

ASSESSMENT, EVALUATION, AND APPROACHES TO TECHNICAL TRANSLATIONS OF FMVSS AND TEST PROCEDURES THAT MAY IMPACT COMPLIANCE OF INNOVATIVE NEW VEHICLE DESIGNS ASSOCIATED WITH AUTOMATED DRIVING SYSTEMS

Myra, Blanco
Michelle, Chaka
Clay, Gabler
Loren, Stowe
Warren, Hardy
Joshua, McNeil
Vikki, Fitchett
Virginia Tech Transportation Institute
United States

Ellen, Lee
National Highway Traffic Safety Administration
United States

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ABSTRACT

The project described in this paper provides research findings in terms of options regarding technical translations of select Federal motor vehicle safety standards (FMVSS) and related Office of Vehicle Safety Compliance (OVSC) test procedures. The research findings are based on potential regulatory barriers identified for self-certification and compliance verification of innovative new vehicle designs that may appear in vehicles equipped with Automated Driving Systems (ADSs). This paper documents the framework used to evaluate the regulatory text and OVSC test procedures with the goal of identifying possible options to remove regulatory barriers for the self-certification and compliance verification of ADS-Dedicated Vehicles (ADS-DVs) that lack manually operated driving controls. It also describes the research activities for 15 crash avoidance standards (100-series) and 15 crashworthiness/occupant protection standards (200-series). This research effort incorporates feedback obtained from stakeholders and subject matter experts (SMEs).

RESEARCH QUESTION/OBJECTIVES

The goal of this project was to provide research findings in terms of options regarding technical translations of select Federal motor vehicle safety standards (FMVSS) and related Office of Vehicle Safety Compliance (OVSC) test procedures based on potential regulatory barriers identified for self-certification and compliance verification of innovative new vehicle designs that may appear in vehicles equipped with Automated Driving Systems (ADSs). A technical translation is a modification that would allow regulatory text and/or test procedures that are identified as potential barriers to be carried out with the same basic engineering performance without manual control-specific restrictions. Technical translations developed under this effort present options for the regulatory text (i.e., performance requirements and test procedures) and related OVSC test procedures when a regulatory barrier is present. This paper describes the option development process used to address the technical translations and the testing procedures for 30 select FMVSS, such that the identified potential regulatory barriers could be removed for vehicles operated exclusively by an ADS that do not have the traditional controls used by human drivers. These 30 FMVSS represent a mix of standards where potential straightforward translations are presented (e.g., FMVSS No. 125, "Warning devices") and other standards that could yield findings near-term that could be utilized for mid-term and long-term research (e.g., FMVSS No. 126, "Electronic stability control systems for light vehicles"). An initial set of 12 FMVSS was selected by NHTSA and the research team selected the remaining 18 FMVSS with a focus on how they could contribute to long-term research. Technical translations were used to either present potential modifications to the existing regulatory text or, alternatively, to create new regulatory language that would be capable of accommodating an ADS's functionalities. The FMVSS of focus for this study are illustrated in Figure 1 below.

| Crash Avoidance | | | Crashworthiness & Occupant Protection | | |
|--|--|---|---|--|---|
| 101 Controls and displays | 110 Tire selection and rims and motor home/recreation vehicle trailer load carrying capacity information | 124 Accelerator control systems | 201 Occupant protection in interior impact | 206 Door locks and door retention components | 216a Roof crush resistance |
| 102 Transmission shift position sequence, starter interlock, and transmission braking effect | 111 Rear visibility | 125 Warning devices | 202a Head restraints | 207 Seating systems | 219 Windshield zone intrusion |
| 103 Windshield defrosting and defogging systems | 113 Hood latch system | 126 Electronic stability control systems for light vehicles | 203 Impact protection for the driver from the steering control system | 208 Occupant crash protection | 222 School bus passenger seating and crash protection |
| 104 Windshield wiping and washing systems | 114 Theft protection and rollaway prevention | 138 Tire pressure monitoring systems | 204 Steering control rearward displacement | 210 Seat belt assembly anchorages | 225 Child restraint anchorage systems |
| 108 Lamps, reflective devices, and associated equipment | 118 Power-operated window, partition, and roof panel systems | 141 Minimum Sound Requirements for Hybrid and Electric Vehicles | 205 Glazing materials | 214 Side impact protection | 226 Ejection Mitigation |

