Use of Industry Consensus Standards as a Soft Law Mechanism to Safely Deploy Automated Driving Systems

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I. Introduction

Automotive vehicles have evolved from being primarily mechanical machines to being highly complex electronic systems, many run by sophisticated computers running over 150 million lines of code, in an increasingly automated and autonomous fashion with greater use of artificial intelligence algorithms. This evolution began about 12 years ago with technology companies located in Silicon Valley, such as Google's Self-Driving Car Project, taking the lead on developing automated driving systems (ADS). The term ADS refers to the hardware and software systems that sense, plan, and act to perform the complete driving task as well as crash mitigation and avoidance on a sustained basis, corresponding to the SAE definitions for Levels 3 to 5 of automation.[1] The main difference between ADS and other hardware and software components in a vehicle is that the ADS is effectively replacing the human driver for the two primary driving tasks of situational awareness and control of the vehicle.

The mass appeal of ADS is that human driving is an inherently dangerous endeavor. The World Health Organization estimates that approximately 1.3 million people die annually worldwide by road traffic crashes, which equates to approximately 1 death every 24 seconds.[2] The US National Highway Traffic Safety Administration (NHTSA) estimates that approximately 42,795 people died in roadway crashes in the United States in 2022, a 10% increase from 2020.[3] According to a study conducted by NHTSA, the critical precrash event for approximately 94% of crashes studied were attributable to human driver errors or mistakes.[4] In the United States there were 5,250,837 total police-reported crashes resulting in 38,824 deaths in 2020.[5] Drunk driving and speeding were two leading causes of fatal accidents, causing 11,654 and 11,258 road fatalities respectively during 2020.[6] Distracted drivers were also a leading cause of fatal collisions, with

[1] Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems, Document J3016, SAE Int'l (June 15, 2018).

[2] World Health Organization, *Road Traffic Injuries*, https://www.who.int/news-room/fact-sheets/detail/road-traffic-injuries (June 20, 2022)

[3] NHTSA Estimates for 2022 Show Roadway Fatalities Remain Flat After Two Years of Dramatic Increases. (April 20, 2023). https://www.nhtsa.gov/press-releases/traffic-crash-death-estimates-2022.

[4] National Highway Traffic Safety Admin., *National Motor Vehicle Crash Causation Survey: Report to Congress*, U.S. Department of Transportation. (July 2008), https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/811059.

[5] Stewart, T. (2022, March). Overview of motor vehicle crashes in 2020 (Report No. DOT HS 813 266). National Highway Traffic Safety Administration. Table 2 and 3. https://www.nhtsa.gov/press-releases/2020-traffic-crash-data-fatalities

[6] Stewart, T. (2022, March). Overview of motor vehicle crashes in 2020 (Report No. DOT HS 813 266). National Highway Traffic Safety Administration. Table 4. https://www.nhtsa.gov/press-releases/2020-traffic-crash-data-fatalities

3,142 fatal crashes attributed to drivers who failed to keep their focus on the roads.[7] An ADS will not suffer from the same issues (such as intoxication, speeding, distraction and inattention, and drowsiness) that currently cause the majority of the underlying crashes by human drivers. As a result, ADS-equipped vehicles have the potential to greatly reduce the number and the severity of motor vehicle crashes.[8] Preliminary data from Waymo and Swiss Reassurance has shown that Waymo ADS-operated vehicles have reduced the frequency of property damage claims by 76% and eliminated bodily injury claims.[9]

We begin our discussion with an overview of key factors affecting the automotive industry and how they will affect regulation. From there, we provide a brief review of the current state of automotive safety regulation in the United States and the position of the United States Department of Transportation (USDOT) on current ADS regulation. We then address hard law and soft law approaches to regulation of ADS and conclude that soft law makes the most sense at this time. The article then describes how industry consensus standards–standards developed by industry groups (such as IEEE)–can address ADS safety and describes one such standard. The article also explores limitations on using industry consensus standards to address ADS safety. Finally, we conclude by making recommendations to three principal groups: regulators, industry, and academia.

II. Key Trends Affecting the Automotive Industry and Impacts on Regulation

In this section, we outline key trends resulting in profound changes in the automotive industry and the resulting influence on the regulatory landscape.

First, automakers are transitioning their vehicles away from being powered by internal combustion engines and to hybrid and electric powered vehicles, with a few even offering solar generation. This electrification of vehicles means that vehicle architecture can be simplified, especially with respect to hardware. In addition to becoming powered by electrification, vehicles are transitioning from being primarily mechanical to becoming much more electrical systems running sophisticated computer hardware, complex software, and using AI algorithms in an interdependent system of systems. Electronics have shifted from being 18% of the total cost of a new car in 200 to 40% of a new car in 2020.[10] This shift to electronics will continue to increase with consolidated workloads being run on more powerful domain controller computers. Vehicles are also starting to become interconnected via in-vehicle wireless or using smartphones to communicate to other vehicles (V2V), roadway infrastructure (V2I), and through the cloud and "everything" via V2X. The interconnectedness of vehicles creates new opportunities on roadways, but also creates new risks, such as opening pathways for cybersecurity threats or remote commandeering of vehicles.

Second, advances are being made in automotive safety related technology. Over the past 20 years, vehicle manufacturers have begun including advanced driver assistance systems

[7] Stewart, T. (2022, March). Overview of motor vehicle crashes in 2020 (Report No. DOT HS 813 266). National Highway Traffic Safety Administration. Page 18. https://www.nhtsa.gov/press-releases/2020-traffic-crash-data-fatalities

[8] It may be that ADS create new types of crashes that a human driver would not otherwise cause. However, most experts believe that the number of new crashes caused by ADS will be significantly less than the number of crashes caused by human drivers today.

[9] Luigi Di Lillo et al, Comparative Safety Performance of Autonomous- and Human Drivers: A Real-World Case Study of the Waymo One Service, September 2023, https://arxiv.org/ftp/arxiv/papers/2309/2309.01206.pdf.

[10] Eric Tingwall, *Electronics Account for 40 Percent of the Cost of a New Car*, May 2, 2020, https://www.caranddriver.com/features/a32034437/computer-chips-in-cars/.

