Transportation Research Part A 136 (2020) 85–98

Contents lists available at ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

Regulations for on-road testing of connected and automated vehicles: Assessing the potential for global safety harmonization

Dasom Lee[1], David J. Hess*,[2]

Department of Sociology, Vanderbilt University, PMB 351811, Nashville, TN 37235-1811, United States

ARTICLE INFO

Keywords:
Connected and automated vehicles
Autonomous vehicles
Regulations
Harmonization
Safety

ABSTRACT

Although there is great media attention to connected and automated vehicles (CAVs) and strong public interest in the technology, it is still under development. Their deployment to the broader public will require new regulations and road traffic rules that are also under development, and there is not yet a globally harmonized approach. This paper reviews the main safety and liability issues for CAVs with a focus on the rules developed for on-road testing to date in Australia, the United States, and Germany. It also reviews government policies from Victoria, Australia, and California, the United States, and it provides an appendix on European Union (E.U.) regulations. After a review of similarities and differences regarding safety and liability provisions, the study suggests how the current provisions can be brought together toward a globally harmonized approach to safety issues that builds on best practices in the three countries.

1. Introduction

1.1. Importance

The advent of connected and automated vehicles (CAVs) represents a technological transition with a significance equivalent to that of the emergence of the internal combustion engine. The transition is also likely to coincide with the shift in ownership to car-sharing schemes (i.e., selling rides, not cars) and the electrification of transportation. There is widespread support for the transition to highly automated vehicles, and one major justification used to support the transition is the long-term potential for improvement in traffic safety (European Commission, 2018; Fraedrich and Lenz, 2016; Lari et al., 2015; Litman, 2015). There are also potential social equity benefits because fully driverless vehicles could bring mobility to those who cannot drive (e.g., elderly or disabled people) and to those who are under-served by public transportation. The environmental benefits of the CAV transition are more ambiguous because the change could increase commuting and vehicle cruising, but the electrification of transportation and the decarbonization of electricity could reduce environmental side effects. More generally, the CAV transition could result in a different urban built environment because of changes in traffic, parking, and the use of roads and streets (European Commission, 2018).

Because there is widespread support for the CAV transition from the technology sector and from national governments, there is a need to develop regulatory guidance for the introduction of test vehicles (Boeglin, 2015; Brodsky, 2016; Pearl, 2018). Several different policy challenges have been identified for the immediate use of test vehicles and for the long-term introduction of

* Corresponding author.
E-mail addresses: Dasom.lee.1@vanderbilt.edu (D. Lee), david.j.hess@vanderbilt.edu (D.J. Hess).
[1] ORCID: 0000-0002-6387-0121.
[2] ORCID: 0000-0001-8117-0260.

https://doi.org/10.1016/j.tra.2020.03.026
Received 19 June 2019; Received in revised form 19 March 2020; Accepted 23 March 2020
Available online 08 April 2020

widespread use of CAVs, among them safety, (cyber)security, privacy, cost, licensing, liability, infrastructure requirements, and sustainability (Fagnant and Kockelman, 2015; Lim and Taeihagh, 2018; Taeihagh and Lim, 2019). Various countries that are already serving as testing centers for CAVs have begun to develop policies and rules for on-road testing, and questions of harmonization are beginning to emerge. After a background section that reviews the leading types of regulatory challenges and the existing literature to date on government responses, this study will contribute to the existing literature by comparing government guidance and on-road testing rules in three countries where CAV testing is already occurring: Australia, the U.S., and Germany. Rather than attempt to cover the wide range of regulatory issues in a long-term perspective, this review will focus on how safety considerations together with provisions for liability and insurance are being addressed in the current phase of on-road testing. Because safety has become especially important in the wake of fatalities associated with CAV testing and with advanced features in human-driven cars, it will be important to address safety issues to gain public trust and acceptance. By providing a broad overview of the regulatory and guidance policies regarding CAV testing in these three countries, the study will show points of convergence and divergence, and it will discuss potential elements of a harmonized policy.

1.2. Contribution

With the increasing importance of CAVs as a technology that can dramatically change our daily lives, government policies will be needed to protect the safety of the public in trial environments. The existing literature provides an excellent overview of the strengths and weaknesses of currently existing regulations, rules, and related policies (Gasser et al., 2013; Kröger et al., 2019; Schreurs and Steuwer, 2016; Shladover and Nowakowski, 2019; Taeihagh and Lim, 2019). Particularly after the fatal accident in Arizona in 2018 (National Transportation Safety Board, 2018), which involved a CAV test vehicle with a human driver-monitor, safety and related issues such as liability have become increasingly important in countries where on-road testing has begun. This study analyzes the policies in Australia, U.S., and Germany regarding on-road testing of CAVs and bring these approaches together. Because the approaches are largely complementary, there is potential for harmonization of best practices.

2. Background

2.1. Definitions

According to SAE International, an Automated Driving System (ADS) refers to "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" (SAE International, 2018: 3). This definition refers to levels 3, 4, or 5 driving automation systems (defined in the next paragraph), in which a human driver's interactions with the vehicle are either limited or eliminated. However, a term is also needed to refer to the broader range from level 1 through 5, and SAE International uses "driving automation systems" for "any level 1–5 *system* or *feature* that performs part or all of the *DDT* on a *sustained* basis" (SAE International, 2018: 4).

To date, most discussions of driving automation systems refer to six levels of automation (SAE International, 2018; for Germany's levels of automation, see Section 4.3.2 below). SAE level 0 only includes limited warnings and momentary emergency interventions, and this level is declining quickly because most cars that are being manufactured have some level of driver assistance. SAE level 1 driving automation systems provide longitudinal (brake or acceleration) support or lateral (steering) support, whereas SAE level 2 driving automation systems provide both longitudinal and lateral support. SAE level 3 ADSs operate within the operational design domain; however, under some circumstances, the system will issue a prompt for the driver-monitor to take over control of the vehicle (SAE International, 2018). SAE level 4 involves ADSs within an operational design domain but does not require a "fallback" situation (when the human driver is needed to take over control of the vehicle). At SAE level 5, the vehicle can drive without any limitations on the operational design domain and without the need for driver fallback. SAE levels 3 through 5 have become the focus of new regulations and laws because these levels depart significantly from human-controlled driving and because there are significant safety controversies.

Another set of terms also warrants clarification. In some of the government policy documents, the term "automated vehicle" is used. For example, the U.S. Department of Transportation accepts the SAE definition of ADS for levels 3–5, but it uses "automated vehicle" to refer to "a vehicle fitted with any form of driving automation (SAE levels 1–5)" (e.g., U.S. Department of Transportation, 2018: 45). In Australia the term "automated vehicle" is used in a general way without specifying levels (National Transport Commission, 2017). This study will follow the SAE terminology except where it is necessary to refer to government documents that use the term "automated vehicles." Some of the government reports and policy documents also refer to disengagement, which refers to a situation where a human safety driver is required to take control because the vehicle is incapable of interpreting a traffic situation. Frequency of disengagement can become a metric of safety and of the transparency of reporting.

