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

Chapter 5.1: Fleet Specifications

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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.

The fleet specification guideline was developed recognizing 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 guideline 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.

This report may be useful to Class 8 truck fleets who are seeking to specify equipment and automation systems to meet their operation needs and for manufacturers or developers of heavy ADS Class 8 vehicle systems to identify development and integration needs for ADS fleet operations.

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

5.1 FLEET SPECIFICATIONS

Early in the project the research team sought input from fleets through fleet manager questionnaires. Essentially, the research team identified potential early adoption uses cases for ADS including Exit-to-Exit, Yard-to-Exit, and Truck Queueing, and conducted research on what expectations stakeholder have of ADS technology in these use cases. This information served to inform the approach for developing guidelines. This is discussed in section 5.1.1. Then, using a literature search, various systems on existing trucks that may require special consideration towards the integration of ADS technology into CMVs generally, and for these use cases, were identified. These include the placement of safety equipment, electrical components, batteries, sensors, controls, displays, and other components for equipping CMVs with ADS as described in section 5.1.2.

5.1.1 Fleet Specifications for ADS-equipped CMV Use Cases

This project took an industry-first approach focused on how fleets will be able to integrate ADS-equipped trucks. In the near term, it is unlikely a company will have an entire fleet of ADS-equipped trucks to serve all possible freight operations. It is more likely that a segment of truck fleets will be ADS-equipped without a driver, but much of the fleet will remain conventional trucks and ADS-equipped trucks that require human driver involvement. The research team conducted discussions with truck industry partners regarding the use cases having the most appeal to truck fleets.

The goal of this activity was to outline a set of use case specifications, which were derived from fleet users, to support the development of the fleet ADS CONOPS. To support effective ADS deployment, input from fleet users is a critical step in the process. Participating truck fleets specified their needs as a function of their real-world operational experiences. Considering the needs of the end user is an important part of the design process. This user-centered design paradigm will help ensure that the needs of the end users (i.e., truck fleets) drive the ADS technology design.

This task was completed with discussions with the team's truck industry partners. To meet the goals of this task, the VTTI team held discussions with fleets, yielding six respondents. The discussions were on (i) Functional, (ii) Non-Functional, and (iii) Contextual topics for each of the use cases: (1) Exit-to-Exit (e.g., highway), (2) Yard-to-Exit (e.g., origin to destination, such as regional and short haul), and (3) Truck Queuing. Functional discussions focused on specific functions/behaviors fleets expect of the ADS in each use case. Non-functional questions focused on general ADS performance/quality attributes in each use case, for example safety, security, usability, maintainability, scalability. Contextual questions focused on assumptions about the operating environment needed for the ADS to operate effectively in each use case. The research team developed a set of assumptions to bound the discussions and provide context to support fleet input. Three key assumptions were:

- The ADS will operate in a mixed environment (e.g., ADS-equipped trucks and human-operated trucks).

- The ADS will perform with a quality and success rate that is similar or better than an experienced truck driver.
- The ADS will be compliant within existing regulations and/or has an approved exemption to operate in the use case.

The following sections outline each of the three use case scenarios, list the questions/topics posed to fleet representatives, and summarize their responses. Each use case is presented in turn, along with the topics covered with the Functional, Non-Functional, and Contextual topics. Responses are in italics.

5.1.1.1 Exit-to-Exit (Highway)

It is expected that some of the earliest deployments of ADS-equipped trucks will occur on long, open stretches of highways (especially in the western and southern United States) rather than in urban areas. This use case studied the feasibility of operating an ADS-equipped truck from exit to exit on the U.S. highway system. A human driver operates the ADS-equipped truck until entering the U.S. highway system. The ADS-equipped truck will operate in automated mode once on the approved U.S. highway system. The human driver resumes control upon exiting the U.S. highway system or when the ADS-equipped truck requests the driver take over or any time the human driver desires to take control of the truck.

Functional Requirements: Please specify the services/abilities you expect from the ADS in this use case (i.e., what specific functions/behaviors do you expect of the ADS in this use case)? Answer this with respect to what the ADS must do in this use case (a specific function/behavior). Some key questions for this use case are:

(A) How does the role of the driver impact the utility of this use case (e.g., is it only useful when this use case can be driverless/unmanned)? Is there a business case for having a driver in the truck (but potentially sleeping or inattentive for some of the time)? Is there a business case when you always need a fully attentive driver, even though the ADS is doing all the driving?

Once ADS is fully operational, the true value will be when a truck can operate completely unmanned. Although L2 technology is of great assistance to drivers today, when L4 is available, having a driver onboard would likely be viewed as redundant and less cost-effective. Expectation is the driver to be attentive for a variety of reasons (e.g., unknown or sudden reaction to unknown road conditions, debris, animals, or possible ADS malfunction).

(B) How attractive is the “transfer hub” model?

Over the next few years, the transfer hub model is a reasonable way to pilot test and assess the benefits of L4 ADS. This model works well with operations in proximity to arterial highways. Longer term, for an over-the-road irregular route model, an end-to-end model would be most efficient.

(C) Do you need to operate your trucks for this use case (i.e., the ADS developer oversees the containers for a certain stretch of road)?

Once fully operational, the ADS developer could maintain primary oversight of L4 trucks (e.g., health checks, etc.). However, there would need to be ongoing interface with the carrier that would provide information, such as current location, delays in transit, updated time for departure for the customer, etc.

(D) Does there need to be an extensive exit-to-exit (interlinking) network already set up before you will start using this use case? Or, is just one or two "A to B" lines (possibly in the middle of nowhere) enough for you to start moving traffic to those nodes?

Just one or two A to B lines will be appropriate to get started for pilot testing purposes. As this process expands, additional sites will need to be established, especially for over-the-road carriers.

(E) How will you rebalance your logistics in a mixed-use environment once some routes are able to have driverless exit-to-exit? For example, Dallas to LA has a reliable driverless exit-to-exit operation and a container needs to go from Chicago to San Francisco. Will you now reroute the package to go from Chicago down to Dallas and then from LA to San Francisco (thereby increasing mileage and other logistical costs) to take advantage of that driverless Dallas to LA potential?

The decision would likely be dependent on the load, the customer needs, and efficiency of the transportation option (e.g., teams, intermodal, or L4/exit-to-exit). Ideally, a route will be mapped and certified; thus, a more direct, exit-to-exit approach can be used.

(F) What part of the "ideal" exit-to-exit ADS use case are you willing to give up in order to deploy the technology faster? For example, what's a nice-to-have vs. a must-have to roll the technology out on an everyday basis?

An absolute "must have" is safety. The development of exit-to-exit hubs is not ideal and will likely require a degree of complexity to establish (locations, driver schedules, etc.), but this approach will be a reasonable trade-off to deploy the technology more quickly to assess the future benefits. Related to safety, an ideal ADS should be driverless.

Non-Functional Requirements: Please specify the performance/quality attributes of the ADS in this use case (i.e., what are the general ADS performance/quality attributes supposed to be in this use case)? Answer this with respect to what the ADS shall be in this use case (an overall property of the ADS, but not a specific function). Examples include safety, security, usability, testability, maintainability, extensibility, scalability, etc.

(A) How do you think about balancing the trade-offs between decreased costs vs. decreased efficiency (although it is often optimistically assumed that ADS, especially driverless, will both decrease costs and increase efficiency, in reality it is more likely that labor costs will be decreased, but operational complexity and efficiency might be adversely affected, especially in the early days).

Trade-offs (cost vs. complexity) are expected early in the development process. However, this will be necessary to learn and achieve true efficiency over time. Negative impacts to the service *model would hinder use. Shippers would need to be agreeable to extended transit times unless the operating lanes fit in our existing network.*

(B) Would you roll out the ADS for hazmat or high-value cargo? Why not, if, by definition, the ADS has as good or better performance than a human driver?

Long-term there would be no reason not to use ADS for hazmat or high-value loads. However, given the potential risks (and the sensitivity) associated with hazmat loads and the potential security questions that will arise with high-value loads, it's likely these load-types would be hauled via ADS after the technology has matured. Need to have enhanced security features.

(C) How do you believe this use case is affecting human driver recruitment? Driver retention? Dispatch logistics?

In the short-term, there will not be an impact on driver recruitment. Although the rate and pace of technology will continue to accelerate, drivers and prospective drivers will soon realize there will always be a need for skilled truck drivers in the immediate future. With respect to the dispatch process, there will be some complexity in pairing freight, equipment, and exit-to-exit schedules. However, these challenges will be confined to specific lanes designated for ADS in the short-term.

(D) How important is it for the ADS to be integrated and supported by an OEM (as opposed to an independent ADS tech vendor)?

For large carriers, the expectation will be that the ADS is purchased during regular cycles. ADS is installed and supported by the OEM, just as with any other tractor component. Although retro-fitting is feasible by an independent ADS technology vendor short-term, long-term independent ADS providers will likely need to align themselves with a specific OEM to enable system integration with OEM system components.

(E) What happens if the ADS is only available from a particular OEM? Will you only start purchasing the ADS-equipped trucks or wait until the ADS is available on your traditional OEMs?

Independent ADS retro-fitting will not be a barrier to using ADS technology. However, long-term carriers will expect their OEM of choice to provide ADS as an available spec.

Contextual Requirements: Within this use case, what assumptions about the operating environment are needed for the ADS to operate effectively (i.e., the traffic system in which the ADS operates is variable, what environmental/contextual variables should be considered)? This is a reciprocal relationship, so please consider how the environment/context impacts the ADS and vice versa.

(A) Should we expect the highways where exit-to-exit ADS becomes possible first to suddenly get much more congested? To what extent does that wash away the potential benefits?

Although it is certainly a consideration, other options could include the use of different exits or even co-location of "hubs" with other carriers. However, this is not viewed as a realistic outcome. Carriers move freight as commerce has a directional flow. There may be enough incentive to redirect freight in ADS lanes, but there are no advantages in additional time and mileage in most cases.

(B) Are there fears that if a competitor rolls out ADS on that stretch of road first, they will have a huge competitive advantage and take over the entire market for that road segment before others have a chance to respond?

Not necessarily. Given the number of different customers and the volume of freight in various regions of the country, early adopters are likely to see an initial benefit, but "fast-followers" will adopt a similar approach and over time experience similar benefits. However, it is possible that early adopters will control the technology and monitoring.

(C) Is it risky to be an early adopter (why would you want to be the first to roll this kind of service instead of waiting for it to be more proven first)? How do you balance those risks?

Early adopters will be able to understand the true benefits of ADS, where and how to apply these benefits, and, ultimately, have input on "the how" technology is developed and used. Additional benefits include the ability to provide insight to customers on the future use of ADS for freight-hauling efficiency, as well as the ability to provide input to regulators on how to best establish rules and regulations for ADS. Early adopters will also be able to determine which segments of trucking are not ready for ADS, which will allow for a more effective allocation of resources. Evolving technology typically hits the truckload sector first, but with exit-to-exit, it may be more beneficial to less-than-truckload rather than platooning.