(ADAS), such as automatic emergency braking, lane assist, forward collision warning, and blind spot detection. ADAS has been increasing motor vehicle safety and becoming incorporated in more vehicles as standard equipment. In recognition of the advances being made in vehicle safety, the US, and European New Car Assessment Programs (NCAP) are expanding beyond providing safety star ratings for crash protection and rollover resistance to recommending specific ADAS technologies with demonstrated performance testing. Increased understanding and growing acceptance of ADAS by regulators, insurers, and the public paves the way for even more automated and autonomous vehicles such as ADS-equipped vehicles. Many of the ADAS sensor systems and features of today are effectively subsystems of the ADS-equipped vehicles of tomorrow.

Third, the automotive ecosystem and supply chain is changing. In the past, the US automotive industry consisted primarily of three major original equipment manufacturers (OEMs) and their Tier 1 suppliers (who supply directly to the OEMs and often have a systems integration role) and supply chain partners, plus imported vehicles primarily from auto OEMs in Europe, Japan, and Korea. Today, the industry for ADS-equipped vehicles includes several of the traditional automotive companies such as GM (via Cruise), as well as Mobility as a Service (MaaS) providers, such as Uber and goods transport companies, large tech companies, such as Alphabet's Waymo and Amazon's Zoox, as well as start-up entrants, such as Aurora, May Mobility and Pony.ai, semiconductor companies such as Intel/Mobileye and Nvidia, and a myriad of joint ventures between vehicle makers and ADS providers, such as Motional, a joint venture between Aptiv and Hyundai. The ADS ecosystem is now more complex with players having varying degrees of automotive, safety, and regulatory know-how and sophistication.

Fourth, ride sharing, MaaS, and vehicle sharing models are disrupting the long-standing model of personal vehicle ownership. We are seeing societal shifts with young adults delaying getting their driver's licenses and a growing number of people opting not to buy personal vehicles. With the advent of ADS-operated vehicles, it is anticipated that, over time, there will be a shift to more fleet vehicle ownership and less personal vehicle ownership. This shift will result in fewer vehicles being sold overall but used with much higher utilization and replaced much more frequently as a result.

Fifth, the nascent ADS industry is gaining traction. The ADS-equipped vehicle industry is slowly and steadily moving beyond the testing stage into ridesharing deployment. Residents and visitors to cities, such as Phoenix and San Francisco, can now download an app and travel in ridesharing ADS-operated vehicles. In the locations which were used for ADS testing and early deployment, there have been both teething pains as ADS companies, municipalities, and the public learn how to adapt to having ADS-operated vehicles on the public roadways as well as a sense that the streets are genuinely becoming safer as a result of the ADS-operated vehicles. Automated freight and goods delivery vehicles are being deployed, initially with safety drivers, primarily in the southwestern United States and are traveling millions of miles per year. Due to the newness of the ADS industry, we don't know what we don't (yet) know. In recent years, for the first time, sizable fleets of ADS-operated vehicles are being deployed and sharing the roadways with human drivers, cyclists, pedestrians, motorcycles, and others. Industry, municipalities, regulators, and road users all are learning how to interact with ADS-operated vehicles and adapting accordingly. Each incident is a learning experience and provides necessary feedback on what is and is not working and will inform revisions that need to be made in vehicle hardware and software, testing, simulations as well as in industry consensus standards and eventually in regulation.

These five trends have a significant influence on the regulatory landscape for ADS-equipped vehicles. Seven such significant influences are included here:

- Regulators now need extensive expertise in computer hardware, software, and AI systems, wired and wireless communications technology, cybersecurity, event data recorders and data storage systems for automated driving, and computer simulations to understand what is happening, what can potentially go wrong, and how best to mitigate potential risks.
- Regulators need to understand how well ADAS and ADS technologies work, what their limitations are, and when these technologies should become part of standard vehicle fitment.
- It is becoming increasingly difficult to ascertain what is causing ADAS-equipped vehicles to behave in unintended ways, such as well-documented reports of unintended vehicle acceleration and phantom braking, and to then assign responsibility and culpability.
- Regulators now need to work with a much broader range of industry players in addition to the traditional automotive supply chain. New entrants, like tech industry and MaaS companies, have varying levels of knowledge of safety-critical systems and automotive requirements and regulations. These new entrants have had to gain automotive and safety related expertise, and regulators had to forge new relationships with new companies. Building trust and demonstrating trustworthy behavior takes time.
- Fleet operators are expected to have an increasingly important role in the era of ADS-operated vehicles, both for transporting goods and people. Fleet ownership and operation may present new regulatory, insurance, and risk management challenges.
- Given the safety benefits promised by ADS-operated vehicles, regulators have new responsibilities to foster innovation and to remove barriers.
- Regulators are in effect guardians of the public good, especially with respect to saving lives and preventing injuries from roadway crashes. Once ADAS and ADS-operated vehicles are proven to be significantly safer than human driven vehicles, then regulators will be challenged with enabling widespread adoption which may or may not reflect public and political sentiment, especially if there is real or perceived mistrust of the emerging technology or job disruption as a result.

III. Evolution of US Motor Vehicle Safety Regulation

Not only is the technology used in motor vehicles and the automotive industry shifting and changing, the regulatory approach to addressing safety in a vehicle has shifted. The United States automotive industry has encountered three principal phases of federal regulation of motor vehicle safety. The first regulatory phase began with the introduction of the mass-produced automobile in the early 1900s until the mid-1960s. During this time, Congress utilized a laissez-faire approach to motor vehicle safety, with most of the efforts implemented at the state level and focused on the driver. In the mid-1960s, following Ralph Nadar's influential book "Too Fast At Any Speed," Congress enacted significant automobile regulation creating the predecessors to the federal agencies we know today.[11] This second regulatory phase saw the newly appointed federal agencies

[11] Simultaneously, state products liability law began to become developed in the 1960s, where automakers began to face lawsuits about alleged defects in their vehicles.

attempt to impose restrictive Federal Motor Vehicle Safety Standards (FMVSS),[12] on the automakers. These federal agency impositions resulted in a more adversarial relationship between the USDOT and the automakers over the FMVSS and the requirement that certain safety features (such as seatbelts, airbags, and anti-lock brakes) become standard equipment. It took over a decade for airbags to become standard equipment in automobiles, which began at the end of the 1970s and continued until the mid-1990s.