The term "connected and automated vehicles" (CAVs) is also widely used to refer to vehicles that are equipped with driving automation systems and can communicate with other road users. For the discussion that follows, the term "CAV" will be used to refer to vehicles with driving automation systems at levels 3 or higher (that is, to vehicles equipped to use ADSs). The most common and widely used connected-vehicle technology is a cellular- or Wi-Fi-based system that receives information on traffic conditions, but vehicles increasingly have LIDAR and radar equipment in operation. Some researchers use the term "connected and autonomous vehicles" (Bansal and Kockelman, 2017; Sheehan et al., 2019; Talebpour and Mahmassani, 2016), and others use the term "connected and automated vehicles" (Guanetti et al., 2018; Rios-Torres and Malikopoulos, 2016; Shladover, 2018). SAE International (2018: 28) cautions against the use of the term "autonomous" because of ambiguities created. Likewise, Nowakowski et al. argue that "autonomous" refers to "independent, self-organizing, or self-determining" systems, whereas "automated" refers to a system that "replaces human labor with machine activity" (Nowakowski et al., 2015: 3). For those who use the term "autonomous" in this context, it would only make sense if it refers to the relationship between the human driver-passenger and the vehicle (the vehicle is increasingly autonomous from the driver), not to the relationship between the vehicle and the traffic environment. In this paper, the term "connected and automated" is implied with the use of the term "CAV," rather than "connected and autonomous," following the usage of the U.S. Department of Transportation (2018).

2.2. Policy challenges

2.2.1. Overview

The CAV transition presents several policy challenges, among which the most discussed to date are safety, privacy, liability, infrastructure requirements, and sustainability. Because CAVs are so new, there is little research on regulation and societal dimensions, and Maurer (2016) described research in this area as "unfamiliar territory" (2016: 1). The existing research tends to be addressed not only to the research community but also to a diverse group of interested parties such as policymakers (Maurer, 2016: 1).

Once safety is assured with the further development of the technology, consumer groups and government regulators will move on to other issues such as consumer privacy, data protection, infrastructure design, and environmental effects. As the use of CAVs shifts from on-road testing to more widespread adoption, privacy issues will become more salient. Although capacity for communication with other vehicles is important for safety, it can also lead to privacy issues because the travel time, location, and activity of users are tracked. On this issue Petit and Shladover wrote, "The vehicle industry has expressed concerns about the privacy implications and the risks of cyberattacks in these cooperative systems, particularly for the safety-critical applications involving collision warning and collision avoidance" (Petit and Shladover, 2015: 546). Another area of concern is the effects on traffic and the need for new infrastructure, both of which require more research and policy attention; however, these developments will take time and will likely be addressed later on. With respect to environmental effects, Fraedrich et al. (2019) suggested that a prominent concern with CAVs is that car travel will increase and could further exacerbate congestion, but these effects will depend on how CAVs are introduced to the public and on the rules for their use.

This study will focus on safety and liability issues. The Report on the Seventy-Second Session of the Working Party on Road Traffic Safety of the United Nations Economic Commission for Europe focused on safety, cyber security, and data and reporting (United Nations Economic Commission for Europe, 2016). The report highlighted safety management assessments and data reporting procedures (see also United Nations Economic Commission for Europe, 2018a, 2018b). Because safety is based not only on the vehicle itself but also on the connection with the surrounding environment such as Internet connectivity and communication with other road users, data and reporting have become an integral component of safety. Liability is a closely related issue because when safety is compromised and there is a collision, it is necessary to determine where liability lies. In the future, when there is no driver, liability will potentially become a complex issue that will likely require adjustments to current road traffic and liability regulations. The remainder of this section examines the background literature on safety and liability in more detail.

2.2.2. Safety and liability

Advocates for and manufacturers of CAVs defend their introduction based on claims that in the long run CAVs will reduce human errors, which have been estimated to play a role in approximately 94 percent of accidents, with one quarter of those caused by driver distraction (European Commission, 2018; Favarò et al., 2017; Singh, 2015; Young et al., 2007). Although there is a dispute regarding this statistic (Koopman, 2018a), there is also widespread belief that in the future the transition could significantly improve road safety (Lari et al., 2015; Litman, 2015; Wachenfeld and Winner, 2016). For example, on the prospect of having a future transportation system that is significantly safer, Duffy and Hopkins wrote, "The benefits of autonomous cars are plentiful: increased safety for car passengers, who no longer have to fear drunk, reckless, or distracted drivers" (2013: 453). Similarly, Koopman and Wagner (2017) argued that with real-time learning of new behaviors, it is possible that CAVs can learn or react differently to the same situation at different time periods. It also has been speculated that because CAVs can make decisions faster than human drivers, there would be an overall reduction in accident rates (Lin, 2016).

Despite the widespread view that in the long run, a transportation system with few or no human drivers will decrease accidents in comparison with the existing system, there are still questions about what additional safety regulations will be needed both for the current period of testing and for the envisioned world of widespread adoption. After fatal accidents with CAVs, consumer safety organizations have questioned the safety of CAVs and have sought stronger safety policies (Hess, 2020). Similarly, there is also substantial evidence to indicate that the public is concerned about the safety of CAVs. For example, Chase's (2018) analysis of five polls on public attitudes towards CAVs in the U.S. indicated that the public is unsure about how safe on-road test vehicles are, and accidents involving CAVs have contributed to the skepticism. Koopman (2018b) also noted that ensuring the safety of CAVs is complicated and that CAVs will make different mistakes from the average human driver. For example, safety is strongly connected with the ability to assess changing configurations of traffic, pedestrians, other drivers, and infrastructures, and thus a great deal of contextual intelligence is needed to negotiate unexpected and changing road and traffic conditions. In general, engineers and computer scientists may tend to underestimate the complexity of building automated systems that have interactions with humans.

The development of safety policies for CAVs would build on an existing, extensive global regime of standards. Global manufacturers work with two sets of vehicle safety standards, one developed by the U.S. Federal Motor Vehicle Safety Standards (FMVSS) and the other by the United Nations Economic Commission for Europe and the E.U. (European Commission, 2019a). Certification of standards also varies between "type approval" countries (the EU area and Australia), where the government authority oversees the certification, and self-certification countries, where the tests are conducted by the manufacturers (the U.S.; Canis and Lattanzio, 2014; Road Vehicle Certification System, 2019; European Commission, 2019b). Shladover and Nowakowski note that there are two main dimensions of automotive safety: "functional safety with respect to internal faults" and "driving behavior competency to deal with external hazards in the driving environment" (2019: 128). For the latter dimension of safety, Straub and Schaefer also emphasize "mechanisms for communication with other road users" and "passenger mediation for other road user communication with AVs" as two of the primary policy considerations (Straub and Schaefer, 2019: 173). Another dimension of safety is the provision for detailed reporting of data for test vehicles so that information is gathered on potential safety risks that could lead to safety improvements.