(D) If a certain stretch of highway has reliable ADS for an exit-to-exit portion (especially a driverless one), how/why would you make sense on that segment of road? Even if the overall fleet operations remain mixed, why wouldn't you take full advantage and deploy only ADS-equipped trucks on that stretch of highway as soon as possible?

It would be dependent upon the flow of freight and lane density. These variables differ by carrier and are dependent upon their customer mix. However, if the equipment is available and drivers can be matched on each end of the load, the decision would be to determine if the "ADS" route would be offset by improved efficiencies (time, distance, fuel, etc.).

5.1.1.2 *Yard-to-Exit*

Many fleets report struggling with severe driver shortages and, as a result, long delays associated with deliveries where trucks run repetitive, predictable, and relatively short routes. For example, this is typical of the batch processing of intermodal containers that is required to quickly and efficiently load/unload trains and/or ships onto CMVs with intermodal trailer chasses. An ADS-equipped truck could fully automate a certain proportion of the trucks that drive such repetitive loops between loading and unloading locations. This use case identifies trucks running the same, fixed route all day, which would then enable the deployment of low-level and high-level automation in a mixed-fleet model. Because this operation may involve the use of driverless vehicles, for safety and regulatory reasons, one approach may be to test and validate the technologies with commercial truck fleets operating on private roads and/or very lightly trafficked roads before attempting to transfer them onto carriers operating on busier public highways.

Functional Requirements: Please specify the services/abilities you expect from the ADS in this use case (i.e., what specific functions/behaviors do you expect of the ADS in this use case)? Answer this with respect to what the ADS must do in this use case (a specific function/behavior).

(A) How does the role of the driver impact the utility of this use case (e.g., is it only useful when this use case can be driverless/unmanned)? Is there a business case for having a driver in the truck (but potentially sleeping or inattentive for some of the time)? Is there a business case when you always need a fully attentive driver, even though the ADS is doing all the driving?

Will be difficult to find drivers where the ADS does most of the work.

(B) Do you need to operate your trucks for this use case (i.e., the ADS developer oversees the containers for a certain stretch of road)?

Yes.

(C) What part of the "ideal" yard-to-exit use case are you willing to give up in order to deploy the technology faster? For example, what's a nice-to-have vs. a must-have to roll the technology out on an everyday basis?

Safety is the #1 factor.

(D) What happens if the ADS can only work for part of the year (say in summer when there is no rain), but is not reliable in the event of snow or heavy rain? Is that a dealbreaker and the ADS won't be adopted at all until it can work in all weather conditions that could reasonably be expected on the applicable route?

This is not a deal breaker. Integration will take time; hopefully, the ADS will increase in functionality in time for large-scale implementation. It would be difficult to get drivers for part of the year if this were not addressed relatively soon after implementation.

Non-Functional Requirements: Please specify the performance/quality attributes of the ADS in this use case (i.e., what are the general ADS performance/quality attributes supposed to be in this use case)? Answer this with respect to what the ADS shall be in this use case (an overall property of the ADS, but not a specific function). Examples include safety, security, usability, testability, maintainability, extensibility, scalability, etc.

(A) How do you think about balancing the trade-offs between decreased costs vs. decreased efficiency (although it is often optimistically assumed that ADS, especially driverless, will both decrease costs and increase efficiency, in reality it is more likely that labor costs will be decreased, but operational complexity and efficiency might be adversely affected, especially in the early days).

(B) Would you roll out the ADS for hazmat or high-value cargo? Why not, if, by definition, the ADS has as good or better performance than a human driver?

Yes, if safety is better than a safe human driver. If it also has security features.

(C) How do you believe this use case is affecting human driver recruitment? Driver retention? Dispatch logistics?

Why would you need to hire drivers if they are being phased out? Some drivers would leave. Logistics personnel will likely be the same, at least initially, but then they would leave as more ADS are integrated into the fleet.

(D) How important is it for the ADS to be integrated and supported by an OEM (as opposed to an independent ADS tech vendor)?

Would feel better if it comes from an OEM rather than retrofit, but not a deal breaker.

(E) What happens if the ADS is only available from a particular OEM? Will you only start purchasing the ADS-equipped trucks or wait until the ADS is available on your traditional OEMs?

Would purchase some portion of power units to start slow until available from an OEM.

Contextual Requirements: Within this use case, what assumptions about the operating environment are needed for the ADS to operate effectively (i.e., the traffic system in which the ADS operates is variable, what environmental/contextual variables should be considered)? This is a reciprocal relationship, so please consider how the environment/context impacts the ADS and vice versa.

(A) Are there fears that if a competitor rolls out ADS on that stretch of road first, they will have a huge competitive advantage and take over the entire market for that road segment before others have a chance to respond?

Yes.

(B) Is it risky to be an early adopter (why would you want to be the first to roll this kind of service instead of waiting for it to be more proven first)? How do you balance those risks?

Yes, and no. There is risk, but also reward. Will most likely use a small-scale implementation before ramping up.

(C) Do you believe the commercialization of this kind of use case encourages a greater shift to intermodal freight (at the expense of over-the-road or dedicated line haul)? Or could the opposite be true?

Believe this will increase intermodal freight unless transfer hubs are far from rail yards.

(D) How might the availability of ADS impact the important dynamic of a trucking fleet's key railroad relationships? Does the railroad end up with more (or less) power?

More difficult to implement at rail yards given their rules/regulations.

5.1.1.3 *Truck Queuing*

This use case would enable the truck to operate without a driver in the seat while queueing to be loaded or unloaded. With the ADS enabled, a driver could go off-duty and rest in a sleeper berth or even leave the vehicle and obtain rest in another location. Therefore, the waiting period could potentially be used for driver rest and not count against the driver's HOS, increasing the driver's overall productivity, the carrier's bottom line (more distance could be covered in the day), and safety (drivers would be better rested and less pressured by time).

Functional Requirements: Please specify the services/abilities you expect from the ADS in this use case (i.e., what specific functions/behaviors do you expect of the ADS in this use case)? Answer this with respect to what the ADS must do in this use case (a specific function/behavior).

(A) How does the role of the driver impact the utility of this use case (e.g., is it only useful when this use case can be driverless/unmanned)? Is there a business case for having a driver in the truck (but potentially sleeping or inattentive for some of the time)? Is there a business case when you always need a fully attentive driver, even though the ADS is doing all the driving?

The driver does not need to be attentive. Driver can take a nap. However, port terminal management may require a driver to be onboard and/or needs to be on standby.

(B) Do you need to operate your trucks for this use case (i.e., the ADS developer oversees the containers for a certain stretch of road)?

Truck fleet would like to have oversight of the vehicle.

Non-Functional Requirements: Please specify the performance/quality attributes of the ADS in this use case (i.e., what are the general ADS performance/quality attributes supposed to be in this use case)? Answer this with respect to what the ADS shall be in this use case (an overall property of the ADS, but not a specific function). Examples include safety, security, usability, testability, maintainability, extensibility, scalability, etc.

(A) How can this solution be balanced and/or integrated with other demand smoothing options ports may be considering (such as peak pricing or incentives to come during off-peak hours)?

The port terminal decides if these vehicles are allowed; fleet has little impact. No rights in the terminal.

(B) Is there a minimum queueing length/time that is required for this solution to make sense?

Rather have the ADS drive regardless of length in the queue.

(C) How should we think about the queue outside the port's gate vs. the queue once you are past the gate?

Limited rights once you pass the gate. Outside the gate is a less complex environment. Gate requires security checkpoint and different machinery.

(D) How do you think about balancing the trade-offs between decreased costs vs. decreased efficiency (although it is often optimistically assumed that ADS, especially driverless, will both decrease costs and increase efficiency, in reality it is more likely that labor costs will be decreased, but operational complexity and efficiency might be adversely affected, especially in the early days).

Decreased costs would be primary concern, efficiency will come later.

(E) Would you roll out the ADS for hazmat or high-value cargo? Why not, if, by definition, the ADS has as good or better performance than a human driver?

Not for hazmat.

(F) How do you believe this use case is affecting human driver recruitment? Driver retention? Dispatch logistics?

Make their job easier. Increase driver retention. Logistics would improve.

(G) How important is it for the ADS to be integrated and supported by an OEM (as opposed to an independent ADS tech vendor)?

Would want to be supported by an OEM eventually.

(H) What happens if the ADS is only available from a particular OEM? Will you only start purchasing the ADS-equipped trucks or wait until the ADS is available on your traditional OEMs?

Depends on the size of fleets. Lots of fleets in this space buy used trucks from larger carriers. If there is a mandate to buy electric vehicles such as proposed in California, that will require purchase of new vehicles.

Contextual Requirements: Within this use case, what assumptions about the operating environment are needed for the ADS to operate effectively (i.e., the traffic system in which the ADS operates is variable, what environmental/contextual variables should be considered)? This is a reciprocal relationship, so please consider how the environment/context impacts the ADS and vice versa.

(A) Are there fears that if a competitor rolls out ADS on that stretch of road first, they will have a huge competitive advantage and take over the entire market before others have a chance to respond?

Not in this use case; most are owner operators (90%).

(B) Is it risky to be an early adopter (why would you want to be the first to roll out this kind of service instead of waiting for it to be more proven first)? How do you balance those risks? How will the terminal and unions think about ADS?

This is always a risk. Do it now or you'll be behind the curve. This is a pivot point.

5.1.2 Industry Practices and References for ADS-equipped CMVs

The following information was collected during a literature search that identified subsystems and components on existing trucks that may need special consideration during the purchase and specification process when planning to equip a CMV with an ADS. A summary of each of the component areas is provided with descriptions of the guidance provided, how it applies to ADS operations, and the specific need for the specification consideration.

5.1.2.1 Placement of Safety Equipment

Scope: Guidelines for the placement of safety equipment including warning triangles (formerly referred to as flares) in heavy-duty commercial vehicle cabs.

Guidance: Guidance for safety equipment pertaining to Federal Motor Carrier Safety Regulations (FMCSR), 49 Code of Federal Regulations (CFR) 393.95, includes these considerations: amount of space, storage location for fire extinguishers for access from within the cab or for safety operator standing on the ground, location to avoid interference with other components in the cab, location of warning triangles, location of additional fire extinguishers, attachment strength to avoid cab damage, designation for safety equipment in manufacturer's owner manual, and mounting strength to last the life of the vehicle.

ADS Application: ADS-equipped CMVs carry components similar to conventionally operated CMVs on which FMCSR 49 CFR 393.95 safety equipment is required, and ADS-equipped CMVs also carry additional batteries and electronics that may require additional fire extinguishers. Warning triangles are an important consideration for ADS-equipped CMVs that are operated without onboard personnel.

Need: ADS-equipped CMVs will require a convenient and commonly understood location for safety equipment for onboard operators, as well as easy access to fire extinguishers for staff or emergency personnel supporting from outside an ADS-equipped CMV operating without onboard personnel. ADS-equipped CMVs that pull off onto the shoulder to arrive at a minimal risk condition (MRC) will need to set warning triangles when operating with or without onboard personnel. The process of setting warning triangles or similar flare-like technology may need to be innovated.