The third phase began in the 1990s and has taken on a new life in the age of automated features in automobiles. Instead of having an adversarial approach, the National Highway Traffic Safety Administration (NHTSA), the primary regulator of motor vehicle safety, began working collaboratively with industry to jointly accomplish its safety goals. Rather than compelling safety critical features on automakers, NHTSA has worked with automakers to help foster development of safety critical features and to develop workable timelines for their inclusion in automobiles. Over the past 15 years, automakers have developed numerous safety features that reduce the likelihood and severity of crashes. These have included ADAS functionality, like automatic emergency braking, lane assist, forward collision warnings, and blind spot detection. Rather than requiring automakers to include many of these ADAS as standard equipment, NHTSA's approach has been to work with automakers to set benchmarks and timelines for making certain ADAS standard equipment. This shift in regulatory attitude has brought NHTSA significant success in regulation of automobile safety in the United States.

The new approach by NHTSA reflects the federal approach to ADS. NHTSA began its official statements on ADS by issuing a preliminary policy statement in 2013. Since then, the USDOT has issued four more policy statements on ADS safety and deployment. NHTSA has continued the soft law approach to their initial regulation of ADS. At the time of this article, NHTSA has not yet enacted any safety standards directly addressing "how safe is safe enough" for an ADS to be deployed. Instead, NHTSA has focused on removing regulatory barriers[13] that exist to the deployment of ADSs, collaborating with ADS manufacturers on the testing and deployment of their systems on roadways, and issuing guidance and policy statements to help shape the development and deployment of ADS. One significant example of this was the March 2022 NHTSA ruling relaxing the requirement to always have a human driver behind the wheel and to permit vehicles to be developed without steering wheels and pedals.[14]

IV. Approaches for Regulating ADS Safety

There are various approaches to regulating ADS safety which differ in degree of regulatory oversight, type of relationship between regulators and those being regulated (based on level of trust, industry maturity, openness, and competency, which can tend towards being adversarial or collaborative), real or perceived level of risk or potential for harm, level of being supportive and

[12] When we discuss "industry consensus standards," we are referring to standards created by industry groups (such as those created by IEEE, ISO, SAE) that are not legally binding. In contrast, FMVSS are legally binding safety standards promulgated through a formal regulatory process by NHTSA.

[13] The authors believe it is important to distinguish between regulatory action that removes barriers to deploying highly automated vehicles and regulatory action that attempts to preemptively regulate the industry. When we speak of hard law in this context, we are speaking about preemptive regulation of the automated vehicle industry and not regulatory action to remove barriers.

[14] NHTSA, *Occupant Protection for Vehicles with Automated Driving Systems*, (March 3, 2022), https://www.nhtsa.gov/sites/nhtsa.gov/files/2022-03/Final-Rule-Occupant-Protection-Amendment-Automated-Vehicles.pdf.

removing potential barriers, being proactive and proscriptive versus more watchful waiting and collective learning before intervening. The initial response to regulating a new automotive technology typically takes one of two forms:

> Hard Law: Hard law, for lack of a better definition, is formal law or rulemaking by the government. Hard law would include Congressional Acts or regulations that regulate specific conduct. In the motor vehicle safety space, the most prominent are the Motor Vehicle Safety Act and the FMVSS. Under this approach, a governmental body prospectively regulates a new automotive technology. An ADS example is the European Union's regulations governing ADS with uniform procedures and technical specifications for the type-approval of the ADS (Regulation 2019/2144 of the European Parliament). States have enacted a variety of laws relating to ADS, some of which have been to merely remove barriers and to explicitly authorize ADS-operated vehicles (see Florida), while others have been more restrictive (see California).
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> Soft Law: Soft laws are standards, guidance, or frameworks made by non-governmental bodies, such as IEEE and ISO, or, in the ADS space, the Automated Vehicle Safety Consortium. These soft laws consist of "instruments or arrangements that create substantive expectations that are not directly enforceable, unlike 'hard law' requirements such as treaties and statutes."[15] The government does not prospectively regulate a new automotive technology and allows self-regulation to occur with monitoring by regulators. Under this model, governments complement self-regulation by adding compliance and hard law regulations as events occur, industry maturity, unknowns become known, public perception evolves with greater acceptance, and both industry and regulators gain cumulative experience with the technology.[16] An example of this model has been the U.S. federal government's approach to regulating ADS.

The authors have outlined key factors that should be considered when deciding whether to use hard law or soft law and have bolded the one that they believe the industry is currently most representative:

[15] Gary E. Marchant, Brad Allenby, Soft Law: New Tools for Governing Emerging Technologies, Bulletin of the Atomic Scientists. 73. 1-7 (2017).

[16] It is theoretically possible to do laissez-faire in perpetuity, but the authors observe that very few technologies enjoy such perpetual non-regulation.

Table 1: Soft and Hard Law Governance and the State of the ADS Industry			
Category	**Regulatory Characteristics**		
	Soft Law Governance	**Hard Law Governance**	**Status of ADS (as of September 2023)**
Industry	**Industry not well defined and relatively immature**	Industry stable, well defined, and relatively mature	**Some companies are in the testing phase, while other companies are deploying their technology commercially in limited geographic regions**
	New players to the industry, varying levels of experience	Established, highly experienced industry players	**Industry consists of traditional automotive OEMs and Tier 1s, ride sharing companies, new entrants, ADS manufacturers, and new and old component manufacturers**
	Industry demonstrates the ability and willingness to self-regulate	Industry does not demonstrate the ability and willingness to self-regulate	**Industry is seeking to self-regulate, with the exception that industry is seeking federal preemption to prevent patchwork of state laws and to have regulatory barriers removed**
	Industry is taking a slow, steady, considered, and measured approach in a responsible fashion	Industry is proceeding with implementation quickly, and misleading the public and regulators, requiring strict enforcement	**Industry, for the most part, is taking a slow, steady, considered, and measured approach in a responsible fashion with extensive vehicle testing and simulation. There is at least one industry player not following industry best practices, pushing limits, and misleading the public.**
	Industry cooperates to develop standards and to share best practices	Industry does not cooperate to share best practices among competitors	**Industry is developing standards (ISO, IEEE, SAE, etc.) and sharing best practices like RSS**
	Industry cooperates to share data.	**Industry does not cooperate to share data**	**Mixed. Certain players are openly sharing information and others are not.**
Uncertainty	**More unknowns than knowns**	More knowns than unknowns	**More unknowns than knowns**
	Able to tolerate ambiguity and lack of precision	Not able to tolerate ambiguity and lack of precision	**Industry can tolerate a certain amount of ambiguity while the ADS is being tested, but there may be a need for federal preemption of state law if patchwork of laws arises.**
Technology	**Technology changing rapidly, innovation needs to be fostered**	Technology is relatively stable, technical specifications are well understood, regulation of technical performance is feasible	**Technology changing rapidly**
	Technology relatively immature	Technology relatively mature	**Technology relatively immature**
	High need for flexibility	Low need for flexibility	**High need for flexibility**