With respect to liability, current law includes a variety of forms of insurance for vehicles and their uses. As CAVs proceed to higher levels of automation, the importance of insurance for drivers or vehicle owners may decline, but other types of insurance, such as product liability insurance for manufacturers or comprehensive insurance for fleet owners, may become more important (Pütz et al., 2018). Several studies have discussed potential liability issues related to a future of widespread CAV use (Anderson et al., 2014; Duffy and Hopkins, 2013; Schroll, 2014). Although these studies present an important perspective on future laws that will be needed as the technology becomes more available to the public, this paper specifically focuses on the current phase of test vehicles, and there is little literature on liability and insurance issues for on-road test CAVs. In most cases, manufacturers and testing companies of the CAV are considered liable for any accidents and collisions. However, as with the safety issue, there are already some provisions that address insurance and liability in the rules governing the current phase of on-road testing. Analyzing the liability system of the testing environment can provide some basis for the more future-oriented discussion of needs for liability rules when CAVs become more widely available.

In summary, questions have emerged about what additional safety regulations, safety-related reporting requirements, and insurance and liability rules should be required for the long-term future of CAVs. In this study, rather than speculate about what rules might be needed in the future, the developments with respect to these issues for the current period of on-road vehicle testing are examined.

2.3. Research questions

In addition to the general background literature on safety and liability, this research project builds on a small group of studies that have examined regulatory issues for CAVs. The studies fall into two groups: those focused on specific countries and subnational jurisdictions and those that adopt a comparative perspective. An example of the first group is Shladover and Nowakowski's (2019) detailed account of California's testing regulations as well as certification challenges. The authors also provide a list of findings from peer-reviewed reports, which are drawn from a number of relevant experts. Similarly, Gasser et al. (2013) reviewed German regulations on CAVs and showed that there have been uncertainties in understanding the ADSs and how they should be implemented.

Other studies on regulations utilize a comparative perspective. For example, Taeihagh and Lim (2019) summarized safety, liability, privacy, cybersecurity, and industry risks across a range of countries, including Australia, China, Germany, Japan, Singapore, South Korea, the U.K., and the U.S. They argued that Singapore and Germany have the highest safety controls and that Germany has the highest liability regulation to date. In a comparison of Germany and the U.S., Kröger et al. (2019) argued that CAV penetration rates could become higher in Germany because of a greater share of luxury cars and the more rapid fleet turnover. Overall, they claim that national regulatory policies for CAVs can help the CAV industry to flourish while avoiding negative consequences. Schreurs and Steuwer (2016) also provided a comprehensive regulatory overview that is broadly focused on European countries, Japan, and the U.S. They claimed that think tanks and non-governmental organizations are important for addressing issues that are not only technological but also social, environmental, and regulatory.

This study builds on the country-specific and comparative studies by focusing on the currently existing regulations for safety and liability for the testing of vehicles with ADSs. The comparative analysis that follows has two main research questions:

What policies are currently in place that provide rules for CAV safety-related issues for on-road testing and pilot projects in countries with advanced regulations?

Who are the liable parties in CAV on-road testing collisions, and what rules or guidance govern liability and insurance?

Comparative research in response to these questions in turn provides the basis for a discussion of the potential for harmonized global policy.

3. Methods

This paper provides a comparative analysis of safety regulations currently in existence for on-road testing in three countries: Australia, U.S., and Germany. The countries were chosen based on their involvement in and contributions to developing rules for on-road testing of CAV and ADS vehicles. Australia's regulations were selected because the country is including advanced elements in their regulations such as safety management planning and data monitoring of performance of CAVs. The State of Victoria was selected as an example of regulatory implementation for Australia because it has the most recent regulatory regime that was introduced in the country and because it addresses safety-related issues much more than the other two states with CAV regulation (New South Wales and South Australia). In the U.S., the analysis focuses on the national guidelines proposed by the National Highway Traffic Safety Administration (NHTSA) of the U.S. Department of Transportation. In this country, 33 states accommodate trials of

CAVs. California was selected as an example of regulatory implementation because it has been one of the main testing grounds for CAVs. The study also analyzes policy guidance in Germany, which is one of the main vehicle manufacturers in the world. Because Germany has no regulations to date at the level of the länder (subnational state governments), the analysis focused only on its federal regulations. However, the appendix summarizes the guidance documents at the EU level.

The review was conducted using journal and article database search engines, including Google Scholar and ProQuest. Searches were conducted using the keywords "autonomous vehicle regulation," "automated vehicle regulation," "CAV regulation," and "self-driving regulation" with the relevant country name attached. The review also included government resources such as acts, reports, and guidelines. Moreover, reports and articles by the news media and by consumer organizations were used to assess the significance of the issues and the regulations (or lack of regulations). Bibliographic and other references were also used in a "snowball" method to identify existing sources. Over 100 articles and documents were selected and read to assess accurately the regulations in each region, and additional 50 articles were read for the general background research on automated vehicle regulations.

Three types of information on each geographic region were collected: safety, liability, and data and reporting. A qualitative analysis of different regions was then conducted, and countries that did not have distinctive or advanced regulations on CAVs were excluded. Initially, the project started out with a number of countries: Australia, China, Germany, Japan, Singapore, South Korea, and the U.S. However, China, Japan, Singapore, and South Korea were excluded because their regulations were much less developed in comparison with the other three countries. Therefore, the analysis focused on the countries that had the most elaborate rules for CAV on-road testing, which are Australia, the U.S., and Germany.

After collecting the relevant information on safety, liability, and data and reporting, the next step was an inventory of the safety practices in the three countries. From that inventory, 10 best practices were selected based on shared areas of safety rules and concerns across the countries and the comparison of different ways of addressing the concerns.

4. Results

4.1. Australia

4.1.1. National guidelines

In November 2016, the National Transport Commission (NTC) of Australia was asked to develop options for legislative reforms in relation to "safety, productivity, environmental, and mobility gains" because the current legislative framework was perceived to be a barrier to the development of CAVs (Wheelahan et al., 2018). Michael McCormack, Australia's Deputy Prime Minister, emphasized the importance of safety in connection with productivity: "I want to ensure these new technologies are deployed in a manner which improves safety, productivity, accessibility, and livability for Australians in both urban and regional areas" (The Nation, 2019). The NTC produced a discussion paper in November 2016, and it released the finalized document *National Guidelines for Trials of Automated Vehicles in Australia* in May 2017 (National Transport Commission, 2017). Although the federal government agency supported the principle of "nationally consistent conditions for automated vehicle trials in Australia" (National Transport Commission, 2017: 1), it also left room for substantial differences in state-level regulations.