Reference: Technology & Maintenance Council. TMC Recommended Practice RP 403A: Placement of Safety Equipment, 10/2019. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

5.1.2.2 Electrical

Power Cable Assemblies

Scope: Power cable routing, cable gauge size, battery and power terminals.

Guidance: Minimum shielded and unshielded distance from hot components, cable size, terminal connection process, and parts specifications.

ADS Application: Specification and installation of ADS sensing and computing power cables.

Need: ADS-equipped CMVs have significant power demands for sensors, computing resources, and data collection and communication subsystems to support object, event, detection, and response ADS task.

Reference: Technology & Maintenance Council. TMC Recommended Practice RP 105D: Design and Installation of Copper Power Cable Assemblies, 10/2020. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

Wiring Harness Protection

Scope: Minimum guidelines for protection of wiring harnesses from operational and environmental conditions.

Guidance: Guidance covers general function, conditions (i.e., abrasion, temperature, chemical resistance, cut resistance, and moisture), cable insulations, and harness coverings. Application guidelines include considerations for metal edges for routing, fastening structures, minimum distance between fasteners, clip types and coatings, flex between moving parts, and protection from operational and environmental hazards. Specifications are included for types of harness coverings: woven braid material, taping materials, plastic tubing, and heat-reflective wraps.

ADS Application: Wiring harness routing and clipping between components for ADS sensing and computing.

Need: ADS-equipped CMVs require durable and reliable bundled wiring harnesses to maintain functionality when exposed to extreme vibration in cab interior and exterior as well as survival from severe temperatures, snow/ice, and road debris during long trips between manual inspections. Harnesses are commonly located in areas that cannot be easily inspected visually without removing interior or exterior body panels or other substantial disassembly of non-interfacing parts.

Reference: Technology & Maintenance Council. TMC Recommended Practice RP 114B: Wiring Harness Protection, 10/2020. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

Wiring Harness Routing, Clamping, and Protection

Scope: Routing, clamping, and protecting wiring harnesses used on 12- or 24-volt wiring systems in trucks, tractor trucks, trailers, and dollies among vehicle locations.

Guidance: Wiring harness routing and clipping between components for ADS sensing and computing. Environmental considerations include water, corrosion, chemicals, vibration, abrasion, impact, sand and dust, temperature extremes, electromagnetic interface/radio-frequency interface, tensile loads, and flexing (e.g., door hinges). Guidance includes description of the source of the issue, interacting factors that accelerate issues, and steps to mitigate or avoid the environmental issues are provided. Methods are provided to increase harness protection. Material guidelines provide information on types, temperature limits, and specific materials. Guidelines are also provided for mounting, routing, installing, and fastening.

ADS Application: ADS-equipped CMVs require durable and reliable bundled wiring harnesses to maintain functionality when exposed to extreme vibration in cab interior and exterior as well as survival from severe temperatures, snow/ice, and road debris during long trips between manual inspections.

Need: Harnesses are commonly located in areas that cannot be easily inspected visually without removing interior or exterior body panels or other substantial disassembly of non-interfacing parts.

Reference: Technology & Maintenance Council. TMC Recommended Practice RP 154A: Guidelines for Wiring Harness Routing, Clamping, and Protection, 3/2018. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

Routing and Clipping

Scope: Additional and redesigned wires, cables, and connections are needed to engineer and install ADS on trucks, resulting in cable ties and mounts gaining popularity as hose, wire, and cable management solutions (Shalabi, 2014).

The SAE Heavy-Duty Electrical Connector Performance Standard (J2030_201506) encompasses connectors between two cables or between a cable and an electrical component and focuses on the connectors external to the electrical component (SAE, 2015).

The SAE Surface Vehicle Recommended Practice (J1742) provides suggested practices for connections for high voltage onboard vehicle electrical wiring harness, including test methods and general performance requirements (SAE, 2010).

The SAE Heavy-Duty Wiring Systems for On-Highway Trucks (J2202_201912) provides recommended practices and guidelines on the material selection, construction, and qualification of components and wiring systems used to construct nominal 12-volt direct current (VDC) and/or 24 VDC electrical wiring systems for heavy-duty vehicles (SAE, 2019).

Guidance: The SAE Duty-Vehicle Electrical Connector Performance Standard (2015) "provides environmental test requirements and acceptance criteria for the application of connectors for direct current electrical systems of 50 V or less in the majority of heavy-duty applications typically used in off-highway machinery. Severe applications can require higher test levels or field-testing on the intended application." The standard provides guidance on wire, cable, and connector assembly, test sequence, test methods, applications, and considerations. See J2030_201506 for detailed recommendations.

The SAE Surface Vehicle Recommended Practice (J1742) provides general equipment requirements and detailed test and acceptance requirements, including terminal and connector mechanical tests, terminal and connector electrical tests, environmental, special, and severe duty tests, and test sequences (SAE, 2010). See J1742 for detailed recommendations.

The future of commercial truck electrical systems will offer a multi-voltage electrical system, which will include voltages above a nominal system and new technologies and requirements not included in the current standards (SAE, 2019). The Recommended Practices detail test procedures, requirements, design requirements, and identify appropriate operating performance requirements. See J2202 for detailed recommendations (SAE, 2019).

ADS Applications: To accommodate new or redesigned wires, cables, and connection solutions on ADS CMVs, equipment such as cable ties and mounts are gaining popularity as hose, wire, and cable management solutions (Shalabi, 2014). Determining wire, cable, and hose routing is traditionally the last step in the design and development process, though this is changing as OEMs are finding that working with suppliers up front to address routing issues results in reduced routing and clipping warranty claims due to reduced wear and extended life of the equipment. Factors that can increase wear and tear on routing and clipping equipment include torque, strain, vibrations, repetitive stress, and extreme temperatures. Addressing these factors up front by manipulating equipment design, materials, and installation and mounting practices can reduce malfunction by extending the life and reliability of the equipment (Shalabi, 2014). This is especially practical for ADS CMVs, especially after-market equipment modifications, as there is an even greater need for planning and forethought on routing and clipping design and placement considerations to accommodate additional sensors, wires, cable management, and equipment access points discreetly and with limited space. Additionally, the serious concerns and consequences of equipment malfunctions and failures on ADS CMVs further support these changes in routing and clipping solutions.

Need: The future of commercial truck electrical systems will offer a multi-voltage electrical system, which will include voltages above a nominal system and new technologies and requirements not included in the current standards (Park, 2018). Standards for heavy-duty wiring systems and harnesses and electrical connector performance should include new technologies and considerations for higher voltage electrical systems.

References:

Park, J. (2018). The future of electrical systems on heavy duty trucks. *Heavy Duty Trucking*. Accessed from (https://tmcconnect.trucking.org/tmclibraries/newrplibrary).

SAE Surface Vehicle Recommended Practice. (2010). *Connections for high voltage on-board vehicle electrical wiring harnesses-Test methods and general performance requirements* (J1742). Accessed from https://saemobilus-sae-org.ezproxy.lib.vt.edu/content/J1742_201003.

SAE Surface Vehicle Recommended Practice. (2019). *Heavy-duty wiring systems for on-highway trucks (J2202)*. Accessed from https://saemobilus-sae-org.ezproxy.lib.vt.edu/content/J2202_201912/

SAE Surface Vehicle Standard. (2015). *Heavy-duty electrical connector performance standard (J2030)*. Accessed from https://saemobilus-sae-org.ezproxy.lib.vt.edu/content/J2030_201506/

Shalabi, L. (2014). Routing and clipping. *OEM Off Highway*. Accessed from https://www.oemoffhighway.com/home/article/10166645/routing-and-clipping.

Wiring System Identification

Scope: Minimum requirements are provided for wiring system identification.

Guidance: Electrical circuit wires should be readily identifiable by technicians (e.g., color, number, letters, symbols). A wiring diagram should be provided for each vehicle, and it should comply with SAE J2191, SAE EA-1128, and TMC RP 146.

ADS Application: Circuits and wires may be added to the vehicle during installation and/or integration activities.

Need: New circuits and wires on ADS-equipped CMVs should be identified to increase troubleshooting and maintenance ease and to support safe maintenance practices.

References:

Technology & Maintenance Council. TMC Recommended Practice RP 120B: Wiring System Identification, 04/2021. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

Electrical Circuits Identification

Scope: Standard circuit identification for heavy vehicle electrical circuit diagrams specified in SAE J2191.

Guidance: Endorsement of common methods to organize and identify circuits on heavy vehicles to increase understanding among technicians, assist in use of the service manual, and reduce vehicle downtime as specified by SAE J2191. A list of circuits and subsystems is provided to promote consistency by developers and manufacturers. An identification method is provided including primary circuit identifier, separator, and supplemental suffix.

ADS Application: During design and development of new electrical ADS subsystems, alignment with common assembly categories can be implemented.

Need: Complex electrical and electronic subsystems are added to ADS-equipped CMVs. Applying pre-existing and consistent categories during design may improve development, integration, and maintenance activities.

Reference: Technology & Maintenance Council. TMC Recommended Practice RP 146: Identification of Standardized Electrical Circuits for Class 8 Vehicles, 10/2020. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

Electrical Circuit Diagrams

Scope: Standard graphic symbology for heavy vehicle electrical circuit diagrams specified in SAE J2221.

Guidance: SAE J2221 as applied to heavy vehicles when developing a building-block circuit diagram. The benefits of symbols include universality, providing enhanced communication, technician recognition, avoiding design over-specification, and clear visual display information.

ADS Application: Diagrams developed during design and development of new electrical ADS subsystems that are added to ADS-equipped CMVs from the point of interface with existing or other developers/manufacturers specified in other product materials.

Need: Complex electrical and electronic subsystems are added to ADS-equipped CMVs. Planning for the consistent communication and layout of circuits during design can improve efficiency and safety of human interactions by making diagrams of complex systems available during the purchase specification, installation, and repair and maintenance performed by developers and fleets. These diagrams also support roadside enforcement and emergency first responder interactions.

Reference: Technology & Maintenance Council. TMC Recommended Practice RP 145: Symbols for Electrical Circuit Diagrams, 10/2020. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

Circuit Protection

Scope: Covers circuit protection of D.C. wiring systems due to exposure to high current levels.

Guidance: Guidelines for primary and secondary protection devices with electrical and physical considerations for design of power feed circuits excluding batteries, starter motors, and generator/alternator circuits.

ADS Application: Specification and installation of circuit protection for components for ADS sensing and computing subsystems.

Need: ADS-equipped CMVs require circuit protection across sensors, computing resources, and data collection and communication subsystems.

Reference: Technology & Maintenance Council. TMC Recommended Practice RP 111C: Circuit Protection, 10/2021. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

Electrical Circuit Protection Components and Fuses

Scope: Heavy-duty commercial vehicle circuit protection component types, descriptions, functional explanation, and information for proper replacement.