As described in Table 1, most of the factors for the ADS industry tend to favor soft law over hard law. The remainder of this section will describe in detail the other challenges to using federal regulation to prospectively regulate safety of ADS.

The major challenge with any federal regulation is that "we don't yet know what we don't know" about ADS, any such regulation would likely be premature. As described in Section II, ADS deployment is occurring in the US in a phased approach and is rolling out slowly and cautiously. Currently, United States consumers can use ADS-operated ride sharing vehicles in select cities like Phoenix, San Francisco, and Austin, with testing underway in several other locations. There are also automated shuttles programmed to travel set routes in various locations throughout the United States and testing underway for commercial vehicles hauling freight, with backup human safety drivers. Private consumer ownership of ADS that completely removes the driver from the loop is not currently being considered, with most traditional automakers focusing on deploying vehicles with lower levels of ADAS automation for consumer use or considering commercial fleet deployments of ADS, which would be simpler to control and regulate due to the limited number of vehicle operators.

Federal safety regulations will also suffer from a pacing problem. ADS deployment and development is occurring at a relatively fast pace. The systems themselves are changing every day as new data is collected, new situations are encountered, software is updated, and hardware is tweaked. The ADS software systems are machine learning systems and are constantly improving and evolving. In contrast to the speed of technology, regulation and Congressional action takes time. The Administrative Procedures Act requires administrative agencies to follow a set process to develop and issue regulations, which can take years and is hard to shift with technology once the promulgation process is undertaken, and once adopted, the process of changing existing regulations is lengthy and time consuming. There is a real risk that regulations become outdated as technology changes throughout the regulatory process. Even if a regulation does not become outdated during the promulgation process, there is a significant risk that it would become outdated as the industry further matures, and the ADS is updated and enhanced.

For these reasons, we do not recommend that federal regulators prospectively regulate the safety of ADS through hard law mechanisms (such as an Act of Congress or promulgation of regulations). However, this observation does not mean that hard law and government do not have a role in shaping the safety of ADS. One benefit of using industry standards and other soft law mechanisms such as frameworks and best practices to address ADS safety is that there are still opportunities for NHTSA and courts to impact safety of ADS through recalls or litigation or punitive fines/damages. In other words, NHTSA and safety advocates are not just left defenseless. NHTSA has the power to order a recall of components of a motor vehicle if the component does not comply with the FMVSS or, more relevant, to defects related to motor vehicle safety (regardless of whether the part complies with the FMVSS). Defect is defined to "include any defect in performance, construction, a component, or material of a motor vehicle or motor vehicle equipment."[17] NHTSA has stated that it intends to use the notice and recall mechanism to regulate ADS[18] and is routinely investigating crashes involving ADS-equipped vehicles. Litigation or

[17] 49 U.S.C. § 30102(a)(3).

[18] National Highway Traffic Safety Administration, NHTSA Enforcement Guidance Bulletin 2016-02: Safety-Related Defects and Automated Safety Technologies, 81 Fed. Reg. 65705-01 (Sept. 23, 2016).

punitive fines/damages can also serve to rectify problems either through judgments or courts finding that a certain component is defective due to a design or manufacturing defect.

Although recalls, punitive fines/damages and lawsuits are retrospective regulations that require "harm" to have occurred, they act as deterrents as recall campaigns, fines and litigation can be financially and reputationally costly. The recall power, in and of itself, can enable NHTSA to have leverage to police compliance with safety standards and to ensure that components are relatively safe through cooperation and information requests.

V. Use of Industry-Consensus Standards as Soft Law Mechanisms to Address ADS Safety

Industry-consensus standards and the standard setting process can enable and improve ADS safety in a technology agnostic manner. Several international standards organizations, such as IEEE, ISO, and SAE, are well established and comprised of ADS global experts with representation from industry, academia, and public policy groups. In the figure below, many of the primary current industry-consensus standards for ADS are shown and grouped accordingly:

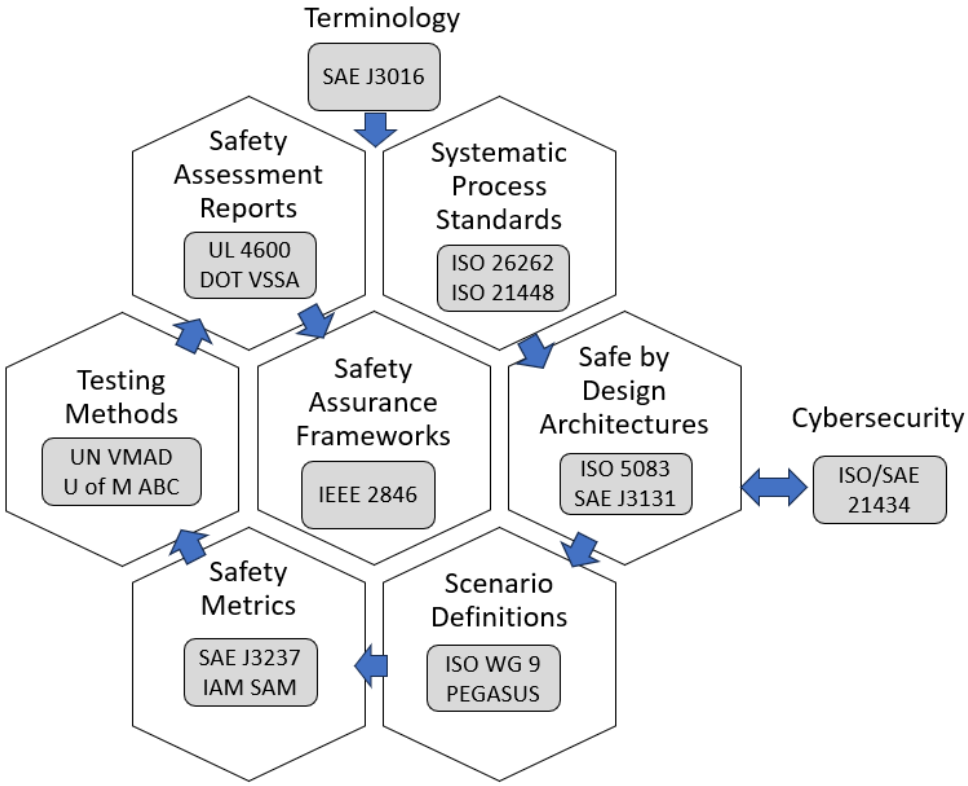

Figure 1: Automated Vehicle Safety Assurance Standards, adapted from an IEEE P2846 overview presentation made by Jack Weast in January 2022. A summary of each of these industry-consensus standards and best practices are included in Appendix 1. In addition, Francesca Favaro and Scott Schnelle of Waymo LLC have published a detailed assessment: ADS Standardization Landscape: Making Sense of its Status and of the Associated Research Questions on arxiv.org / 2306.17682 with a modified diagram centered around the question of "how safe is safe enough?"

Industry-consensus standards and their processes engage key global stakeholders, including automotive OEMs and Tier 1s, technology companies, MaaS providers, semiconductor and supply chain providers, regulators, and university researchers. The collaborative process of developing a standard allows for the sharing of ideas, lessons learned, and best practices among these expert groups in a constructive way and ensures the standards are technically viable and relevant. The standards development process assesses what should be done, what can be done, and how best to do it. When standards are adopted, they require consensus among the varying stakeholders and generally result in a uniform, tech neutral, objective standard with the potential to greatly accelerate tech adoption and shared industry learning.

Because of industry's involvement, there are two salient benefits to industry-consensus standards. First, industry-consensus standards can be implemented quicker as there is "buy-in" from industry. Second, industry-consensus standards do not suffer from a pacing problem like federal regulation because they are being set by industry (who can evolve the standard in real time to the technology and amend existing standards faster than governments can amend regulations) and by having the ability to move faster than regulations.

An example of the benefits of using industry consensus standards can be explored by the success of IEEE 2846. IEEE 2846, the Institute of Electrical and Electronics Engineers (IEEE) standard for Assumptions in Safety-Related Models for Automated Driving Systems, was approved in March 2022. The membership of the IEEE P2846 Standards committee was broad and diverse in multiple ways:

- Multi-stakeholder perspectives were provided from a number of different views, including, companies representing the traditional automotive supply chain such as OEMs, Tier 1s, and Tier 2s (suppliers to the Tier 1 suppliers); MaaS providers and fleet operators; academic and government researchers; test and validation providers; large and small tech companies, semiconductor suppliers, and ADS suppliers.
- Companies and organizations located throughout the world participated, including from the United States, Europe, China, Taiwan, Korea, Japan, and Israel. The global geographic representation allowed for a world perspective of the challenges faced by safely deploying ADS. Additionally, this global perspective helped ensure that the industry consensus standard would be informed by collective real-world experience in diverse driving conditions with differing driving styles and cultures and regulations, as well as to ensure that the standard had global application.
- There was participation from adjacent industries with common interests in ADS for transportation of goods (freight, cargo and first mile/last mile delivery), robotics, and vehicles used in agriculture, mining, and construction.
- The National Institute of Standards and Technology (NIST) participated in the standards development process of IEEE 2846 and NHTSA provided information and monitored progress.
- IEEE 2846 Work Group has been engaging with policy makers and regulators around the world to discuss how IEEE 2846 can help in the creation of regulatory frameworks for Automated Vehicles.
- The standard was shared and reviewed in public forums in early 2022 to solicit additional public feedback and insights.

There was open sharing of information and best-known methods among top industry players. Intel/Mobileye contributed their Responsibility Sensitive Safety (RSS) model, Nvidia contributed its "Safety Force Field" approach, and Aptiv/Motional contributed its "Rulebooks" approach. This information sharing provided a constructive starting point for the standard and facilitated developing a transparent, explainable, noncompetitive, nonproprietary, tech agnostic solution and set of defensible assumptions that could be validated, verified, and adopted by industry. Additionally, this allowed industry players to learn about other safety practices being deployed and to assess their own internal safety practices in light of that information. The committee charged with formulating IEEE 2846 explicitly considered other relevant industry-consensus standards to delineate which areas needed to be specifically addressed in IEEE 2846. For example, Figure 1 was considered, and the committee identified the areas where the IEEE 2846 standard complemented the other industry-consensus standards. The IEEE 2846 standard provides a safety assurance framework for acceptable risk, with guidance for evaluating the performance of an ADS, and providing a minimum set of assumptions on reasonably foreseeable behaviors of other road users in the development of safety-related models.

In summary, use of industry consensus standards has multiple benefits. Global, industry-wide technical expertise leverages the state-of-the-art experience of multiple companies and organizations from both the automotive and transportation sectors as well as the tech companies with specialized knowledge in computing, software, simulation, and AI, which greatly augments the expertise of regulators on what can and should be done and how best to do it to make ADS safer and more reliable and trustworthy. Industry consensus standards can be efficient and flexible tools to keep pace with the fast-moving ADS industry and can be updated more rapidly than traditional regulations. Standards can provide industry guidelines and frameworks, enable innovation, facilitate public/private partnerships, and increase trust between regulators and those being regulated. This in turn fosters public trust and confidence in ADS safety and reliability when companies adhere to the established standards and guidelines. Industry consensus standards can be referenced in regulations as an acceptable solution or means of compliance. Transportation is a global industry and industry-wide ADS consensus standards can promote global harmonization of regulations, and better enable transport of people and goods across borders.