The greatest emphasis of the guidance document was on safety. In order to ensure safety of on-road testing, the agency recommended pre-trial testing of the vehicle at a test facility that has a closed track. For on-road testing, it recommended a human safety driver in the test vehicle unless a specific exemption of permit is granted for the test. It also recommended that the trialing organization develop a safety management plan to detail the main safety risks and how they would be mitigated or eliminated. Trialing organizations were asked to follow existing crash reporting requirements and to report any serious incidents to the relevant road transport agency (National Transport Commission, 2017). Some parts of their recommendations were less specific. For example, the federal guidance document noted that "vulnerable road users" should "be considered carefully as part of the safety management of all trials taking place on public roads" (National Transport Commission, 2017: 10). It also stated, "Trialing organizations will need to consider how their trial may impact existing infrastructure and how they plan to address this" (National Transport Commission, 2017: 10).

One important feature of the federal guidance was a recommendation for all trialing organizations to obtain a permit that discloses information on trial location, a detailed description of the technology, and traffic management plans. If a permit is not required by the state government, the trialing organization is still expected to comply with Australian laws, including road rules and traffic laws, vehicle standards, and privacy and surveillance laws.

The federal government also provided guidance on data and reporting. The NTC recommended that new data be captured using "in-cabin cameras, biometric, biological or health sensors" (National Transport Commission, 2019a). These technologies are not currently used or are in limited use in test vehicles, but if required for the general public in the future, they could create privacy issues. Moreover, there could be other forms of data available from test vehicles such as speed, location, and direction. These types of data can have sensitive private information, and the NTC stated that there could be new privacy challenges in the future (National Transport Commission, 2019a).

With regard to liability, Australia's national guideline states that trialing organizations must have appropriate insurance, which can include compulsory third-party insurance, comprehensive vehicle insurance, public liability insurance, product liability insurance, self-insurance, and/or work or occupational health and safety insurance. In August 2019, the NTC published *Motor Accident Injury Insurance and Automated Vehicles*, which stated the need to provide access to compensation for injuries caused by CAVs and to keep the responsible parties liable. Additionally, the paper noted that the NTC should consider data access for insurers to determine liability (National Transport Commission, 2019b).

4.1.2. Victoria

Victoria is chosen over other two Australian states with CAV regulations, namely South Australia (Parliament of South Australia, 2016) and New South Wales (New South Wales Government, 2017), because it addresses safety issues in much more detail and because its regulations were developed after those of the other two states. Victoria introduced the Road Safety Amendment (Automated Vehicles) Act of 2018, which went into effect on February 27, 2018. Under this Act, a CAV trialing organization must apply for a permit from VicRoads. The application has the following main components: details of the applicant, the vehicles, any vehicle supervisor, the nature of the trial, and a safety management plan. VicRoads also has the power to impose certain conditions on the trial including the days of the trial, compliance with the safety management plans, the driver's alcohol and drug blood level, and real-time monitoring of the performance. In Victoria, it is an offense to use a test vehicle that does not have an ADS permit or to utilize trialing conditions that breach any of the specified terms in the application of the permit. The legal burden for any accidents falls on the entity responsible for the trial (Parliament of Victoria, 2018).

Victoria's safety management plan addresses a number of concerns that consumer organizations have raised. The safety management plans, which are required as a condition of the ADS permit, include information on "safety risks, pre-trial testing, system failures, transition processes between the ADS and vehicle supervisor, road infrastructure, dynamic driving task competence, compliance with relevant road traffic laws, interaction with police officers and other emergency services, managing change, risk to other road users, security and privacy, fitness for duty, and training of vehicle supervisors" (VicRoads, 2018: 1). Additionally, Victoria requires that all trials be recorded in real time to monitor performance, location, and compliance of the test vehicles. This rule places more pressure on ADS permit holders in Victoria to be transparent about their records and data. Penalties for violation are fines of $79,285 (approx. $54,567 USD) for corporations and $15,857 (approx. $10,713 USD) for individuals.

4.2. U.S.

4.2.1. National guidelines

Although the U.S. Department of Transportation (2018) claims that it is important to have federal regulation for ADSs, the U.S. does not have any unique federal regulations and only provides guidelines to the state governments. The U.S. Department of Transportation's, report, "Preparing for the Future of Transportation: Automated Vehicles 3.0" recognized that the department's "primary focus [is] on safety, while expanding the discussion to other aspects and modes of surface transportation" (U.S. Department of Transportation, 2018: 2). The main purpose of this report was to encourage the safe and effective integration of ADS test vehicles into the existing road systems and to facilitate safe interactions with conventional vehicles, pedestrians, and other road users. State, local, and tribal governments were characterized as responsible for "licensing human drivers, registering motor vehicles, enacting and enforcing traffic laws, conducting safety inspections, and regulating motor vehicle insurance and liability" as well as "planning, building, managing and operating transit and the roadway infrastructure" (U.S. Department of Transportation, 2018: 18).

The 2018 document built on previous versions, including the September 2017 document "Automated Driving Systems: A Vision for Safety 2.0" (U.S. Department of Transportation, 2017). The 2.0 report had a more detailed set of recommendations for the safety elements of the ADSs. The report encouraged the adoption of voluntary safety self-assessments by companies with test vehicles, noted the need to consider crashworthiness especially for vehicles without a human driver, and stated that data recording and crash data in particular were valuable resources for the further development of ADSs to prevent the recurrence of potential crash scenarios. The report encouraged the voluntary collection of data for on-road testing, including the data on whether or not the human safety driver was in control of the vehicle "leading up to, during, and immediately following a crash" (U.S. Department of Transportation, 2017: 14). Overall, the guidance document emphasized the importance of voluntary actions to ensure automotive safety. For example, it encouraged the adoption and publication of the Voluntary Safety Self-Assessment to demonstrate the entities' concern for safety and to build public trust and acceptance. With respect to insurance, the report recommended that state governments consider how to allocate liability among CAV owners and whether the owner, operator, passenger, or manufacturer should carry insurance (U.S. Department of Transportation, 2017).

4.2.2. California

The State of California has been one of the leading players in ADS technology in the U.S. In July 2012, California approved Senate Bill 1298, which specified rules for the testing of CAVs (California Legislative Information, 2012). In December 2015, the California Department of Motor Vehicles (DMV) introduced a draft that implemented the law by requiring a human safety driver inside the vehicle and an "event data recorder" that records at least 30 s before a collision (State of California Department of Motor Vehicles, 2015). This document also stated that manufacturers of CAVs will self-certify the safety of the vehicle to meet with all applicable Federal Motor Vehicle Safety Standards (FMVSS) and to meet the traffic laws with respect to hazardous situations. Additionally, a "functional safety plan" was required, which identifies and assesses hazardous situations that can occur during CAV testing. After the 2015 draft, the DMV released another statement in September 2016 acknowledging and supporting NHTSA's release of the Federal Automated Vehicle Policy (State of California Department of Motor Vehicles, 2016). The 2016 federal policy of the Obama administration was later replaced by Trump Administration's guidelines (U.S. Department of Transportation, 2016, 2017, 2018; for a summary of changes, see Congressional Research Service, 2019).