Guidance: Circuit protection devices serve to protect circuits from thermal damage caused by current that exceeds the circuit's design specifications by opening the circuit. The range of devices includes mini fuse and breaker, automatic transfer case (ATC; closed blade), fuse and breaker, maxi fuse and breaker, glass fuse, and polymeric positive temperature coefficient (PPTC) and fusible link wire. Consider SAE J156 for further detail on fusible links. Consider SAE J1284 for ATC/ATO (closed and open) type fuses. Recommendations are provided, including that a circuit protector be operated at no more than 75%–80% of its rating, as well as safety factors to avoid tripping induced by surge. Characteristics and images of the circuit protection devices are provided.

ADS Application: Specification and installation of circuit protection for components for ADS sensing and computing subsystems.

Need: ADS-equipped CMVs require circuit protection across sensors, computing resources, and data collection and communication subsystems.

Reference: Technology & Maintenance Council. TMC Recommended Practice RP 156A: Electrical Circuit Protection Components, 5/2016. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

Fuses

The functional safety of AVs starts with the electrical power supply that feeds into all of the safety-relevant components. The wiring system is the vehicle's central nervous system and must be designed to ensure that the system is functional under all conditions and scenarios. The electrical wiring system includes all cables and wiring, connectors and terminations, coverings, seals, other incorporated items to maintain the integrity and performance of the electrical system, and the connectors to mating devices (see SAE J2174).

Scope: SAE J2174 establishes the minimum performance requirements for electrical distribution systems for use in dollies and trailers in single or multiple configurations for 12-VDC nominal applications (SAE, 2020). The SAE Recommended Practices (J2202) provide guidelines on materials, construction, and qualification of components and wiring systems used to construct electrical wiring systems for heavy-duty vehicles, as well as requirements for operating performance (SAE, 2019).

Guidance: The wiring industry is no different post-ADS than it was pre-ADS. Automotive wiring harnesses are still manually built by people who individually attach thousands of components. General guidance should follow SAE J2174, which covers guidelines, requirements, assembly, installation, and testing and SAE Recommended Practices J2202, which covers wiring system construction and operating performance.

ADS Applications: How companies design, engineer, manufacture, and deliver vehicle wiring harnesses has completely changed with the growth of automated systems. Automotive OEMs are looking at new electrical architectures to simplify harness designs so they can minimize wiring complexity and cost. For the Tier 1 OEMs, wiring harnesses are a very labor-intensive product with thousands of part numbers going into making each vehicle's wiring harness, and the finished product weighing 150 pounds or more (Morrison, 2019). OEMs have to coordinate all the materials and components for these products and ship them from all around the world. This creates an incredibly long, complex supply chain with hundreds of design changes occurring along the way, all of which need to be individually tracked, implemented, and validated.

The variation in automotive wiring harnesses is extremely vast with optimized architectures, especially for cost and weight (Morrison, 2019). Many different architectures have risen to meet the needs of individual vehicle designs and are going to continue to evolve as vehicles continue to leverage new, next-generation technologies. For example, AVs will have to implement centralized data storage and scalable, modular system architectures, and the wiring and networking components will have to evolve to support them. A question for next generation wiring challenges is optical or wireless instead of copper. A variety of parameters will factor into these decisions, extending from the vehicle's network and software considerations to their physical wiring and electrical performance specifications.

Needs: Simplified automotive wiring harness designs will lend themselves to more automated assembly and delivery processes and allow OEMs to implement changes more quickly, which will reduce costs across the entire chain (Morrison, 2019). In addition to the raw materials required to build wiring harnesses, including connectors, terminals, wire, tape, and various other components, OEMs have to store a certain amount of inventory to prevent potential supply disruptions.

There is no standard to guide OEMs on an approach to meet the high-speed network needs of ADS vehicles. Ethernet, CAN, and local interconnect network (LIN) approaches are available, each with pros and cons, but the proprietary and application-specific protocol make it difficult to identify a standard (Morrison, 2019).

As vehicles become more software-driven, there will be a greater need for diagnostics to ensure that critical systems are functioning properly (Morrison, 2019). Hardware, data, communications, back-up and fail-safe mechanisms, and diagnostic capabilities will need to be ramped up.

References:

Morrison, G. (2019). *Automotive wiring undergoes an architectural revolution*. Accessed: https://www.connectorsupplier.com/automotive-wire-harness-content-increasing/

SAE Surface Vehicle Standard. (2019). *Heavy-duty wiring systems for on-highway trucks* (J2202). SAE International. Accessed from https://saemobilus-sae-org.ezproxy.lib.vt.edu/content/J2202_201912/

SAE Surface Vehicle Standard. *Heavy-duty wiring systems for trailers 2032 mm or more in width* (J2174). (2020). SAE International. Accessed from https://saemobilus-sae-org.ezproxy.lib.vt.edu/content/J2174_202002/

Electrical Systems Connectors

Scope: Minimum guidelines for design, performance, and application of connectors for heavy-duty vehicles.

Guidance: General connector guidance on soft mold-over, locking features, friction type, and environmental protection. Provides connector design minimum pull force recommendations to ensure proper connector mating based on cable size (gauge). Also provides guidance on corrosion preventative compound application.

ADS Application: Specification of connectors between ADS components.

Need: ADS-equipped CMVs require durable and reliable connections to maintain functionality when exposed to extreme vibration in cab interior and exterior as well as survival from severe temperatures, snow/ice, and road debris during long trips between manual inspections.

Reference: Technology & Maintenance Council. TMC Recommended Practice RP 113B: Electrical Systems Connectors, 4/2020. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

Plug and Receptacle Wire-to-Terminal Interface

Scope: Performance standard for wire-to-terminal connections.

Guidance: The performance guideline provides current, cycling, and aging standards per SAE J560 for plugs and receptacles. Failure mechanisms are specified, including relaxation of the materials, corrosion of the wire-to-terminal, overheating, chemical changes, and loose/improper/fractured terminal screw. Environmental exposure test descriptions, procedures, and pass/fail criteria are described. The guideline covers thermal aging, temperature/humidity cycling, and current cycling.

ADS Application: Specification of connectors between ADS components and between ADS and other vehicle hardware interfaces.

Need: ADS-equipped CMVs require durable and reliable connections to maintain functionality when exposed to extreme vibration in cab interior and exterior, as well as survival from severe temperatures, snow/ice, and road debris during long trips between manual inspections. According to Naval Research Laboratory environmental laboratory test results, internal corrosion in the plug and socket is the primary cause of J560 coupler electrical failures.

Reference: Technology & Maintenance Council. TMC Recommended Practice RP 147: J560 Plug and Receptacle Wire-to-Terminal Interface Performance Guidelines, 10/2020. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

Electrical Terminals and Connectors Corrosion

Scope: Guidance for truck, tractor truck, and trailer manufacturers, and fleet maintenance to specify products for electrical terminals and connector products that can withstand high temperatures, be compatible with plastic materials, reduce insertion and withdrawal forces, reduce fretting corrosion, and provide a barrier for environmental corrosion.

Guidance: The benefits of connection lubricants are discussed, and resistive criteria are provided. The advantages and disadvantages when applying lubricants to the electrical wiring harness connection system are listed. The types of lubricants and factors to consider when selecting a lubricant include operating temperature, lubricant compatibility, performance, application, and life.

ADS Application: Specification of connectors between ADS components and between ADS and other vehicle hardware interfaces.

Need: ADS-equipped CMVs require durable and reliable connections to maintain functionality when exposed to extreme vibration in cab interior and exterior, as well as survival from severe temperatures, snow/ice, and road debris during long trips between manual inspections.

Reference: Technology & Maintenance Council. TMC Recommended Practice RP 155A: Selection and Application of Corrosion-Preventing Materials for Sealed and Unsealed Electrical Components, 5/2021. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

Design for Preventing Vehicle Electrical Fires

Scope: Recommendations to prevent Class 7–8 heavy-duty commercial vehicle electrical fires.

Guidance: Recommendations are a result of TMC's Electrical Thermal Events Solutions Task Force and with input from the ATA's Technical Advisory Group and the Truck Manufacturers' Association. Recommendations for developers and equipment users include these topics: battery cable routing, circuit protection, power supply fuses, limits to use of Type 1 circuit breakers, design of branch circuits, starting motor design, lamp installation, electrical cables and harness routing, environmental protection of circuit protection distribution centers, and circuit protection for directional and emergency flashers.

ADS Application: Circuits and wires may be added to the vehicle during installation and/or integration activities.

Need: When adding new circuits and wires to ADS-equipped CMVs, protective measures should be taken by selecting, locating, and routing wires and components to mitigate the risk of vehicle electrical fires.

Reference: Technology & Maintenance Council. TMC Recommended Practice RP 168: Design Recommendations for Preventing Vehicle Electrical Fires, 10/2020. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

5.1.2.3 Batteries

Battery Considerations for Engine Cranking

Scope: Provides battery specifications for cold cranking ampere and reserve capacity ratings.

Guidance: 12-volt and 24-volt battery cold cramp amperes (CCA) at engine oil viscosity and remote capacity, which is the number of minutes a battery can supply 25 amperes of current at 80 °F (27 °C) while maintaining a minimum of 1.75 volts per cell.

ADS Application: Specification and installation of batteries to support ADS sensing and computing subsystems.

Need: ADS-equipped CMVs introduce new loads on batteries to meet the demands of sensors, computing resources, and data collection and communication subsystems. These new loads may affect traditional battery cold-start and spare capacity.

Reference: Technology & Maintenance Council. TMC Recommended Practice RP 109A: Battery Ratings and Engine Cranking Requirements, 3/2003. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

Battery Vibration

Scope: Survival of batteries to excessive heavy-vehicle vibration.

Guidance: Based on OEM bench tests and field evaluations of vibration, it has been concluded that "a vibration resistant battery was just as important as proper battery mounting procedures" (TMC RP 125A). Must comply with TMC RP 125, SAE J3060, and SAE J537. Specific parts of the SAE testing protocol and criteria are provided for Class 6–8 applications. OEM recommendations are provided for battery location, battery carrier, and hold down. Recommendations are also provided for fleets to support battery life.

ADS Application: Specification and installation of batteries to support ADS sensing and computing subsystems.

Need: ADS-equipped CMVs may introduce additional batteries to meet the demands of sensors, computing resources, and data collection and communication subsystems. The specifications and mounting of additional batteries may affect ADS operations.

Reference: Technology & Maintenance Council. TMC Recommended Practice RP 125A: Battery Vibration Standards, 4/2019. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

Managed/Isolated Battery Systems

Scope: Considerations when isolating or managing vehicle subsystem or device demands on vehicle batteries.

Guidance: Battery isolation system functionality is defined; for example, isolation when the engine is OFF while allowing dual charging while the engine is ON. Battery management system functionality is defined, for example, disconnection or prioritization of auxiliary and parasitic loads. Other practices are referenced: TMC RP 109, TMC RP 139, RP 140, and SAE J2185. Guidance is provided on management mechanisms, signaling devices, fusing, and wiring, as well as items that should (e.g., radio, dome, cigar/auxiliary power outlet) and should not be managed (e.g., electronic engine control, safety lighting, anti-lock brake system [ABS], and medical A/B/C-positive airway pressure [PAP] devices [TMC RP 445]).