Figure 1. 100-series and 200-series FMVSS of focus

DATA SOURCES

NHTSA recognizes that advanced-concept vehicle designs are on the horizon and may not be addressed throughout the current FMVSS. The findings from this project help identify potential regulatory barriers to self-certification and compliance verification of some of these advanced-concept vehicles that are equipped with ADSs. SAE International’s (SAE’s) Recommended Practice *J3016 Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles* [1] defines an ADS as “The hardware and software that are collectively capable of performing the entire DDT [Dynamic Driving Task] on a sustained basis, regardless of whether it is limited to a specific operational design domain (ODD); this term is used specifically to describe a level 3, 4, or 5 driving automation system.” The same Recommended Practice defines Automated Driving System-Dedicated Vehicle (ADS-DV) in this way: “A vehicle designed to be operated exclusively by a level 4 or level 5 ADS for all trips within its given ODD limitations (if any)” but goes on to say that level 3 systems could possibly be included under this term in the future [1]. However, this project’s development of FMVSS technical translation options focused on a particular type of ADS-DV; i.e., vehicles designed to be operated exclusively by an SAE level 4 or level 5 ADS for all trips, and which are not equipped with manually operated driving controls. Thus, level 3 ADS-equipped vehicles (i.e., vehicles equipped with a user interface that permits operation by a human driver) were outside of the scope of this project, even if they could be categorized as ADS-DVs under the SAE definition.

A report prepared by the United States Department of Transportation (USDOT) Volpe National Transportation Systems Center entitled *Review of Federal Motor Vehicle Safety Standards (FMVSS) for Automated Vehicles: Identifying Potential Barriers and Challenges for the Certification of Automated Vehicles using Existing FMVSS* [2]—referred to hereafter as the “Volpe Report”—included two reviews of the FMVSS: 1) a review to identify standards that include an explicit or implicit reference to a human driver, and 2) a review to identify standards that might pose a barrier for compliance verification of a wide range of concept vehicles that may be equipped with an ADS. From this review, 13 automated vehicle concepts were defined to reflect the identified barriers and potential future applications of automated vehicle technology. The 13 concepts differed in their design convention and speed classification. Design convention considered differences in the application of advanced features that take full advantage of automation (e.g., removing steering wheel). Speed classification regarded low-speed (e.g., speed restricted to 40 kmph/25 mph) and high-speed (i.e., no speed restriction).

The ADS-FMVSS project presented herein focused on design concepts similar to three design concepts from the Volpe Report [2] which do not have vehicle controls for human drivers. Those concepts are:

- *Highly Automated Vehicle with Advanced Vehicle Design*
- *Highly Automated Vehicle with Novel Design*
- *Low Speed Highly Automated Vehicle with Advanced Design*

The Volpe Report categorized certain types of regulatory barriers for ADS-equipped vehicles and linked them to corresponding standards and concepts [2; Appendix B]. It identified several regulatory barriers, highlighting uncertainty about how vehicles with innovative designs would execute some FMVSS test procedures and, therefore, how these vehicles would be tested to verify compliance with the standards. The Volpe Report was used during the current project to develop a framework to describe ADS-DV features. The vehicle features for each of the three concepts noted above were grouped into cohesive categories in the framework development process. These categories identified the main areas where ADS-DV concept designs could potentially need very specific terminology and specifications relating to FMVSS regulatory barriers (i.e., technical translation options). The framework focused on concepts that are impacted by the technical translations, concepts that helped the research effort anticipate how an ADS may perform the entire DDT without user intervention, and any safety-related aspects of interest. In addition, the work included expanding the features of interest to include features not described in the Volpe Report that may be necessary for the implementation of advanced and novel designs (Figure 2).



Figure 2. Categories and features of interest

METHODS

The translation process that was used entailed analyzing the language of select 100-series (crash avoidance) and 200-series (crashworthiness/occupant protection) FMVSS for key terms or descriptions that might present regulatory barriers to vehicle compliance, in order to then develop options as to how the language could be altered. Crosscutting analyses were developed to drive consistency in the translation options and clarify when individual standards required unique options or approaches. Each FMVSS evaluation produced a set of options that NHTSA may consider for translating the FMVSS for ADS-DVs.

Potential ADS-DV barriers indicating a possible need for translations were analyzed at two levels: 1) regulatory language, and 2) implementation of test procedures. Several parts of the regulatory language include standards that are incorporated by reference (e.g., American National Standards Institute [ANSI], ASTM International [ASTM], International Organization for Standardization [ISO], SAE). The standards incorporated by reference are part of the

FMVSS regulatory language and were analyzed in the same way as the rest of the regulatory text. A taxonomy was then developed for completing and capturing the translation analysis.