California's 2012 law authorized the state's Department of Motor Vehicles to develop rules for test vehicles without the human safety driver inside the vehicle. In February 2018, building on the already existing rules on on-road testing of CAVs, the Adopted Regulatory Text for Driverless Testing Regulations (Title 12, Division 1, Chapter 1, Article 3.7 – Testing of Automated Vehicles) allowed test CAVs without a human safety driver to be on public roads in California for the first time. Similar to the 2015 regulation, the 2018 rule also required a mandatory permit for testing. The main difference from the previous regulation is the types of permits that are available for the manufacturers. California has three types of permits: Manufacturer's Testing Permit; Manufacturer's Testing Permit – Driverless Vehicles; and Permit to Deploy Autonomous Vehicles on Public Streets. The first permit requires a human safety driver who is an employee, contractor, or designee of the manufacturer. The driver must also understand the limitations and the weaknesses of the automated vehicle in order to respond appropriately. California also requires a training program for automated vehicle safety drivers, and a description of this training program must be submitted to the state government (State of California Department of Motor Vehicles, 2018a).

Although the California rules allow manufacturers to test a vehicle without the presence of a human safety driver inside the vehicle, a remote human monitor or operator who has a communication link with the vehicle is required. Consequently, the second permit, "Manufacturer's Testing Permit – Driverless Vehicles," was introduced. The permit is only given if the manufacturer specifies "the operational design domain of the test vehicle, a list of all public roads in the jurisdiction where vehicles will be tested, the date that testing will begin, the days and times that testing will be conducted on public roads, the number of vehicles to be tested, and the types of vehicles to be tested" as well as the contact information of the manufacturer (State of California Department of Motor Vehicles, 2018a: 11). There must be a communication link between the vehicle and the remote monitor, and the manufacturer must certify that the vehicle is capable of driving without human presence. Moreover, authorities in locations where vehicles will be tested must be provided with written notification, and there should be a communication link between the local law enforcement and the vehicle. California also requires a training program for remote operations, submission of an annual disengagement report, and submission of a collision report to the DMV within 10 days of an event (State of California Department of Motor Vehicles, 2018c).

The third permit, "Permit to Deploy Autonomous Vehicles on Public Streets," allows manufacturers to deploy CAVs within California. This permit is specifically designed for "governing the public use of automated vehicles on California roads," which became effective on April 2, 2018 (State of California Department of Motor Vehicles, 2019). In order to obtain this permit, the manufacturers must provide a description of the levels of automation of the CAV (SAE level 3, 4, or 5) and the vehicle's operational design domain, compliance with all FMVSS standards, a certification that the vehicle can meet California's traffic laws, and a certification that the vehicle meets international cybersecurity standards. For deployment, a vehicle must be equipped with a data recorder and must meet current industry standards to help defend against, detect, and respond to cyber-attacks. Additionally, a copy of a law enforcement interaction plan is also required (State of California Department of Motor Vehicles, 2018c).

In addition to the compliance with the FMVSS, California also requires every manufacturer with the testing permit to submit an annual disengagement report. Disengagement reports are available to researchers and the public upon request, and recent collision reports are available online (State of California Department of Motor Vehicles, 2020). Some examples of the problems reported in these disengagement reports are poor lane markings in a report by BMW, incorrect behavior prediction in a report by Honda, and failure to detect an object clearly in a report by Waymo (State of California Department of Motor Vehicles, 2018b). Although the reports are potentially useful in assessing the safety of CAVs because the causes of disengagements are also reported, their value is limited because of inconsistencies in reporting. Some of the strengths and weaknesses of this approach to safety reporting are discussed in the comparison section below.

The CAV trial permit states that manufacturers must have liability protection in the form of $5 million of insurance, surety bond, or a certificate of self-insurance. They are required to cover any personal injury, death, or property damage that may occur from the operation of CAVs. The permit is valid for two years, which then must be renewed by the manufacturer.

4.3. Germany

In the past, many European countries have depended on international regulations for their transportation regulations, such as the 1968 Vienna Convention on Road Traffic, developed by the United Nations Economic Commission for Europe. The role of the E.U. has been important because its constituent units publish communications (European Commission, 2017a, 2017b) and build platforms on which European countries can gather and discuss CAV regulatory environments (European Commission, 2017c). However, there was also some sentiment that the E.U. was not moving quickly enough and that the area had fallen "slightly behind regarding strategies for testing infrastructure" (Medina et al., 2017: 45). Germany has been developing its own CAV testing regulations at the federal level, with little reference to the E.U. regulations.

Germany is a global leader of automobile manufacturing and home to global brands such as Volkswagen, Mercedes-Benz, BMW, and Audi. The country's Federal Highway Research Institute provided insightful research on CAVs as well as the different levels of automation that influenced SAE definitions. Most countries use the definition provided by the SAE described above (Inagaki and Sheridan, 2018). In Germany, there were originally only five levels, and they were not numbered as level 0, level 1, etc. (Gasser et al., 2013); however, subsequent categorizations have added the sixth level of "driverless" systems (Verband der Automobilindustrie, 2015; see also Fraedrich et al., 2016). Although the terminology and definitions are not identical with those of SAE International, the six German categories of the Verband des Automobilindustrie are similar: driver only (level 0), assisted (level 1), partly automated (level 2), highly automated (level 3), fully automated (level 4), and driverless (level 5).

German traffic regulation is based on the German Road Traffic Code Straßenverkehrs-Ordnung (Bundesministerium der Justiz und für Verbraucherschutz, 2013), which is in accordance with the Vienna Convention on Road Traffic and was last amended in November 2016. Section 23 of the StVO states that drivers may not occupy themselves with tasks that may distract them from paying attention or in any other way cause them to neglect driving tasks. Although this regulation is important for conventional vehicle users, it can be seen as outdated for vehicles with ADSs. One report based on the 2013 rules stated that the regulatory law and the actual performance of CAVs do not coincide, but to date the problem has had little effect on safe driving because drivers are in control of the vehicle (Gasser et al., 2013). The report also noted that new regulations will be needed to legalize operator-based automation especially because advanced ADSs are not yet covered.