ADS Application: ADS-equipped CMVs require power to meet the demands of sensors, computing resources, and data collection and communication subsystems.

Need: ADS-equipped CMVs may require the introduction of additional batteries to the vehicle. Some critical functions may need to be managed if not isolated from other high-priority vehicle powertrain demands or low-priority convenience devices when the vehicle is operational.

Reference: Technology & Maintenance Council. TMC Recommended Practice RP 136C: Managed/Isolated Battery Systems for Electric Start Systems, 5/2021. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

5.1.2.4 Controls, Displays, and Instruments

Location and Operation of Instruments and Controls in Cabs

Scope: Recommendations for controls and displays in the cab of heavy-duty commercial vehicles.

Guidance: Recommendations promote consistency of controls and displays for onboard vehicle operators. The primary function and location are organized based on classically understood human factors and ergonomics performance criteria. The location and orientation are specified for these controls: lamp switches, gauges, wiper controls, tractor-trailer and trailer parking brake controls, engine/emission switches, indicators and telltales and warning lights, object detection displays, rearview mirrors, door controls, steering wheel and stalks, manual and automatic shift controls, seat setting controls, and accessory and secondary instruments.

ADS Application: Consistency in the design and location of controls and displays on ADS-equipped CMVs can support activities by operators who engage in continuous or intermittent control and monitoring of the vehicle depending on the intentions of the onboard operator and depending on the location and state of the vehicle and weather compared to the ADS ODD.

Need: Depending on the status of the vehicle operation with the ADS ODD and the status of the ADS, onboard operators may need to engage with the vehicle through manually operated driving controls and displays to take over control when exiting the ODD or in the event of ADS failures leading to minimal risk events.

Reference: Technology & Maintenance Council. TMC Recommended Practice RP 401D: Location and Operation of Instruments and Controls in Motor Truck Cabs, 10/2020. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

Location and Operation of Instruments in Sleepers

Scope: Recommendations for displays used to check status of heavy-duty commercial vehicles in the sleeper of heavy-duty commercial vehicles.

Guidance: No guidance discovered.

ADS Application: Consistency in the design and location of displays in sleepers on ADS-equipped CMVs can support the needs of onboard operators to check the status of the ADS.

Need: Onboard operators may need to check the status of the ADS operation through displays from the sleeper area before an ADS-equipped CMV reaches the boundaries of its ODD in normal operations and before receiving warnings in the event of ADS failures leading to MRCs.

Reference: Unspecified

In-Cab Trailer ABS Malfunction Lamps

Scope: Minimum performance for in-cab trailer/dolly ABS malfunction lamps.

Guidance: The guidance includes a description of function, color, labeling, mounting position, and states of the malfunction lamp used for combination vehicles to communicate trailer and trailer converter dolly ABS messages into the cab. Environment specifications reference SAE J1455. Electric and electronic systems should coexist with J1939 and J1587 and require no unique equipment for servicing.

ADS Application: Guidance for in-cab ABS lamp could be considered for application to ADS status lamp in-cab to onboard operator or on the exterior of the truck or tractor-trailer to other vehicle operators. Federal Motor Vehicle Safety Standard (FMVSS) No. 121 requirements for power vehicles (tractor-truck) and trailers and dollies are referenced and quoted.

Need: Similar to the high-priority communication of ABS malfunction to human drivers, ADS-equipped CMVs should communicate indication and warning status of ADS to onboard operators. Additionally, this element may inform design considerations for over-the-air communication to inspectors, law enforcement, and operators of other vehicles that may benefit from a lamp that communicates ADS status on the exterior of each vehicle and combination vehicle.

Reference: Technology & Maintenance Council. TMC Recommended Practice RP 144: Minimum Performance Requirements for In-Cab Trailer ABS Malfunction Lamps, 4/2019. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

Interior Displays

Scope: OEMs and display manufacturers are introducing innovative display designs and layouts to address current ADS concepts, as well as mapping out steps and plans for future designs and display needs (Pawsey, 2018). OEMs are competing to produce the most aesthetically pleasing, personalized, and functional HMI systems.

The FMVSS (36 FR 22902) "specifies performance requirements for the location, identification, color, and illumination of motor vehicle controls, telltales, and indicators" (ECFR, 2021).

The FMVSS No. 101 Ground Vehicle Standard, "Controls and Displays," specifies requirements for the location, identification, and illumination of motor vehicle controls and displays for commercial vehicles (National Highway Transportation System Administration [NHTSA], 1971).

The ISO 2575.2010 standard, "Road Vehicles-Symbols for controls, indicators, and telltales," specifies symbols and display colors for use on controls, indicators, and telltales applying to passenger cars, light and heavy commercial vehicles, and buses to ensure identification and facilitate use (ISO, 2010).

Guidance: Safety standards for motor vehicles assume that a human occupant will be able to control the operation of the vehicle, and many standards incorporate performance requirements and test procedures geared toward ensuring safe operation by a human driver. Some standards focus on the safety of drivers and occupants, in particular seating arrangements. Standards impose specific requirements for the visibility to a human driver of instrument displays, vehicle status indicators, mirrors, and other driving information (NHTSA, 2018).

Standards, regulations, and requirements for interior displays, including location, identification, illumination, brightness, color, messaging space, and conditions for controls, telltales, and indicators, and displays are detailed in the FMVSS (36 FR 22902) §571.101 Standard No. 101: Controls and displays (ECFR, 2021). This standard also facilitates the proper selection of controls under day and night lighting conditions in order to reduce the diversion of the driver's attention from the driving task and mistakes in selecting controls.

Standards to ensure the accessibility and visibility of controls and displays to reduce safety hazards caused by diversion of driver attention from the driving task and mistakes in selecting controls, under all lighting conditions, are outlined and detailed in the FMVSS No. 101 Ground Vehicle Standard, "Controls and Displays" (NHTSA, 1971).

Standards for vehicle controls, indicators, and telltales specify symbols used on controls and displays to ensure proper identification and use, as well as indicate the display colors of optical telltales, which inform the driver of operation and malfunction status (ISO, 2010).

ADS Applications: OEMs are focusing on developing and improving HMIs and providing driver information in a quick and easy format to improve reaction time, decrease eyes off road, and support a vehicle environment that offers a seamless transition between automated and manual driving modes (Pawsey, 2018). Interactive displays that are highly responsive to touch and visual stimulus are a key feature of ADS interior displays (Bepari, 2019). Near-future innovations such as augmented reality and 3D displays will facilitate ADS display functionality and the HMI experience. Longer term future vehicle displays will be non-driving task centric, freeing up the driver to concentrate on tasks other than driving, via the interior display.

OEMs are currently developing and refining fully reconfigurable instrument clusters with advanced digital display technologies, driver monitoring features, and ADS integration. Driven by the need to conserve cost, space, and power consumption, OEMs are designing domain controllers that integrate the instrument cluster, infotainment, and heads-up displays into one electronic control unit (ECU).

Digital solution displays with embedded functionality, including camera systems and ambient lighting, are being developed (Pawsey, 2018). Integrated infrared driver monitoring cameras designed for facial recognition, head, and eye-gaze tracking are important technologies to determine driver alertness and preparedness to take over vehicle control when needed.

Windshield solutions for heads-up displays and augmented reality solutions that can be integrated into ECUs are also being developed (Bepari, 2019).

Multi-layered display systems that provide a 3D display of the instrument panel will be a safety feature in ADS vehicles that provide information to the driver in a way to facilitate quicker understanding and information processing and reduce eyes-off-road time (Pawsey, 2018). The 3D designs are also supposed to alleviate headaches, eye strain, and fatigue.

Need: NHTSA's current safety standards do not prevent the development, testing, sale, or use of ADS built into vehicles that maintain the traditional control features of human-operated vehicles. However, some Level 4 and Level 5 AVs may be designed to be controlled entirely by an ADS, and the interior of the vehicle may be configured without human controls (i.e., no information displays). For such ADS-equipped vehicles, NHTSA's current safety standards constitute an unintended regulatory barrier to innovation (NHTSA, 2018).

References:

Bepari, S.A. (2019). What's trending in the automotive display market? *Electronic Design*. Accessed from: https://www.electronicdesign.com/markets/automotive/article/21807933/whats-trending-in-the-automotive-display-market.

Electronic Code of Federal Regulations. (2021). Part 571-Federal Motor Vehicle Safety Standards. Subpart B-Federal Motor Vehicle Safety Standards. §571.101. Standard No. 101; Controls and displays. Accessed from https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=&SID=635b08ab5e31e3bf86ebf4cb93c6aecb&mc=true&n=pt49.6.571&r=PART&ty=HTML#se49.6.571_1101

ISO. (2010). *ISO 2575:2010 – Road Vehicles-Symbols for Controls, Indicator, and Tell-tales*. Accessed from https://www.iso.org/standard/54513.html

National Highway Transportation System Administration. (1971). *Controls and displays*. Accessed from https://saemobilus-sae-org.ezproxy.lib.vt.edu/content/FMVSS100/

National Highway Transportation System Administration. (2018). *Preparing for the future of transportation: Automated Vehicles 3.0.* Accessed from: https://www.transportation.gov/sites/dot.gov/files/docs/policy-initiatives/automated-vehicles/320711/preparing-future-transportation-automated-vehicle-30.pdf

Pawsey, C. (2018). Displays and autonomous driving challenges and solutions in the US. *Automotive IQ*. Accessed from https://www.automotive-iq.com/electrics-electronics/articles/displays-and-autonomous-driving-challenges-and-solutions-us.

Interior Controls

Engineering and installation standards and recommendations for Level 1 to Level 3 ADS will not functionally change for interior controls, as drivers will be responsible for manually manipulating these controls. However, in more advanced ADS (primarily Level 4 and Level 5), the majority of interior controls that are traditionally manipulated by the driver will be controlled by the ADS ECU.

Scope: FMVSS No. 101 (36 FR 22902) "specifies performance requirements for location, identification, color, and illumination of motor vehicle controls, telltales and indicators" (ECFR, 2021).

FMVSS No. 101 Ground Vehicle Standard, "Controls and Displays," specifies requirements for the location, identification, and illumination of motor vehicle controls and displays for commercial vehicles (NHTSA, 1971).

The ISO 2575.2010 standard, "Road Vehicles-Symbols for controls, indicators, and telltales," specifies symbols for use on controls, indicators, and telltales applying to passenger cars, light and heavy commercial vehicles, and buses to ensure identification and facilitate use (ISO, 2010).

Guidance: Current safety standards for motor vehicles assume a human occupant will be able to control the operation of the vehicle, and many standards incorporate performance requirements and test procedures geared toward ensuring safe operation by a human driver. Standards impose specific requirements for the visibility for a human driver of instrument displays, vehicle controls and status indicators, mirrors, and other driving information (NHTSA, 2018).

Standards, regulations, and requirements for interior displays, including conditions for controls, telltales and indicators, and displays are detailed in the FMVSS (36 FR 22902) §571.101 Standard No. 101: Controls and displays (ECFR, 2021). This standard also provides guidance on facilitating the proper selection of controls under day and night lighting conditions in order to reduce the diversion of the driver's attention from the driving task and mistakes in selecting controls.