Documents incorporated into the FMVSS by reference (49 CFR § 571.5 [3]) posed a unique challenge for translation, since they were issued by organizations outside of NHTSA (e.g., ASTM, SAE) and then became part of the regulatory text when incorporated by reference in the FMVSS. Through rulemaking, NHTSA can change its incorporation by reference of those documents, and can decide to no longer incorporate them, adopt them in part, or incorporate a different document provided by the external organization.

The process for developing the technical translation options for the FMVSS of focus is outlined in the steps below:

- 1) Transfer the standard and related test procedure(s) into a spreadsheet designed for this effort.
- 2) Identify relevant information and documents.
- 3) Obtain relevant incorporated references by external organizations (e.g., SAE, ANSI standards) and evaluate potential barriers to ADS-DV self-certification or compliance verification.
- 4) Evaluate the language of both the standard and the test procedure to identify references to the driver, driver-oriented displays, designated seating positions, bidirectionality, manual controls, or other language that could pose a barrier for ADS-DV self-certification or compliance verification.
- 5) Coding the translation type as 0, 1, or 2 (as shown in Figure 3 below).
- 6) Suggest potential translations of the standard text and test procedures for ADS-DVs, including investigating options for new testing methods.
- 7) Identify FMVSS requirements where a technical translation was evaluated but not performed. When not clearly evident why a translation was not performed, document the reasoning for which a translation either cannot occur (based on current knowledge of ADS-DVs) or was deemed unnecessary.
- 8) Document specific barriers in translating the standard/test procedure language to ADS-DVs.

| Reason | | Technical Translation Type Description |
|----------|------------------------------------|--|
| 0 | Not performed | Translation evaluated but not performed. |
| 1 | Translation is straightforward | The translation performed is straightforward. |
| 2 | Limited research may be beneficial | Can translate standards or provisions of standards, maintaining current performance levels, with some limited amount of research for NHTSA to conduct compliance verification for both conventional vehicle designs and new vehicle designs associated with Automated Driving System - Dedicated Vehicles (ADS-DVs). |

Figure 3. Technical translation taxonomy

Every section within the FMVSS of focus was coded from the choices shown in Figure 3. The reasons and descriptions were based on the best forecast of what might need to be addressed during the course of the project. Those categorized as *0-Not performed* were deemed as non-problematic for ADS-DVs within the scope of this project. The code of *1-Translation is straightforward* is self-explanatory; i.e., the determination was made that the translation options provided allowed for a straightforward translation to be performed for ADS-DVs. Any translations of standards coded as *2-Limited research may be beneficial* may require additional testing and/or research to develop the appropriate translations.

By way of example, the spreadsheet for FMVSS No. 102 is shown in Figure 4. Translation options are included in the spreadsheet in red text. Note that driver definitions 1 and 2, referenced in Figure 4 below, are potential translation options provided for the driver definition in 49 CFR § 571.3. These definition options were created as the word “driver” is used throughout various FMVSS.

| S3.1.4.2 Identification of shift positions and of shift position sequence | | | |
|--|------------------------|---|---|
| Standard Text | Translation Options | | Potential Considerations |
| <p>Except as specified in S3.1.4.3, if the transmission shift position sequence does not include a park position, identification of shift positions, including the positions in relation to each other and the position selected, shall be displayed in view of the driver whenever the ignition is in a position in which the engine is capable of operation.</p> | <p>Option 1</p> | <p>...shall be communicated to the driver ...</p> | <p>Uses driver definition 1.</p> <p>Eliminates the dependency on a display.</p> <p>Opens the possibility of other communication means to human drivers (e.g., auditory). May need to provide conditional language such as "via visual or electronic means."</p> <p>May need a means to confirm operation for ADS.</p> |
| | <p>Option 2</p> | <p>Except as specified in S3.1.4.3, if the transmission position sequence does not include a park position, identification of positions, including the positions in relation to each other and the position selected, shall be displayed in view of the driver in a vehicle with a transmission shift mechanism intended for operation by a human driver, and shall be communicated to the ADS driver in a vehicle equipped with such a system, whenever...</p> | <p>Uses driver definition 2.</p> <p>Separates the human and ADS.</p> <p>If taken out of context, exclusion of "shift" could be ambiguous. "Shift" could be kept as currently stated while keeping the distinction between human and ADS.</p> |
| | <p>Option 3</p> | <p>...shall be displayed in view of the human driver whenever the ignition is in a position in which the engine is capable of operation.</p> | <p>Use driver definition 2.</p> <p>Only display information for vehicle operated by a human driver.</p> |

Figure 4. FMVSS No. 102: Transmission Shift Position Sequence, Starter Interlock, and Transmission Braking Effect

Work on the 100-series standards focused on addressing some of the fundamental aspects that cut across many of the FMVSS, such as definitions for driver and seating position, service brake application, and gear position/selection, as well as on developing initial considerations for translating requirements for telltales and addressing bidirectional vehicles. Work on the 200-series standards focused on occupant protection for ADS-DVs with conventional seating.