In response to such gaps, in 2017 the German government provided modificatons to the German Road Traffic Act (Straßenverkehrsgesetz, StVG) to address CAV-related regulations (Bundesministerium der Justiz und für Verbraucherschutz, 2019). This law specifically addressed VDA level 3 (automated features can be used to drive the vehicle under limited conditions, and when the automated system requests, the driver must be ready to take over driving). For higher levels of automation, permits are given on an individual basis. Moreover, the changes to the StVG require that the ADS comply with traffic regulations and recognize the need for control by the human safety driver when necessary. The driver should be able to deactivate the ADS at any time. The law does not require the driver to pay full attention at all times, but the driver must take the control of the CAV without any delay when required. The law also stipulates the use of a monitoring system (a black box; sections 63a and 63b of StVG) for safety, and it requires a determination of who is liable if there is an accident, such as whether it was the fault of the driver or the ADS (Burianski and Theissen, 2017). Under the law, the human safety driver is expected to be able to take control of the vehicle when prompted. If an accident is caused by the human safety driver's failure to regain control of the vehicle when prompted (such as would occur if the safety driver were napping), both the safety driver and testing company (vehicle owner) can incur liability. However, if the accident is not the fault of the safety driver (e.g., caused by a malfunction of the ADS), then the safety driver is not liable (Baumann and Duisberg, 2017; Bundesministerium der Justiz und für Verbraucherschutz, 2019).

There were two main points of criticism regarding the AV law. First, the current liability regulation does not accommodate future cars at the highest two levels of automation. The liability rules are likely to create some disincentives for owning or choosing CAVs in Germany; therefore, some revision of this liability system may be needed in the future. Second, the law regarding the black box is too vague because it is unclear who owns the data, and data privacy could become an issue (Burianski and Theissen, 2017).

5. Discussion

This section of the paper compares and contrasts the similarities and the differences between the countries' rules for on-road testing of vehicles with ADSs, and it proposes a direction for future harmonization. The comparison is based on three main types of safety issues for which there were clear differences—safety driver presence, safety management, and data and reporting—and one category of liability (see Table 5.1).

5.1. Comparative analysis

There were significant differences regarding rules for driver presence. Of the three cases, only California does not require a human safety driver in the CAV while testing. For driverless vehicles, California requires remote supervision of the CAV with a continuous connection.

With respect to safety management, all three countries have a strong emphasis on this dimension of safety, but there were also some differences. Victoria has incorporated safety management plans in its permit procedures, and the state government has backed up the rule with relatively high penalties for permit violation. California also requires functional safety plans for the testing of CAVs. Additionally, California follows the U.S. approach of self-certification of the broader safety requirements. Germany does not require safety plans like those of Victoria or California. However, in Germany only VDA level 3 is currently allowed, and it is likely that Germany will modify its regulations accordingly for higher levels of driving automation systems.

With respect to the third area of safety rules for on-road testing (data and reporting), there are some similarities, which indicate that all three countries developed the regulations with high regard for data, reporting, and data maintenance. Victoria requires real-time monitoring and recording of performance and location, and it requires compliance with the permit requirements during the test (such as appropriate training, test, or assessment of the safety driver, vehicle meets the examination, test or assessment). Similarly, Germany and California require a black-box that is placed inside the vehicle and records all CAV tests. In addition, California requires disengagement reports that are available upon request from the California Department of Motor Vehicles (State of California Department of Motor Vehicles, 2019). The reports are an important source of information for the government, consumer organizations, and testing organizations. However, they are also controversial because safety drivers may be motivated not to disengage in order to make the statistics appear better. There are also some inconsistencies across different manufacturers despite the same submission form for disengagement reports.

Choosing the liable party if there is any damage or accident is a difficult issue even for accidents with human drivers, and the law for traditional, human-operated vehicles provides only limited precedents. Victoria and California hold the test company liable for failures. The company that is managing the test is also the entity that is responsible for choosing the conditions of trial, and usually the testing company is also the manufacturer or designer of the ADS. Victoria holds the legal entity responsible for testing liable for any damage or accidents. For the time being, these are manufacturing or testing companies. In the German system, the human safety driver, owner of the vehicle, or both can be held liable.

5.2. Best practices

At this early stage of CAV on-road testing, there is limited knowledge about safety risks. It may also be the case that no single set of best practices should be applied to all countries or to all types of vehicle uses (e.g., personal automobiles versus public transportation on highly specified routes). Nevertheless, the comparative analysis suggests that the shared concerns and rules for safety

Table 5.1
Comparing different regulations.

Issue		Victoria, Australia	California, US	Germany
Safety	Safety Driver Present	Yes	Not required	Yes
	Safety Management	Safety management plan required	Self-safety assessment to meet the Federal Motor Vehicle Safety Standards; functional safety plan required	Fluid digital communication recommended (E.U.); only VDA level 3 automation is regulated; higher level permits are given on individual basis
	Data and Reporting	Real time monitoring and recording of performance, location, compliance	Disengagement reporting; recording of accidents (30 s prior)	Black box required; free flow of non-personal data recommended (E.U.)
Liability		Legal entity responsible for the trial	Manufacturer, the owner of the ADS	Safety driver and/or vehicle owner (i.e., testing company)

and liability can be the basis for developing best practices that could become a starting point for harmonization. The ten best practices that emerge from this study's comparative analysis are as follows:

1. On-road testing of vehicles should have at least one human safety driver who is ready to take control to maximize safety until the on-road testing of CAVs is more advanced.
2. If a government decides to shift to testing with a remote monitor, a separate license with additional provisions, as in California, should be required.
3. Safety drivers and remote monitors should be able to deactivate the system easily and at any time.
4. A training program for safety drivers and remote monitors, as is required in California, would also improve safety and help to avoid accidents caused by the failure of safety drivers (as was apparently a contributing cause in Arizona).
5. A full safety management plan as developed in Australia could help to ensure that the testing companies have thought through the safety issues.
6. The requirement that trials are recorded in real time (as in Australia) helps to ensure that safety plans are implemented and can provide information that can help to improve vehicle safety performance.
7. Substantial fines or other penalties for non-compliance with safety rules, as in Australia, would help to incentivize best practices from the testing companies, and the associated investigations could provide detailed information on accidents and disengagement conditions.
8. Testing companies should be required to file disengagement reports as in California, and the reports should be standardized across manufacturers. Annual and public metrics that address possible improvements beyond disengagement reporting would provide additional information to regulators, the public, and consumer safety organizations to help with improvements in safety design.
9. The testing permit should require substantial insurance, as is the case in California.
10. The requirement of a black box for safety investigations, which is already implemented in some countries, would help to improve knowledge and to determine liability in the event of an accident.

This list provides a sense of what a globally harmonized safety regime might look like for the current phase of on-road testing. It should be noted that the technology is changing very rapidly, and discussions quickly become out-of-date. Although this comparative study brings together the best practices in three areas of the world where policy for testing is most developed to date, it is not a comprehensive list of the general parameters of safety regulation. For example, in response to the relatively weak guidance included in bills under consideration in the U.S. Congress, consumer safety organizations developed their own lists of needed safety regulations and guidance that to date are not part of the existing policy (Hess, 2020). However, these provisions are mainly for future systems when CAVs become more widely used in non-testing situations, and the suggestions given above may apply well for the current phase of testing.