Standards for controls to ensure the accessibility and visibility of controls and displays, under all lighting conditions, in order to reduce safety hazards caused by diversion of driver attention from the driving task and mistakes in selecting controls, are outlined and detailed in the FMVSS 101 Ground Vehicle Standard, "Controls and Displays" (NHTSA, 1971).

Standards for vehicle controls, indicators, and telltales specify symbols used on controls and displays to ensure proper identification and use, as well as indicate the display colors of optical telltales, which inform the driver of operation and malfunction status (ISO, 2010).

ADS Applications: With respect to currently available Level 1 and Level 2 automation technologies and Level 3 technologies under development, drivers must understand the capabilities and limitations of the technology, when human monitoring of the system is needed, and where it should be operated (NHTSA, 2018). OEMs may need to consider new approaches for providing information so that drivers can use the technology safely and effectively. In Level 4 and Level 5 trucks, the majority of interior controls traditionally manipulated by the driver will be controlled by the ADS ECU. As part of driver education and training programs, OEMs and AV dealers and distributors may consider including an on-road or on-track experience demonstrating AV operations and how humans interact with redesigned vehicle controls (NHTSA, 2018).

Need: NHTSA's current safety standards do not prevent the development, testing, sale, or use of ADS built into vehicles that maintain the traditional control features of human-operated vehicles. However, some Level 4 and Level 5 AVs may be designed to be controlled entirely by an ADS, and the interior of the vehicle may be configured without manual controls for human manipulation. For such ADS-equipped vehicles, NHTSA's current safety standards constitute an unintended regulatory barrier to innovation (NHTSA, 2018).

A concern is that as ADS and computer technology become more capable and complex, it will be more challenging for drivers and safety monitors to understand what the ADS is doing and how the vehicle is functioning; yet the driver/safety monitor is still responsible to take over manual control when needed. In Level 4 and Level 5 ADS vehicles, manual driving controls will be replaced by automation, potentially degrading manual driving, and vehicle performance and diagnostic monitoring skills currently ingrained in CMV drivers.

References:

Electronic Code of Federal Regulations. (2021). Part 571-Federal Motor Vehicle Safety Standards. Subpart B-Federal Motor Vehicle Safety Standards. §571.101. Standard No. 101; Controls and displays. Accessed from https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=&SID=635b08ab5e31e3bf86ebf4cb93c6aecb&mc=true&n=pt49.6.571&r=PART&ty=HTML#se49.6.571_1101

ISO. (2010). *ISO 2575:2010 – Road Vehicles-Symbols for Controls, Indicator, and Tell-tales*. Accessed from https://www.iso.org/standard/54513.html

National Highway Transportation System Administration. (1971). *Controls and displays*. Accessed from https://saemobilus-sae-org.ezproxy.lib.vt.edu/content/FMVSS100/

National Highway Transportation System Administration. (2018). *Preparing for the future of transportation: Automated Vehicles 3.0*. Accessed from: https://www.transportation.gov/sites/dot.gov/files/docs/policy-initiatives/automated-vehicles/320711/preparing-future-transportation-automated-vehicle-30.pdf

5.1.2.5 Sensors

Radar

Scope: The scope of the SAE Surface Vehicle Information Report is to (1) identify the expected functionality and performance from active safety sensors, and (2) detail a basic understanding of how sensors work. Radar, an active object detection system, uses radio waves to determine the range, direction, and speed of objects. Radar transmits pulses of radio waves or microwaves, which bounce off any object in their path, and then reflect the wave's energy back to a dish or antenna, where it is sensed.

Guidance: Two general methods of measuring distance using radar are direct and indirect propagation methods. Types of automotive radar systems include pulsed, continuous wave, frequency-modulated continuous wave, and radar sensor architectures. Every radar system is divided into two categories: small-angle bi-static radars and mono-static radars. Radar frequency (wavelength) directly influences design and the performance of radar systems. Higher frequency/shorter wavelengths allow for better spatial resolution of the sensor, allow more compact design, and are less susceptible to interference. Two different frequency bands are currently being used in industry (see SAE J3088 for short- and long-range specifications). Radar has some limitations. Due to the low resolution and the lack of semantic features, radar-related technologies for object detection and map updating are still insufficient compared with other perception sensors in high automated driving (Zhou et al., 2020). Radar can be limited by resolution specifications, such as angular, distance, and Doppler resolutions, in addition to obscuration (see SAE J3088). Finally, while most radar sensors react well to adverse weather, there are reported cases where radar functions can be disabled by obscurities, such as the accumulation of ice in front of the sensor. Modern radar sensor returns range, velocity (including sign), angle (typically azimuth but sometimes elevation as well), and signal-to-noise ratio. They may update this information at rates significantly faster than camera systems. Given that radar systems can provide distance, speed, azimuth angle, and signal-to-noise ratio information, a reliable feature extraction and classification process has to be implemented either at the sensor level or the ECU level. To classify objects such as pedestrians and vehicles, the velocity profile and range profile signal features are used, along with other available parameters (size of the object, variations of the Doppler shift, etc.). Since radar is based on the use of radio frequencies, the design of radar solutions is heavily regulated by national organizations, such as the Federal Communications Commission (FCC) in the United States. These regulations define the frequencies that can be used and limit the output power of the devices. For example, at the date of publication, the 77- to 81-GHz band is not yet authorized by the FCC. This band has been approved by the European Union (EU) and Japan.

ADS Application: For high-level automated driving, radar data is used in object detection, object tracking, motion prediction, and self-localization. Because of the limited spatial resolution of radar, radar sensors are often used with vision sensors in applications that require precise shape recognition or object classification. For lane change assistance applications, radar can identify approaching vehicles, and can localize to which lane the vehicle is in. This is true as long as either the target vehicle's range or velocity is different than the surrounding vehicles. If the ranges and velocities of the target vehicles are identical, vision systems can be used to augment the lane information.

Millimeter-wave (MMW) radar is low cost and enables long measuring distance range, dynamic target detection capacity, and environmental adaptability to enhance the stability, security, and reliability of the vehicle (Zhou et al., 2020). MMW has been widely applied on Level 1 and Level 2 ADAS. MMW helps ADAS to find and avoid driving risks and has functionality in frontal collision warning, lane change warning, and automatic emergency braking (AEB). MMWs can be used to control vehicle longitudinal and lateral dynamic and following distance, and therefore have practical application in adaptive cruise control. Finally, MMW radar can adapt to weather conditions and can directly measure objects' speed for a long range.

Need: ADS-equipped CMVs need to be able to sense conditions farther in advance to allow for longer stopping distances (Ackerman, 2021). Sensors should be able to detect other vehicles and calculate trajectories at distances twice that of CMV drivers. Increased accuracy of classifying objects and object size, and better detection and precision for small objects are needed for radar capabilities in ADS, both light and heavy vehicle (Bigelow, 2019). Ground penetrating radar, a promising emerging technology that could help with localization in poor weather conditions, is being monitored by companies as a potentially important sensor modality in the future (Rangwala, 2020).

References:

Ackerman, E. (2021). *This year, autonomous trucks will take to the road with no one on board*. Accessed from: IEEE Spectrum. https://spectrum.ieee.org/transportation/self-driving/this-year-autonomous-trucks-will-take-to-the-road-with-no-one-on-board

Bigelow, P. (2019). Radar finds new place in self-driving technology. *Automotive News.* Accessed from: https://www.autonews.com/technology/radar-finds-new-place-self-driving-technology.

Rangwala, S. (2020). LiDAR vision-helping bring autonomous trucks to your neighborhood. *Forbes*. Accessed from https://www.forbes.com/sites/sabbirrangwala/2020/12/17/lidar-visionhelping-bring-autonomous-trucks-to-your-neighborhood/?sh=4215531073f7

SAE Surface Vehicle Information Report-Active Safety System Sensors (J3088). (2017). SAE International. Accessed from https://saemobilus-sae-org.ezproxy.lib.vt.edu/content/J3088_201711/

Zhou, T., Yang, M., Jiang, K., Wong, H., & Yang, D. (2020). MMW radar-based technologies in autonomous driving: A review. *Sensors (Basel, Switzerland)*, *20*(24), 7283. https://doi.org/10.3390/s20247283

Cameras

Scope: The scope of the SAE Surface Vehicle Information Report is to (1) identify the expected functionality and performance from active safety sensors, and (2) detail a basic understanding of how sensors work.

Guidance: Vision sensors are used in a wide range of applications, capturing the light intensity and color (if applicable) of the surrounding environment in arrays of varying resolution and density. Vision sensors are passive, relying on ambient lighting as a light source, and information can be directly displayed and comprehended by humans without minimal processing, or overlayed with complementary information. Information obtained from vision sensors on an object typically relies on a supplementary form of processing of the acquired image. Vision sensors used in active safety applications use charge coupled device sensors and active pixel sensors for acquiring the image. Advantages and disadvantages of each are further discussed in SAE J3088. The primary technical features of cameras for automotive applications are dynamic range, imaging sensitivity, spectral range sensitivity, resolutions, frame rate, and light-emitting diode (LED) flicker.

The vision sensor is usually incorporated into a camera that includes lenses, power supply, and housing. Some include high-end image processing functions specific to the applications supported, such as sign and lane recognition and distance estimation. Monocular and stereo cameras are further discussed in SAE J3088. Vision sensors generate a very large quantity of data, and therefore the transport of the image data between the sensor and the processing unit can be based on a different protocol that must be considered when selecting a sensor.

Cameras that serve as sensors have some limitations. Algorithms performing feature extraction from images rely on contrast of either color or intensity between objects and their background. In situations where the camera system may not be able to extract key features (e.g., detecting a pedestrian dressed in white against a white snowbank), it is critical to assess the failure potential of identifying the desired features and include safeties in the processing chain. It is important for vision systems to be evaluated under conditions that create a degradation of performance in addition to optimal performance conditions.

ADS Applications: Vision sensors have a wide range of uses in detecting and classifying objects based on visible qualities, such as intensity, color, and shape. They are also used to estimate distance to objects and provide visual feedback information to the driver. Vision sensors are used in collision warning/mitigation applications, adaptive cruise control, lane detection, lane assist, and lane departure warning, sign recognition, obstacle classification (i.e., pedestrian, vehicle recognition), vision enhancement (i.e., night vision, backup camera, blind spot viewing, backseat passenger viewing, etc.), accident recorder, and adaptive headlamp control. Vision sensors are also found inside the vehicle to estimate occupant position, driver pose, and gaze estimation for driver vigilance monitoring.

Of particular interest for CMV applications are visual sensors used in CMV driver monitoring video platforms. These systems have advanced machine vision to capture and categorize risky driving behaviors for CMV driver feedback and training; driver recognition and identification (for multiple drivers operating a tractor); cameras with wide-angle dual lens for better picture quality and accuracy; continual video to capture real-time driving behaviors; and infrared light to provide clear visibility at low light and night. Visual sensors used in CMV driver monitoring video platforms provide reliable video evidence for occasions when fleets need information about an event, or to verify service or ensure driver compliance. Visual data can help to exonerate drivers regarding crash fault and prevention, ultimately saving money, insurance claims, and lives.