Stakeholder Engagement

The involvement of stakeholders and subject matter expert (SME) reviewers was a critical component of the translation process. Stakeholders included companies, organizations, and advocacy groups that were invited to be involved in this project in the early stages based on their experience with FMVSS and ADS-DVs. Additional stakeholder entities were later added; in some cases, organizations asked to be involved and in other cases a need was identified for additional expert feedback. The SME reviewers were a subset of the larger stakeholder group; these were individuals with demonstrated expertise in and knowledge of a particular FMVSS and/or laboratory test procedure along with how potential FMVSS barriers to innovative vehicle designs may be addressed. The SME reviewers for each FMVSS of focus were involved in providing input to the technical translation options developed;

as such, they were able to review the translation development work and provide feedback. In addition, several industry and research entities were engaged as collaborators on this project in order to obtain input and feedback, and produce prototype technology for testing and evaluation. Figure 5 illustrates the various organizations that participated in this project.



Figure 5. The project team, stakeholders, and SME reviewers

The SMEs were divided into working groups based on their expertise with a particular FMVSS and/or OVSC test procedure. The working group members assisted with the review process once technical translation options were developed or feedback was needed for the test methods. The purpose of the SME review process was to ensure that the options being developed did not produce more far-reaching or different regulatory barriers. The SMEs also provided feedback on alternative methods evaluated for test procedures of interest. In addition, stakeholders participated in open project meetings and provided input regarding this project during those events.

Test Procedures

The goal was to identify the equipment and/or procedures that may help NHTSA perform compliance verification on ADS-DVs not equipped with manual controls. Similar to the regulation text translation assessment analysis, the same taxonomy was used to determine appropriate translation options or modifications to data sheet checklists. As an addition to the regulation text translation assessment framework, the test procedure analysis expanded the focus to vehicle functionalities. Developing and evaluating test methods to exercise the required vehicle functionalities may require one or more categories of functionalities. The functionalities, which are also shown in their respective categories later on in this paper, are: steering control, speed control (vehicle/engine), service brake application, parking brake, gear selection, telltales/warnings/indicators, key insertion/removal, ignition start/stop, accessory mode, door open/close, non-driving controls, and visibility.

The following steps illustrate the approach taken as part of the crash avoidance test procedure analysis:

1. Classification of standards
2. Selection of standards for inclusion
3. Implementation and execution
4. Evaluation of test methods
5. Select functionalities needed to verify compliance, if applicable

6. Iteration of testing and evaluation of results as necessary
7. Validation of test platform and execution

The implementation, execution, and evaluation of the testing was first applied to standards containing functionalities with less-demanding requirements to verify the test platform and test methods. The expectation was that this approach would provide a sufficient set of test cases to allow the selection of an appropriate test method that could be applicable for any requirements and associated test procedures.

Five potential methods were identified for verifying compliance; these fall into two general categories that are outlined below. Some are more appropriate for some standards than for others. The methods are:

Vehicle-based

Human control: Testing is performed using a controller console, connected either physically or through a wireless link (which could include teleoperation), to provide manual driving control.

Programmed control:

- Scripted control – A standard set of commands (e.g., “start engine,” “apply parking brake,” “speed = x ”) are used to define the actions the ADS is required to take to execute the test.
- Pre-programmed routine – The steps for executing the test are predefined and compiled into a script that can be run but not modified in the field.

ADS normal operation: The normal operation of the ADS is used to perform some or all of the test procedure.

Non-vehicle-based

Simulation: Simulation, either solely software-based or including a hardware-in-the-loop solution, is used to execute the test procedure.

Technical design documentation: Vehicle-specific technical design and/or build documentation which provides sufficient information and detail (e.g., a wiring diagram showing that a sensor signal is connected to an ADS electronic control unit) to show the system in question was designed to be in compliance with part or all of a particular standard. It should be noted that this is different than the Test Specification Forms that are provided to NHTSA when a vehicle is selected for potential verification testing. Instead, it is technical design documentation used by the manufacturer in the design, construction, and validation of the vehicle.

While the OVSC test procedures are not requirements, they do capture functionalities that are often implied by the regulatory text (e.g., to test the requirements of the backup camera the vehicle must be started and backed up) and which NHTSA currently uses to verify compliance. Bidirectionality provided a unique challenge for functionalities as they do not follow a standard rear vs. front direction determination of the vehicle. Further research is needed to translate test procedures for bidirectional vehicles; thus, this will be performed as part of long-term research.

