smooth." Bumpiness is derived from the inertial measurement unit and looking at the truck's pitch and z-acceleration at speeds greater than 40 mph.
- GPS Satellite Coverage (Count of GPS satellites): Measured as the number of satellites visible to the vehicle.

The data collected during deployments are recorded in 1-minute chunks and will be made publicly available on a Dataverse.

8. Data Security & Cybersecurity

Data security refers to protecting data from unauthorized access, modification, destruction, or disclosure. This includes ensuring the confidentiality, integrity, and availability of data, which can be achieved through various methods such as encryption, access controls, backups, and disaster recovery plans. Cybersecurity, on the other hand, involves protecting computer systems and networks from digital attacks, theft, and damage. It includes a range of technologies, processes, and practices to prevent, detect, and respond to cyber threats such as malware, phishing attacks, ransomware, and denial-of-service attacks.

Overall, data security is a subset of cybersecurity, as it focuses specifically on protecting data, while cybersecurity includes protecting data, computer systems, networks, and other digital assets. Both are critical components of protecting sensitive information and ensuring the safe and reliable operation of computer systems and networks.

There are several reasons why cybersecurity and data security are important for an ADS. Unlike traditional trucks, ADS-equipped trucks rely on complex software and communication systems to operate, making them vulnerable to cyber-attacks that can compromise the safety of the driver, other road users, and the transported cargo. Additionally, ADSs generate sensitive and valuable data such as geolocation, traffic patterns, and cargo information, which can be a target for cybercriminals looking to steal or manipulate that information. Therefore, protecting the integrity, confidentiality, and availability of this data is crucial to ensure the safe and reliable operation of ADS-equipped trucks.

Like many new technologies, ADS development continues to evolve at a rapid pace, especially regarding cybersecurity. The result of this project will be a best practice guide for managing ADS-related cybersecurity issues. It will outline cybersecurity and data security best practices for managing mixed fleets, including both conventional and automated trucks. The guide will provide general guidelines for understanding cybersecurity and how mixed fleets and cybersecurity relate to each other, while also tailoring the guidelines to meet specific fleet systems. The intended audience includes people operating mixed fleets for commercial purposes. This document should be considered a living document, as it tackles cybersecurity topics from a unique angle that has not previously been studied in detail. As such, this document 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. It is our hope that this guide will help CMV fleets, policymakers, and other stakeholders identify relevant concerns and promising mitigation strategies.

9. Summary & Conclusions

The goal of this paper was to provide a high-level overview of a U.S. DOT-funded project aimed at developing a CONOPS for managing ADS-equipped trucks in mixed fleets. Put simply, the focus is on *collecting relevant data* and best practices on a number of key ADS pillars, *conducting demonstrations* to showcase various ODDs for ADS-equipped trucks, and *sharing knowledge* gained during this effort with public and private stakeholders in the ADS CMV space, providing guidance to support deployment.

As outlined, while improvements in the technology and software that drive ADSs are necessary for successful deployment, other challenges exist and must be resolved before these vehicles can be integrated into the freight and highway ecosystems. The CONOPS pillars noted represent key areas that must be addressed to ensure a supportive ecosystem for ADS-equipped trucks such that the full-benefits of ADS-equipped CMVs can be realized.

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