Needs: Practical solutions are needed to address lighting, contrast, and depth data, which are fundamental limitations of camera technologies. Top technology challenges facing AV image sensors include compact and durable sensor packaging and thermal stability (Smithers, n.d.). Building a sensor into a camera housing is a challenge for developers. The size is crucial for the camera and, ultimately, pixel size and count determine the optical diagonal. Additionally, the temperature has a significant impact on the life expectancy of the camera system, and thus the failure rate of the overall camera system. Image sensors on a vehicle must be able to function across a range of challenging environmental conditions; not to mention, the sensor itself is a source of heat. Image sensors deliver the best quality image at a given temperature and read speed, but when outside this range the sensor is functional but with limited image quality or visible artifacts in the picture. Extreme temperatures, especially heat, can distort the image by bright pixilation. Outside-mounted cameras are especially challenging as they are more affected by temperature fluctuations. For example, direct sunlight generates temperatures over 100 degrees Celsius in an active camera. The primary concern is to determine the intrinsic heat in the sensor and ensure there are no mechanical shifts in the optical path.

References:

SAE Surface Vehicle Information Report-Active Safety System Sensors (J3088). (2017). SAE International. Accessed from https://saemobilus-sae-org.ezproxy.lib.vt.edu/content/J3088_201711/

Smithers. (N.D.) *Top technology challenges for autonomous vehicle image sensors*. Accessed from https://www.smithers.com/resources/2019/mar/challenges-for-autonomous-vehicle-image-sensors

LIDAR

Scope: The scope of the SAE *Surface Vehicle Information Report* is to (1) identify the expected functionality and performance from active safety sensors, and (2) detail a basic understanding of how sensors work.

Guidance: Light Detection and Ranging (lidar), an active sensing technology, can measure the distance to targets by illuminating them with light and analyzing the backscattered light. The majority of lidar sensors use ion laser light sources, though LEDs and lasers are also used. Most automotive commercial lidar systems use infrared light wavelengths, though a wide range of light wavelengths can be used, including ultraviolet, visible, and infrared. In automotive applications, the backscattering of light is caused by simple reflection, or Raleigh scattering. Three general methods of measuring distance using lidar include incoherent or direct energy detection (also known as pulsed lidar), coherent energy detection, and structured light method. Pulsed lidar is commonly used in automotive technologies. See SAE J3088 for details on specifications, sensor detection and processes, and uses.

Lidar has a higher frequency and shorter wavelength compared to radar. Unlike radar, commercial light-based sensors do not estimate an object's speed in real time but rather rely on acquisition of the distance differential between two acquisitions to estimate speed. Lidar has a much higher spatial resolution than radar, enabling more precision and management of interference in a more constrained manner. The reflectivity of an object is the major external factor influencing the performance of lidar sensors. Many factors can influence reflectivity, and therefore lidar performance (see SAE J3088).

Variants of lidar sensor architecture include light source, wavelength, photodetector type, and scanned vs. flash lidar. See SAE J3088 for details on each type, including properties, specifications, uses, and applications.

Lidar lasers can burn the retina of the eye; therefore, automotive lidars must be designed for eye safety. U.S. and European regulations exist for eye safety, and the Maximum Permissible Exposure is the key indicator to evaluate safety (see J3088 for detailed specifications). The limitations of lidar include angular resolution, distance resolution, obscuration of small particles, field of view or illumination, mounting location, and range or distance profile of the scene (see SAE J3088).

A key challenge with current lidar in trucking is the ability to handle a large field of vision at low ranges and a smaller field of vision at high ranges with accurate resolution. A stepped field of vision in both directions would be helpful to the perception suite (Rangwala, 2020). Additionally, performance, durability, and reliability under more extreme conditions of shock and vibration need to be addressed. Flash lidar solutions could be advantageous for trucking applications due to improved reliability, though such lidars do not currently provide the required range, resolution, and field-of-view performance for trucking automation. Since lidar is immature compared to other sensors, improvements can be instilled quickly and often; therefore, the perception stack needs to be able to accommodate these improvements seamlessly.

ADS Applications: Lidar sensors are distance and range profile determination sensors and can serve applications similar to those of radar sensors. Lidar resolution is directly related to sensor cost; therefore, determining the sensor resolution requirements is important to consider. Lidar sensors are monochromatic and cannot sense color and thus cannot be used in applications that require color information to inform precise shape recognition or object classification. Camera sensors must accompany lidar for these applications. Lidar is appropriate in complex urban situations where multiple objects or dense range profiles must be acquired, due to the higher spatial resolutions and reduced sensitivity to interference. Additionally, the structured light sensors of lidar have in-cabin applications to determine occupant position and driver attentiveness.

Applications of lidar sensors include parking assistance and backup parking aid, adaptive cruise control, collision warning, collision mitigation, blind spot detection, lane change assist, and rear crash avoidance.

Need: For lidar requirements, the perception range for a front-facing unit with high resolution and field of view is critical, as are the capabilities of the sensor stack to reliably work in all weather conditions (Rangwala, 2020). Since lidar performance is impacted by weather, trucking companies often rely on radar and cameras to perform under bad weather conditions. Sensor mounting is also key; specially designed mounts ensure that higher shock loads minimize impacts on performance and reliability. Lidar systems that maintain reliability in harsh environmental conditions are also key. To help with roadway debris, higher resolution lidar within a specified field of view near the horizon could help find debris earlier. Finally, fleets also cite the importance of close relationships with lidar suppliers so that as the capabilities of the technology and needs of the drivers evolve, and new sensors become available, they can seamlessly be integrated into operations (Rangwala, 2020).

References:

Rangwala, S. (2020). *LIDAR vision-helping bring autonomous trucks to your neighborhood*. Accessed from https://www.forbes.com/sites/sabbirrangwala/2020/12/17/lidar-visionhelping-bring-autonomous-trucks-to-your-neighborhood/?sh=41da300873f7

SAE Surface Vehicle Information Report-Active Safety System Sensors (J3088). (2017). SAE International. Accessed from https://saemobilus-sae-org.ezproxy.lib.vt.edu/content/J3088_201711/

GPS/Other Antennas

Scope: Identify the functionality and performance to be expected from GPS sensors. Establish a basic understanding of how sensors work regarding GPS (see SAE J3088).

Guidance: GPS is a space-based satellite navigation system that provides information on location and time, in all weather conditions, anywhere on Earth. GPS requires an unobstructed line of sight to four or more GPS satellites. Advancing technologies and new demands on the existing GPS system have led to efforts to update and modernize the GPS system.

The design and installation of GPS systems into the vehicle must account for some common GPS signal degradations, including ionosphere and troposphere delays, signal multipath, receiver clock errors, orbital errors, number of visible satellites, satellite geometry, and internal degradation of the satellite signal (see SAE J3088).

ADS Applications: Originally developed for mapping and navigation systems, GPS has been employed to use vehicle location data to aid active safety systems. It can provide location and speed data to warn the driver of speeding or upcoming road delays and hazards. GPS can also be used in vehicle-to-vehicle communication (see SAE J3088).

Needs: Multi-frequency receivers are recommended to reduce errors, such as signal delay, which can come from atmospheric interference. The most commonly used frequency combination is L1/L2, but L5 is being used for more modern GPS units.

Precise Point Positioning or Kinematic Positioning may be used to aid in finding the precise location of the vehicle. These programs and services may often be used for free, or for a nominal membership fee (Hexagon).

References:

Hexagon/NovAtel. *Applications of High-Precision GNS*S. https://novatel.com/industries/autonomous-vehicles

SAE Surface Vehicle Information Report-Active Safety System Sensors (J3088). (2017). SAE International. Accessed from https://saemobilus-sae-org.ezproxy.lib.vt.edu/content/J3088_201711/

Camera and Sensor Connectors/Cabling

Scope: Camera/monitor/sensor connector and cabling guidance for heavy-duty commercial vehicles.

Guidance: The various types of connectors and cables are described. Images of connectors and pinouts are provided. The connectors described include these analog types: Bayonet-Neil-Concelman (BNC) video coaxial, Deustsches Institut fur Normung (DIN) connector, Radio Corporation of America (RCA), and Fachkreis Automobil (FAKRA). The connectors described include these digital types: low-voltage differential signal (LVDS) high-speed data and S-video, Ethernet, Digital Visual Interface (DVI), High-Definition Multimedia Interface (HDMI), and

USB. Installation guidelines are also provided, including vehicle interfacing, power and ground connections, routing and clipping, and slack and bundling.

ADS Application: Multiple types of sensors, including cameras, are installed and connected on ADS-equipped CMVs to support detection and perception capabilities.

Need: When designing and installing ADSs on heavy-duty vehicles, a list of connector and cable types can improve implementation. Proper installation can ensure durable performance and communication of sensors to the ADS.

Reference: Technology & Maintenance Council. TMC Recommended Practice RP 183: Video Camera and Sensor Connector and Cabling Guidelines, 3/2019. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

5.1.2.6 Body Exterior

Headlamps

Scope: Specifications for headlamps to be equipped on heavy and commercial vehicles.

Guidance: Should comply with RP 111, 112, 113, 114, 120, 127B, FMVSS No. 108, FMVSS 108, SAE J575. Headlamps (halogen/non-halogen sealed beam, 2-lamp replacement bulb) are identified by automotive trade number and expected life at design (assumes 12 V nominal) and accelerated voltages. Guidance is provided on vibration resistance, system operating voltage, voltage surge suppression, and field verification.

ADS Application: Headlamps provide visibility for human operators of vehicles. However, headlamps also increase conspicuity of the vehicle to other vehicles both operated by humans and ADS. Headlamps also assist cameras as sensors.

Need: New lamp output levels may be developed and varied dynamically to accommodate optimal conspicuity and human operational control, while also supporting ADS sensing on ADS-equipped CMVs.

Reference: Technology & Maintenance Council. TMC Recommended Practice RP 124B: Heavy-Duty Headlamp Design Specifications, 5/2021. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

Exterior Lighting Systems

Scope: Guidelines for the design and installation of exterior lighting systems on Class 7–8 combination vehicles.

Guidance: Considerations are provided for signal, marker, clearance, and identification lamps. The guidelines are intended to improve safety and maintenance while reducing downtime and the cost of ownership. System design priorities include motor vehicle safety standards (e.g., FMVSS 108), feature benefits, and application (i.e., on- versus off-highway). Power requirements are addressed because voltages that are too high reduce lamp life and voltages that are too low reduce lighting effectiveness. Some States have made it a requirement that a minimum of 85% of the design voltage must be supplied to exterior lamps. A priority for installation is location. The location of lamps should meet the requirements of FMVSS No. 108, and other components mounted around the lamps should not interfere with the visibility of the lamps.

ADS Application: ADS-equipped vehicles may have additional components mounted on the exterior of the tractor truck or trailer. Similar considerations for these components (e.g., sensors) may benefit from understanding the wiring, mounting, durability, and visibility requirements of exterior lighting systems.