6. Conclusion

Despite the effort to develop safety-oriented rules for the initial phase of on-road testing of vehicles with ADSs, as indicated above public opinion surveys have suggested public skepticism about their safety, even for on-road testing. The three countries that were reviewed in this analysis all have made some progress toward addressing public concern with safety, but they have shown different priorities. Using the advanced practices of these three countries, this study has shown how on-road testing has addressed three types of safety concerns and provided some guidance on liability issues. Drawing on these three cases, ten approaches are summarized as ways to ensure the safety of CAV testing environment using the policy harmonization approach.

Comparing regulations is important not only for policymakers and consumer advocacy organizations but also for engineers and designers, who need to understand both the implications of regulations for design requirements and the effects of the interaction of humans and ADSs on new safety risks. For example, a report published by the Dutch Safety Board (2019) reviewed a range of new and emerging safety issues that will need to be addressed. One issue of significant concern is how to improve design to prevent the human misuse of systems. For example, the national news media in the U.S. widely reported on videos of Tesla drivers sleeping in front of the wheel while their vehicles were on automated mode in busy highway traffic (Lloyd and Chang, 2019). In response to new information such as this event, it may be necessary to require the system design to include tracking of eye movements of the driver for levels up to and including VDA level 3 and SAE level 3 automation. Such features would require the human driver to pay attention while driving or to ensure that drivers are able to take over the vehicle when needed, and these systems are already in place in some vehicles. In summary, new information about human misuse of ADSs will likely create pressures on companies for ongoing safety design innovation.

But the broader point of the example of the sleeping driver is that this use of the vehicle was far from the one recommended or envisioned by the manufacturer, and it is suggestive of a future where human interactions with ADSs are quite unpredictable and will generate unanticipated new risks. Users are not often recognized as the central focus of design, and there is a need to incorporate principles of user-centered design and responsible innovation into ADS design (Dutch Safety Board, 2019). In order for the technology to gain public confidence and to provide broad societal benefits, it is important that policymakers continue to examine, compare, and implement safety rules. A good place to begin is the comparative analysis of the best practices related to safety that are emerging for testing of vehicles with ADSs. Although these practices do not cover a future when there is more pervasive on-road use, they provide some insights into issues that have already been encountered.

Acknowledgements

This project was partially supported by the U.S. National Science Foundation, OISE-1743772, Partnerships for International Science and Engineering (PIRE) Program: "Science of Design for Societal-Scale Cyber-Physical Systems." Any opinions, findings, conclusions, or recommendations expressed here do not necessarily reflect the views of the National Science Foundation. We also thank Philip Koopman, Tom Gasser, and the reviewers for comments on drafts.

Declaration of Competing Interest

The authors have no financial interest in the organizations or technologies described.

Appendix 1. European Union

The E.U. is one of the world's leading exporters of automotive technology, and a report suggests that the extensive use of ADSs will have a spillover effect on other industries such as semiconductors, processing technologies, and digital maps (European Commission, 2018). According to Schreurs and Steuwer (2016: 158), the overarching objectives in the European transport sector include the goals of competitiveness, sustainability, efficiency, lower carbon, and safety. To date these goals have not been brought together into coherent regulatory guidance for vehicles with ADSs.

The fundamental traffic regulation relevant for the E.U., as for other signatories, is the 1968 Vienna Convention on Road Traffic. This international treaty was designed to help organize international traffic and came into force on May 21, 1977, a time that predates ADSs. Because the E.U. currently does not have legislation on traffic rules, a 2018 report from the Commission recommended that its member states follow the international legislation such as the 1949 Geneva Convention and the 1968 Vienna Convention on Road Traffic (European Commission, 2018). The E.U. also recognizes that there should be consistency between national traffic rules and E.U. vehicle rules. In 2019, the United Nations Economic Commission for Europe published a report about the discussion among E.U. countries on ADS regulations and whether the 1968 Vienna Convention required some amendments. For the time being, Germany stated that it was not necessary to edit the Convention and that the Convention could accommodate the highest levels of automation based on thorough review and in-depth knowledge of the latest technology (United Nations Economic Commission for Europe, 2019).

A series of statements and communications issued since 2016 provide guidance to member states. These statements do not discuss liability issues, but they do provide guidance on safety. In 2016, the Declaration of Amsterdam on Cooperation in the Field of Connected and Automated Driving was issued (European Commission, 2017c, Rijksoverheid, 2016). In this statement, Norway, Switzerland, and 27 E.U. member states agreed to meet twice a year to discuss the best practices and regulations. Subsequently, the communication "Autonomous Cars, a Big Opportunity for European Industry" stated that the initiatives on standardizing technical and infrastructural issues have started and that they need to be further solidified (European Commission, 2017a). Moreover, the communication "Building a European Data Economy" suggested the need for the free flow of non-personal data, which would remove unjustified data localization restrictions and enhance the freedom of businesses to use the data within the E.U. (European Commission, 2017b).

The communication "On the Road to Automated Mobility: An EU strategy for Mobility of the Future" specifically discussed CAVs (European Commission, 2018). This communication discussed prior testing of CAVs to confirm and validate the safety of the vehicles. In other words, the Commission suggested that through trial and error, vehicles would become increasingly automated and connected, and they would interact fully with the infrastructures and traffic. The combination of automation and connection is important for the "smoothest and safest traffic flows" (European Commission, 2018). The communication placed a heavy emphasis on assuring the safety of vehicles equipped with ADSs. Because the vehicles will be driven on the roads with pedestrians, cyclists, and motorcyclists, it noted how important it was for safety to be guaranteed for the overall road safety, rather than just the safety of uses of CAVs. Moreover, to ensure further safety, the communication recommended fluid and continuous digital communication between the CAVs and road traffic information so that all systems providing road traffic information are interoperable. In order to foster smooth communication between CAVs and the overall transport system, 5G connectivity infrastructure is expected to enable and accommodate the vehicles as well as to improve the overall transportation system (European Commission, 2018).

The same communication also noted that the expansion of vehicles equipped with ADSs could lead to an increase in traffic, which could lead to an increase in total emissions and congestion. Moreover, it is difficult to assess the extent of communication possible between ADS-equipped vehicles and other vehicles. Consequently, the Horizon 2020 transport work program included projects that examine the behavior of users and public acceptance of the emerging technologies (European Commission, 2018).

References

Anderson, J.M., Nidhi, K., Stanley, K., Sorensen, P., Samaras, C., Oluwatola, O., 2014. Autonomous Vehicle Technology: A Guide for Policymakers. Rand Corporation, Santa Monica, California, USA. https://www.rand.org/pubs/research_reports/RR443-2.html.

Bansal, P., Kockelman, K., 2017. Forecasting Americans' long-term adoption of connected and autonomous vehicle technologies. Transp. Res. Part A: Policy Practice 95, 49–63. https://doi.org/10.1016/j.tra.2016.10.013.