VI. Potential Limitations of Using Industry Consensus Standards

The use of industry-consensus standards for ADS safety assurance has certain limitations. One major limitation is that standards compliance is typically voluntary, and an industry player is not legally obligated to follow all or portions of a standard unless a regulatory body such as NHTSA mandates compliance. This risk can be somewhat mitigated by industry-consensus standards being utilized in lawsuits to show negligence or failure to comply with industry best practices.

Failure to conform by industry can sometimes be the result of poorly defined evaluation criteria, which leaves the evaluation criteria and how to satisfy it to the interpretation of each industry player. Even when industry players claim to comply with an industry-consensus standard, there may be "standard washing"[19] (akin to greenwashing) whereby companies may allege that they are complying with the spirit and intent of the standard, or selectively using concepts from standards, without a hard commitment to following the standard in its entirety.

[19] see generally Koopman.

In certain situations, the voluntary nature of industry consensus standards can also be an advantage if portions of an industry standard become outdated, irrelevant, or otherwise inadvisable. Unlike a federal law or regulation that becomes outdated, which must still be complied with, industry can disregard—by making a safety case—an industry standard for ADS safety—this could be done in conjunction with amending the standard or creating a new standard.

Industry consensus standards are predicated on the logic that the industry will willingly and voluntarily follow the standards and implement the frameworks, guidelines, test procedures, and best-known methods. This assumes the industry players are behaving in a trustworthy manner. A single industry player who is acting in a rogue fashion and not complying with industry-consensus standards or who is otherwise taking advantage of soft law can create problems for the entire industry, undermine public and regulator trust and confidence, and delay adoption of the ADS technology, which could result in greater loss of life and injuries.

One of the potential concerns is that there are several ADS related industry standards from different standards bodies, as illustrated in Figure 1. In general, the standards described in Figure 1 and detailed in Appendix 1 are complementary and are not competing standards. For example, ISO 5083 and SAE J3131 deal with Safety by Design Architectures and SAE J3237 deals with Safety Metrics. Consensus based industry standards are usually developed by industry players to address a specific concern or to help further the entire industry and are generally technology solution agnostic. IEEE 2846 came about because individual companies did not want to make independent interpretations of how safe is safe enough for ADS-equipped vehicles. By pooling best practice approaches, much of the ADS industry was able to come together, debate the merits and shortcomings and to come up with a viable set of standards which make sense to the industry, regulators, and to members of the public. The number of standards is also not as concerning because standards are typically more flexible for a nascent industry like ADS. Collective industry and regulatory knowledge continue to evolve over time and the standards can organically adapt as needed. For example, ISO 21448 started as a section chapter of ISO 26262 and evolved over time to become its own standard focusing on Safety of the Intended Functionality.

Many companies are members of multiple standards bodies and actively participate in multiple efforts such as ISO and IEEE and SAE. This synergy helps to focus efforts in different areas and avoid the potential for competing standards or one company exerting an inappropriate amount of influence over the standards development process which could favor their technology, company, or approach. The consensus building standards efforts are time consuming and it is in everyone's best interests to not duplicate efforts across standards bodies.

One of the concerns with entrusting industry to self-regulate is a real or perceived lack of government oversight which could result in insufficient protection of public safety or societal interests. This can lead to a lack of legal enforcement mechanisms and an inability to hold companies and organizations accountable with consequences for non-compliance. As described in Section III of this article, there are mechanisms by which the government can use to force compliance (whether through recalls, litigation, or fines) that help mitigate the limitation of a lack of legal enforcement mechanisms.

VI. Conclusion and Recommendations

To summarize, the ADS industry and the automotive industry are undergoing a transformative shift in how vehicles operate. This shift creates challenges in regulating ADS, and the use of hard law to regulate ADS safety seems premature at this time. Industry consensus

standards and the process to adopt those standards can partially fill the void for ADS safety and may, in many respects, provide better standards than a regulatory body. Based on our paper, we have the following recommendations:

- **Recommendations for Regulators:**
    - Invest heavily in rapidly increasing ADS knowledge in human-machine interactions, technical skill building, and use of state-of-the-art tools and simulation, particularly at the national level. The FAA is using NASA to provide R&D for Advanced Aerial Mobility. The same need likely exists for ADS, perhaps the Volpe Center can take on a greater role.
    - Be a resource to states and municipalities. It is not feasible or practical or efficient to expect that individual states and municipalities can obtain the expertise to regulate ADS at the state or local levels.
    - Participate in (or if participation is not possible, closely monitor) the industry consensus standard process. This participation or monitoring could be a way to build technical skills and competency for regulators and to assess what is technically feasible or not and why.
    - In certain cases, it will make sense to harmonize regulation across the states and to enact regulation at the federal level. For example, it will not be desirable to have different states enacting different requirements for requiring, or not requiring, a human driver to be behind the wheel of a commercial truck.
    - Use existing regulatory tools, mechanisms, and increased oversight (such as investigations and recalls) to address industry players who do not proactively prioritize safety.
    - Reward actors who proactively prioritize safety by adhering to industry consensus standards and best practices.
    - Foster innovation and experimentation as appropriate particularly in low-risk environments and to remove regulatory barriers.
    - Provide feedback to industry and the standard development organizations on processes or best practices that work or need to be modified, based on the latest industry-wide information or as a result of crash investigations.
    - Investigate incidents and share results in a timely manner with industry and the public to facilitate shared learning and awareness.
    - Maintain the long view and educate the public and labor representatives, as well as federal, state, and local officials on the facts on what is being done to safely deploy ADS, and sharing what is being done with industry consensus standards is tangible evidence the industry is taking a thoughtful, measured approach.
    - Collect credible, robust information as it becomes available to document whether ADS-equipped vehicles are safer than human drivers.
    - Consider utilizing or referencing industry consensus standards and best practices in creating future FMVSS or NCAP for ADS.