Figure 6 shows the 15 crash avoidance FMVSS under study and the associated functionality requirements that are either specified in the FMVSS or that are necessary to execute the associated test procedures. These are organized into categories shown in the first column. The first four categories apply to vehicle operation and the last category (Environment Awareness) addresses items that allow the driver to perceive the environment outside of the vehicle. Within the categories, the functionalities are grouped (e.g., vehicle position control, braking) and ordered by use and occurrence within the standards.

| Category | Functionality | 101 | 102 | 103 | 104 | 108 | 110 | 111 | 113 | 114 | 118 | 124 | 125 | 126 | 138 | 141 |
|------------------------|--------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Driving Tasks | Steering control | | | | | | • | • | | • | | | | • | • | • |
| | Speed control (vehicle/engine) | | | • | • | | • | • | | • | | • | | • | • | • |
| | Service brake application | | | | | | • | • | | • | | | | • | • | • |
| | Parking brake | | | | | | | • | | • | | | | | | • |
| | Gear selection | | • | • | • | | • | • | | • | | | | • | • | • |
| Vehicle Communications | Telltails/warnings/indicators | • | • | | | • | | | | • | | • | | • | • | |
| Key/Ignition Function | Key insertion/removal | | | | | | | | | • | | | | | | |
| | Ignition start/stop | | • | • | • | | • | • | | • | • | • | | • | • | |
| | Accessory mode | | | | | | | | | • | • | | | | | |
| | Door open/close | | | | | | | | | • | • | | | | | |
| Non-driving Tasks | Non-driving controls | | | • | • | • | | • | | | • | | | | | |
| Environment Awareness | Visibility | • | | • | • | | | • | • | | | | | | | |

Figure 6. Functionalities identified in standards and test procedures for the 15 crash avoidance FMVSS under study

Test procedures from FMVSS No. 114, Theft protection and rollaway prevention and No. 138, “Tire pressure monitoring systems,” were selected first for testing as they capture many of the functionalities shown in Figure 6 above. These FMVSS also have less-demanding requirements than others (e.g., FMVSS No. 126, “Electronic stability control systems for light vehicles”) and, as such, allowed early verification of the test platform and test methods. Following the testing of FMVSS Nos. 114 and 138, more demanding standards—such as FMVSS No. 126—will be tested, and the test methods will be refined as appropriate.

CONCLUSIONS

This paper describes the work conducted to create technical translation options for FMVSS and OVSC test procedures for innovative new vehicle designs. These options may assist with the self-certification and compliance verification of automated vehicles without manual controls with regard to existing FMVSS, and note where the existing standards may need to be modified. The test procedure portion of the project focused on the test methods used to exercise the required vehicle functionality (e.g., start/stop ignition, gear selection) for executing the test procedures. A range of test means was considered which included human control, programmed, normal ADS operation, simulation, and technical documentation methods. Multiple criteria were assessed; for example: ease of execution, test time, scalability, and standardization. For each FMVSS of focus during this research, the effort developed one or more potential options for NHTSA to verify compliance with FMVSS requirements for vehicles without manual controls.

With regard to the 100-series (crash avoidance) standards, the effort addressed some of the fundamental aspects that cut across many of the FMVSS and developed initial approaches to translating requirements for telltales, indicators, and alerts in addition to addressing bidirectional vehicles. Vehicle functionalities such as steering, transmission control, and service brake application were identified that are explicitly referenced in FMVSS and OVSC test procedures, and options were developed for potential alternatives that could be used in compliance verification.

Work on the 200-series (crashworthiness) standards focused on occupant protection for ADS-DVs with conventional seating. This included ADS-DVs with forward-facing seating, but without manually operated driving controls (e.g., steering wheel). For ADS-DVs without manually operated driving controls, researchers applied the test procedures that have been developed for the passenger seating positions to the left front outboard seating position, given that the main difference between the two front outboard seating positions in conventional vehicles is the presence or absence of these controls. Subsequent research as part of this effort will focus on knowledge gaps in several areas that could be beneficial since passenger seating preferences (e.g., rear seat) as well as translation considerations for unconventional seating configurations may begin to vary with different concept vehicles.

Limitations

This research was built on current information, which is subject to change. In this complex regulatory and technological landscape, ADSs may continue to evolve and FMVSS may need to evolve along with them. It should also be noted that NHTSA may determine that the options that resulted from this project may be unworkable for legal or policy reasons.

REFERENCES

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