Need: New components mounted in or on the exterior body of tractor-trailers should not interfere with the visibility by and communication to other vehicle operators through the use of exterior lighting systems.

Reference: Technology & Maintenance Council. TMC Recommended Practice RP 148: Exterior Lighting Systems for Signaling, Marker, Clearance and Identification Lamps. 4/2019. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

Lenses and Glass

Scope: Refers to exterior components on the tractor or trailer body with ADS function, including cameras and other sensor that have lenses, and windshields that serve as the physical support for mounted ADS cameras and sensors or housing for built-in sensors. The scope of the SAE Surface Vehicle Information Report (J3088) is to (1) identify the expected functionality and performance from active safety sensors, including exterior cameras, and (2) detail a basic understanding of how these cameras work. This SAE Recommended Practice (J381) details uniform test procedures and performance requirements for the defrosting system of enclosed cab trucks, buses, and other vehicles.

Guidance: Design and installation of exterior cameras and lenses on ADS vehicles must consider proper protection from the external environment, elements, weather, and debris. In order for sensors and cameras mounted on the windshield to function properly, performance of the CMV's defrosting system must be capable of maintaining a cleared viewing area. See SAE Recommended Practices J381 for test procedures and performance requirements (SAE, 2000).

ADS Applications: Exterior cameras have a wide range of uses in detecting and classifying objects based on visible qualities, such as intensity, color, and shape (SAE, 2017). They are also used to estimate distance to objects and provide visual feedback information to the driver. Cameras are used in collision warning/mitigation applications, adaptive cruise control, lane detection, lane assist, lane departure warning, sign recognition, obstacle classification (i.e., pedestrian, vehicle recognition), vision enhancement (i.e., night vision, backup camera, blind spot viewing, backseat passenger viewing, etc.), accident recorder, and adaptive headlamp control.

Windshields are the physical mounting mechanisms for ADS cameras and sensors, in addition to housing built-in sensors, special positioned areas of tint/no tint, heaters, and noise reduction layers, among others (Snow, 2017). The location and position on the windshield of these attached and built-in sensors are extremely precise. For example, lane departure warning systems have precise areas of the windshield that the lens sees through; therefore, great care must be taken during installation to ensure everything is fitted and lined up properly.

Needs: Exterior cameras and lenses that are susceptible to harsh elements and debris can be easily obscured or blocked, which can completely undermine the safety system. To address this from an installation perspective, some OEMs have moved exterior cameras and sensors to behind the windshield (Linkov, 2018). Great care must be taken during installation to ensure that the windshield is fitted and lined up properly due to the precise location and position of attached and built-in ADS sensors (Snow, 2017).

References:

Linkov, J. (2018). The big race to protect car sensors from their biggest foes: Dirt and weather. *Consumer Reports*. Accessed from https://www.consumerreports.org/car-maintenance/protect-car-sensors-from-dirt-and-weather/

SAE Surface Vehicle Information Report. (2017). *Active safety system sensors* (J3088). SAE International. Accessed from https://saemobilus-sae-org.ezproxy.lib.vt.edu/content/J3088_201711/

SAE Surface Vehicle Recommended Practice (J381). (2020). *Windshield defrosting systems test procedure and performance requirements-Trucks, buses, and multipurpose vehicles.* SAE International. Accessed from https://saemobilus-sae-org.ezproxy.lib.vt.edu/content/J381_200009/.

Snow, D. (2017). *Windshield replacement calibration with ADAS: What you need to know*. Accessed from https://info.glass.com/windshield-replacement-calibration-adas/

Brackets and Mounts

Scope: The SAE "Recommended Practice Truck and Bus Aerodynamic Device and Concept Terminology" document (J2971) describes devices and technologies used to control aerodynamic forces on heavy trucks and buses.

Guidance: J2971 describes the mounted devices common on trucks and buses that aid in aerodynamics. They are aerodynamic bumper, mirror, visor/slat, dam, cab edge radius, cab roof fairing, cab roof deflector, side edge turning vane, cab side fairing, cab side flex extender, chassis skirt, chassis skirt ground seal, undercarriage axle fairing, undercarriage fairing, undercarriage bogie fairing, and fender lips. It also lists aerodynamic mounts for trailers/freight boxes and buses. (J2971)

ADS Applications: While aerodynamics may not impact ADS, it does reduce vehicle fuel consumption, which frees up more resources for other systems.

Needs: All mounted parts must be installed properly to achieve aerodynamic benefits. Manufacturers of these products should have training or diagrams to explain how to properly install all mounted aerodynamic parts. (J2971)

References:

SAE J2971, *Recommended Practice Truck and Bus Aerodynamic Device and Concept Terminology*

5.1.2.7 Chassis, Tires, and Wheels

Wireless Tire Pressure Monitoring Systems

Scope: Guidance for heavy-duty commercial vehicle Tire Pressure Monitoring Systems (TPMS) and radio frequency identification (RFID) devices and processing modules used to measure tire inflation and temperature.

Guidance: Guidance and minimum requirements to support interoperability and performance criteria. TPMS sensors and RFID collect tire identification, installation, and pressure and temperature data and communicate to the vehicle's onboard processing unit, where the data can be stored for viewing through in-cab displays or transmitted from the vehicle to dispatch and operations centers.

ADS Application: ADS-equipped CMVs may also be equipped with TPMS and onboard processing units that communicate the status of the tires to onboard data loggers or off the vehicle and over-the-air to roadside inspectors and fleet dispatch or operation centers.

Need: ADS-equipped CMVs may operate for hours without onboard observation or inspection by human operators. Continuous monitoring of each tractor truck and trailer tire's inflation and temperature status during driverless operations can support safe and efficient transportation of goods. Tire performance can be an important indicator of vehicle, roadway, and environmental status.

Reference: Technology & Maintenance Council. TMC Recommended Practice RP 228C: Guidelines for Wireless Tire Pressure Monitoring Systems (TPMS) for Medium- and Heavy-Duty Truck Tires, 3/2018. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

Considerations for Splash and Spray Suppression

Scope: Recommended practices for specifying equipment and evaluation methods to reduce road spray at highway speeds in inclement weather for heavy-duty commercial vehicles. This recommended practice is connected to "Trailers, Bodies, and Material Handling," section S.7 of the manual.

Guidance: "Spray is defined as the projection of standing water from a road surface as vehicles pass through that water at speeds greater than 30 mph" (TMC RP 759). Spray can take the forms of water jets, spray, and mist. Locations for heavy spray include tires, tractor-trailer gap, obstructions to air flow in the undercarriage, and around the rear of the vehicle. Road salts in the spray can increase the problem of obstructing glass, sensors, and lamps. Road surfaces such as non-porous asphalt can increase road spray issues compared to channeled concrete or porous asphalt. Steer tires play an important role in the problem of road spray. Proper selection and maintenance of steer tires to reduce spray include proper inflation, tread depth, and chine—a bead detail available on some steer tires that redirects water back to the paved surface. Some types of trailers, such as flatbed and car carriers, increase road spray. Components that are mounted perpendicular to the direction of travel create spray. Aerodynamically designed body components and elements that reduce drag can reduce road spray.

ADS Application: The performance of sensors mounted on the interior and exterior of ADS-equipped CMVs may be reduced by road spray and splash.

Need: Specifying aerodynamic body components and tires carefully could impact the amount of road spray that may cause ADS-equipped CMV sensors such as cameras and lidar to have reduced performance. The shape and location of sensors mounted on the cabs may increase the road spray and obstructions for other vehicles.

Reference: Technology & Maintenance Council. TMC Recommended Practice RP 759: Splash and Spray Suppression Guidelines, 4/2015. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

5.1.2.8 Trailer Interfaces

Truck-Trailer/Converter Dolly Jumper Cable, Line, and Connectors

Scope: Selection of trailer hook-up lines.

Guidance: Connector design for securing trailers to truck-tractors; cable length and suspension practices to ensure sufficient cable length and to avoid sagging, abrasion, and snagging during trailer turns.

ADS Application: ADS-equipped CMVs that are connected to trailers, which are equipped with sensors on the trailer.

Need: ADS-equipped CMVs seek additional data from trailers to improve detection around the combination vehicle.

Reference:

Technology & Maintenance Council. TMC Recommended Practice RP 107C: Seven Conductor Truck-Trailer/Converter Dolly Jumper Cable and Connector Selection, 5/2014. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

Technology & Maintenance Council. TMC Recommended Practice RP 417B: Selection Guidelines for Pneumatic Tractor-Trailer Hookup Lines, 5/2023. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

Technology & Maintenance Council. TMC Recommended Practice RP 435A: Installation and Inspection Guidelines for Pneumatic Tractor-Trailer Hookup Lines, 5/2023. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

Tractor Truck ABS Power Supply

Scope: Considerations when interfacing with tractor truck ABS.

Guidance: Performance recommendations and test method for tractor truck power available for stop lamp circuits (SAE J560 seven-pin) and dedicated power circuit. Because circuit designs should account for the use of long seven-conductor electrical cords among some tractor trucks, approximate voltage drops in seven conductor cords by length (i.e., 10–22 ft) are provided. Guidance should be combined with TMC RP 141A.

ADS Application: Per SAE J3016 JUN2018, "crash avoidance features, including intervention-type active safety systems, may be included in vehicles equipped with driving automation systems at any level. For ADS features (i.e., Levels 3–5) that perform the complete dynamic driving task (DDT), crash avoidance capability is part of ADS functionality."

Need: ADS-equipped CMVs may apply existing active safety systems such as ABS; therefore, consideration of vehicle network and tractor truck to trailer communication of ABS and interfaces with ADS equipment is important.

Reference: Technology & Maintenance Council. TMC Recommended Practice RP 137D: Antilock Electrical Supply from Tractors through the SAE J560 Seven-Pin Connector, 5/2017. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)

Trailer ABS Power Supply

Scope: Considerations when interfacing with trailer ABS.

Guidance: Performance recommendations and test method for trailer electrical systems and maximum circuit resistances for stop lamp circuits (SAE J560 seven-pin) and continuous power circuits. Recommendations for minimum voltages to support trailer equipment that vary in length, wiring gauge sizes, lighting technology, ABS power consumption, and ground methods. Guidance considers single, double, and triple trailer combinations. Guidance should be combined with TMC RP 137D.

ADS Application: Per SAE J3016 JUN2018, "crash avoidance features, including intervention-type active safety systems, may be included in vehicles equipped with driving automation systems at any level. For ADS features (i.e., levels 3–5) that perform the complete DDT, crash avoidance capability is part of ADS functionality."

Need: ADS-equipped CMVs may apply existing active safety systems such as ABS; therefore, consideration of vehicle network and tractor truck to trailer communication of ABS and interfaces with ADS equipment is important.

Reference: Technology & Maintenance Council. TMC Recommended Practice RP 141A: Trailer ABS Power Supply Requirements, 5/2017. Washington, D.C. (https://tmcconnect.trucking.org/tmclibraries/newrplibrary)