- **Recommendations for Industry**
    - Engage in the industry consensus standard creation process and share insights, experience, and key learnings with the other participants.
    - Collaborate in forums such as the Automated Vehicle Safety Consortium (AVSC), an industry program of the SAE Industry Technologies Consortia (SAE ITC), to

establish ADS-related safety principles and best practices which can inform and lead to standards development.
    - Openly comply with and support industry consensus standards OR identify specific reasons or rationale for why an industry player does not follow all or portions of industry consensus standards.
    - Share, inform, and educate the public on how the industry player is addressing ADS safety (including its involvement or proactive engagement in the industry consensus standard setting process).
    - Openly share data with municipalities and regulators and potentially the media on how well their ADS testing and deployments are performing and compliance with industry standards and best practices.
    - Exert peer pressure on industry players who do not proactively prioritize safety or engage in unethical behavior or deceptive advertising.

- **Recommendations for Academia**
    - Study the industry and the real-world data on the safety of ADS and the implications for human-machine interactions and job disruption and re-training of the labor force.
    - Participate in the industry consensus standard creation process to gain knowledge from industry experts.
    - Collaborate with industry to address high-level research questions, such as the questions posed by Schelle and Favaro in *ADS Standardization Landscape: Making Sense of its Status and of the Associated Research Questions.* https://arxiv.org/pdf/2306.17682.pdf
    - Serve as a watchdog for industry players who do not comply with the industry consensus standards.

Miscellaneous Recommendations

- Courts: Consider the industry consensus standards in cases to determine the reasonableness of actions taken.
- Insurance: Consider the industry consensus standards and an insured's compliance or lack thereof in determining risk and liability in this nascent industry.

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Appendix 1

Brief Summary of Existing Industry-Consensus Standards as of September 2023

Terminology Standards:

SAE J3016: is the Society of Automotive Engineers International's (SAE International) terminology standards document jointly prepared by the SAE On-road Automated Driving Committee (ORAD) and the ISO TC204 Working Group 14 and last updated in April of 2021. Although not a safety standard, SAE J3016 is widely used to explain the levels of driving automation ranging from Level 0 with no driving automation to Level 5 with full driving automation and to clarify the role of the human driver and the ADS at each automation level.

SAE International (2021-04). *Surface Vehicle Recommended Practice: Taxonomy and Definitions* for *Terms Related to Driving Automation Systems for On-Road Motor Vehicles. J3016.*

Systematic Process Standards:

ISO 26262: is the International Standards Organization (ISO) functional safety standard for development of electrical and electronic systems in road vehicles and was originally released in 2011 and updated in 2018. ISO 26262 provides industry guidelines and requirements for the development and production of automotive systems to ensure their safety and reliability and to minimize risk. The standard encompasses the entire lifecycle of the vehicle from concept development to decommissioning. ISO 26262 utilizes a risk-based approach to safety with emphasis on hazard analysis, risk assessments, and determining safety goals for each system. Automotive Safety Integrity Levels (ASILs) are used to quantify the required safety measures based on the severity of potential hazards and consider the likelihood of an incident, the severity of an incident, and level of controllability. Guidance is provided on safety related hardware and software and the processes to be used such as requirements engineering, and verification and validation. Additionally, the standard emphasizes the need for having an effective safety management system with clear responsibilities, documentation, process, and measures to ensure accountability with the organization.

International Organization for Standardization. (2018). ISO 26262-1:2018 Road Vehicles - Functional Safety. ISO.

ISO 21448: is the International Standards Organization (ISO) standard for Safety of the Intended Functionality (SOTIF) for Road Vehicles. The standard provides guidelines for addressing potential hazards and risks associated with the performance and limitations of ADAS and ADS-operated vehicles. The standard focuses on addressing the risks that could arise from the system behaving and functioning as expected and yet may still result in accidents or harm. ISO 21448 provides a framework for managing risk and enhancing safety of ADAS- or ADS- equipped vehicles by using systematic approaches for hazard analysis considering both foreseeable and unforeseeable events, risk assessment and mitigation, scenario analysis including the use of simulation, and system validation, verification and use of best practices such as fail-safe mechanisms, redundancies, and appropriate human-machine interfaces. Originally published in 2019, the standard was last updated in June of 2022.

International Organization for Standardization. (2022). ISO 21448:2022 Road Vehicles - Safety Of The Intended Functionality. ISO.

Safety By Design Architectures:

ISO 5083: is the International Standards Organization (ISO) standard being drafted for addressing "Safety for Automated Driving Systems." This standard is expected to provide guidance for developing and validating a vehicle equipped with an ADS. The standard focuses on "safety by design architecture," as well as verification and validation, and intends to have a positive risk balance and avoidance of unreasonable risk. Over 120 experts from 14 countries are registered at ISO TC22/SC32/WG13 and are actively involved in developing this standard.

International Organization for Standardization. update presentation on ISO TC22-SC32-WG13 and ISO TS 5083 at the UNECE WP.29 GRVA 11th Session (28-Sep-2021). https://unece.org/transport/documents/2021/09/informal-documents/iso-iso-ts-5083-road-vehicles-safety-automated

SAE J3131: is the Society of Automotive Engineers International (SAE International) recommended practice providing a reference functional architecture for a typical on-road ADS, primarily dealing with SAE Level 4 and Level 5 ADS.

SAE International. (March 2022). *Surface Vehicle Recommended Practice: Definitions for Terms Related to Automated Driving System Reference Architecture. J3131. SAE https://www.sae.org/standards/content/j3131_202203/*

Safety Assurance Frameworks:

IEEE P2846: the Institute of Electrical and Electronics Engineers (IEEE) standard for Assumptions in Safety-Related Models for Automated Driving Systems was approved in March 2022. IEEE P2846 builds upon the Responsibility-Sensitive Safety (RSS) model originally developed by Mobileye and Intel for ADS-operated vehicles and published in 2017. RSS effectively translated the rules of the road that humans can agree upon into mathematical formulations that follow the laws of physics. IEEE P2846 expands on the RSS concepts by incorporating assumptions of "reasonably foreseeable" (defined as technically possible with a credible or measurable rate of occurrence) behaviors and considers other road users such as pedestrians, cyclists, and both manned and unmanned vehicles. The IEEE P2846 Working Group also considered the "Safety Force Field" approach from Nvidia and the "Rulebooks" approach from Aptiv/Motional. The intent of using these industry best practices is to help the ADS-operated vehicle navigate through the real world more intelligently and safely without unnecessarily constraining its behavior on the road.

Intelligent Transportation Systems Committee. (March 2022). IEEE Standard for Assumptions in Safety-Related Models for Automated Driving Systems. IEEE 2846:2022. IEEE.

IEEE VT/ITS/AV Decision Making Working Group. (2023). Example Applications of IEEE Standard 2846-2022 to Formal Safety-Related Models. IEEE.

Weast, J. (Jan. 18, 2022) Overview of IEEE 2846. IEEE. **https://sagroups.ieee.org/2846/**

Scenario Definitions:

The PEGASUS Project is an effort of the German Federal Ministry for Economic Affairs and Energy to define scenarios for automated driving. PEGASUS is the **P**roject for the **E**stablishment of **G**enerally **A**ccepted quality criteria, tools, and methods as well as **S**cenarios and **S**ituations for release of highly automated driving functions. PEGASUS utilizes a 6 Layer scheme that considers Road Level, Traffic Infrastructure, Temporary Changes, Objects, Environment, and Digital Information.

Steininger, U. (June 13, 2019) How Safe is Safe Enough? PEGASUS Delivers the Standards for Highly Automated Driving. PEGASUS. NDS Public Conference. https://nds-association.org/wp-content/uploads/2019/06/NDS-Conference-2019__PEGASUS-TUEV-SUED.pdf

ISO WG 9 is the International Standards Organization (ISO) Work Group (WG) which has been formed to address Test Scenarios for ADS. The work group has developed the following set of standards:

- ISO 34501:2022 Road Vehicles – Test Scenarios for Automated Driving Systems – Vocabulary
- ISO 34502:2022 Road Vehicles – Test Scenarios for Automated Driving Systems – Scenario Based Safety Evaluation Framework
- ISO 34503:2023 Road Vehicles – Test Scenarios for Automated Driving Systems – Specification for Operational Design Domain
- ISO 34504:2023 Road Vehicles – Test Scenarios for Automated Driving Systems – Scenario Categorization
- ISO 34505 Draft Road Vehicles – Test Scenarios for Automated Driving Systems – Scenario Evaluation and Test Case Generation

ISO TC22/SC33/WG9. (May 2023). *Test Scenarios of Automated Driving Systems: General Status Report.* Made to UNECE GRVA-16-24. ISO https://unece.org/sites/default/files/2023-05/GRVA-16-24e_1.pdf

Safety Metrics:

SAE J3237: is the Society of Automotive Engineers International (SAE International) standard providing Operational Safety Metrics for Verification and Validation (V&V) of ADS. This standard provides a set of operational safety metrics for the industry to use to quantify ADS competency, and better inform stakeholders of the level of risks associated with ADS-operated vehicles. These safety metrics can be used to facilitate V&V activities and test methodology documentation.

SAE International. (2020-09-16). *Information Report on Operational Safety Metrics for Verification and Validation (V&V) of Automated Driving Systems (ADS) J3237.* SAE. *https://www.sae.org/standards/content/j3237/*

IAM: is the Arizona Institute for Automated Mobility has developed a safety assessment methodology using real-time measurement of metrics to measure safety efficiently and effectively for both human driven vehicles and ADS-operated vehicles. Since Arizona has been an early test

bed for evaluating automated vehicles and was one of the first to offer robotaxis services, there is much information that can be harvested and shared.

AZ Institute for Automated Mobility. (2023) Work in Motion Safety Assessment Methodology. https://www.azcommerce.com/iam/

Test Methodologies:

UN VMAD: The United Nations has a Working Party addressing Validation Methods for Automated Driving. The group is working on New Assessment/Test Methods for Automated Driving: Guidelines for Validating Automated Driving Systems and is assessing Track and Real-World testing as well as Simulation and Virtual Testing.

https://wiki.unece.org/pages/viewpage.action?pageId=60361611

University of Michigan ABC Test: The University of Michigan's MCity researchers have developed the ABC Test as an independent safety assessment for highly automated vehicles using a closed test track to demonstrate vehicle "roadmanship" before ADS-equipped vehicles are deployed on public roadways.

Peng, H., McCarthy, R. (2019). *Mcity ABC Test: A Concept to Assess the Safety Performance of Highly Automated Vehicles.* MCity, University of Michigan. https://mcity.umich.edu/wp-content/uploads/2019/01/mcity-whitepaper-ABC-test.pdf

Safety Assessment Reports:

ANSI/UL 4600: is the American National Standards Institute and Underwriters Laboratories Standards and Engagement standard for highly automated vehicle safety, applying to vehicles in which human drivers can take their eyes off the road. This standard requires a claim-based safety case which includes a structured set of claims, arguments, and evidence supporting the assertion that a vehicle operating with these ADS are acceptably safe for deployment. The focus of this standard is to provide assessment criteria to determine the acceptability of a safety case and covers public road ADS safety for both urban and highway use cases. The second edition of the standards was released in March of 2022.

Underwriters Laboratories. (December 13, 2019) Voting Version. *Standard for the Evaluation of Autonomous Products, UL 4600*. ANSI.

DOT VSSA: is the US Department of Transportation Voluntary Safety Self-Assessment which companies use to describe their safety programs to NHTSA and the public. NHTSA maintains a VSSA Disclosure Index at https://www.nhtsa.gov/automated-driving-systems/voluntary-safety-self-assessment.

NHTSA. NHTSA Voluntary Self Assessment 13069a-ads2.0_090617_v9a_tag.

Cybersecurity:

ISO/SAE 21434 – specifies the engineering requirements for Automotive Cybersecurity risk management in road vehicles and was published in August of 2021.

ISO/SAE. (August 2021). *Road Vehicles - Cybersecurity Engineering*. ISO. https://www.iso.org/standard/70918.html