Baumann, J., Duisberg, A., 2017. German government publishes draft bill for automated driving. Bird Bird. https://www.twobirds.com/en/news/articles/2017/germany/german-government-publishes-draft-bill-for-automated-driving.

Boeglin, J., 2015. The costs of self-driving cars: reconciling freedom and privacy with tort liability in autonomous vehicle regulation. Yale J. Law Technol. 17,

171–203.
Brodsky, J., 2016. Autonomous vehicle regulation: How an uncertain legal landscape may hit the brakes on self-driving cars. Berkeley Technol. Law J. 31, 851.
Bundesministerium der Justiz und für Verbraucherschutz, 2013. Straßenverkehrs-Ordnung (StVO). https://www.gesetze-im-internet.de/stvo_2013/index.html#BJNR036710013BJNE005700000.
Bundesministerium der Justiz und für Verbraucherschutz, 2019. Straßenverkehrsgesetz (StVG). https://www.gesetze-im-internet.de/stvg/BJNR004370909.html.
Burianski, M., Theissen, C., 2017. Germany permits automated vehicles. White Case. https://www.whitecase.com/publications/article/germany-permits-automated-vehicles.
California Legislation Information, 2012. Senate bill 1298. https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201120120SB1298.
Canis, B., Lattanzio, R., 2014. US and EU motor vehicle standards: issues for transatlantic trade negotiations. CRS Report, 43399. https://www.hsdl.org/?view&did=751039.
Chase, C., 2018. Innovation in surface transportation. Advocates for Highway and Auto Safety. https://saferoads.org/wp-content/uploads/2018/09/Advocates-Testimony-for-Innovation-in-Surface-Transportation-Hearing-9-5....pdf.
Congressional Research Service, 2019. Issues in Autonomous Vehicle Testing and Deployment. https://fas.org/sgp/crs/misc/R45985.pdf.
Duffy, S., Hopkins, J., 2013. Sit, stay, drive: the future of autonomous car liability. Sci. Tech. Law Rev. 16, 453–480.
Dutch Safety Board, 2019. Who is in Control? Road Safety and Automation in Road Traffic. https://www.onderzoeksraad.nl/en/page/4729/who-is-in-control-road-safety-and-automation-in-road-traffic.
European Commission, 2017a. Autonomous Cars: A Big Opportunity for European Industry. European Commission, Digital Transformation Monitor. https://ec.europa.eu/growth/tools-databases/dem/monitor/sites/default/files/DTM_Autonomous%20cars%20v1.pdf.
European Commission, 2017b. Building a European Data Economy. Communication from the Commission to the European Parliament, Council, The European Economic and Social Committee and the Committee of the Regions. http://ec.europa.eu/transparency/regdoc/rep/1/2017/EN/COM-2017-9-F1-EN-MAIN-PART-1.PDF.
European Commission, 2017c. Joint statement by Commissioners Oettinger, Bulc and Gabriel, on cooperative, connected and automated mobility. European Commission Press Release Database. http://europa.eu/rapid/press-release_STATEMENT-17-3272_en.html.
European Commission, 2018. On the Road to Automated Mobility: An EU Strategy for Mobility of the Future. Communication from the Commission to the European Parliament, The Council, and the European Economic and Social Committee, The Committee of the Regions. European Commission. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2018:0283:FIN:EN:PDF.
European Commission, 2019a. Mobility and Transport: Road Safety. European Commission. https://ec.europa.eu/transport/road_safety/specialist/knowledge/vehicle/vehicle_safety_policy/who_regulates_vehicle_safety_en.
European Commission, 2019b. Type Approval of Vehicles, International Market, Industry, Entrepreneurship, and SMEs. European Commission. https://ec.europa.eu/growth/sectors/automotive/technical-harmonisation/faq-auto_en.
Fagnant, D., Kockelman, K., 2015. Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. Transp. Res. Part A: Policy Practice 77, 167–181. https://doi.org/10.1016/j.tra.2015.04.003.
Favarò, F., Nader, N., Eurich, S., Tripp, M., Varadaraju, N., 2017. Examining accident reports involving autonomous vehicles in California. PLoS One 12 (9), e0184952. https://doi.org/10.1371/journal.pone.0184952.
Fraedrich, E., Cyganski, R., Wolf, I., Lenz, B., 2016. User Perspectives on Autonomous Driving: A Use-case-driven Study in Germany. Geographisches Institut, Humboldt-Universität zu Berlin. https://elib.dlr.de/103242/1/Fraedrich_Cyganski_Wolf_Lenz_2016_User%20perspectives%20on%20autonomous%20driving.pdf.
Fraedrich, E., Heinrichs, D., Bahamonde-Birke, F., Cyganski, R., 2019. Autonomous driving, the built environment and policy implications. Transp. Res. Part A: Policy and Practice 122, 162–172. https://doi.org/10.1016/j.tra.2018.02.018.
Fraedrich, E., Lenz, B., 2016. Societal and individual acceptance of autonomous driving. In: Maurer, M., Gerdes, J., Lenz, B., Winner, H. (Eds.), Autonomous Driving: Technical, Legal and Social Aspects. Springer, Berlin, Heidelberg, pp. 621–640.
Gasser, T.M., Arzt, C., Ayoubi, M., Bartels, A., Bürkle, L., Eier, J., Flemisch, F., Häcker, D., Hesse, T., Huber, W., Lotz, C., Maurer, M., Ruth-Schumacher, S., Schwartz, J., Vogt, W., 2013. Legal Consequences of an Increase in Vehicle Automation. Bundesanstalt für Straßenwesen. https://bast.opus.hbz-nrw.de/opus45-bast/frontdoor/deliver/index/docId/689/file/Legal_consequences_of_an_increase_in_vehicle_automation.pdf.
Guanetti, J., Kim, Y., Borrelli, F., 2018. Control of connected and automated vehicles: state of the art and future challenges. Annu. Rev. Control 45, 18–40. https://doi.org/10.1016/j.arcontrol.2018.04.011.
Hess, D., 2020. Incumbent-led transitions and civil society: autonomous vehicle policy and consumer organizations in the United States. Technol. Forecast Soc. https://doi.org/10.1016/j.techfore.2019.119825. in press.
Inagaki, T., Sheridan, T.B., 2018. A critique of the SAE conditional driving automation definition, and analyses of options for improvement. Cogn. Technol. Work 21 (4), 569–578. https://doi.org/10.1007/s10111-018-0471-5.
Koopman, P., 2018a. A reality check on the 94% human error statistic for self-driving cars. Safe Autonomy. https://safeautonomy.blogspot.com/2018/06/a-reality-check-on-94-percent-human.html.
Koopman, P., 2018b. Practical experience report: automotive safety practices vs. accepted principles. SAFECOMP, Sept. 2018. http://users.ece.cmu.edu/~koopman/pubs/koopman18_safecomp.pdf.
Koopman, P., Wagner, M., 2017. Autonomous vehicle safety: an interdisciplinary challenge. IEEE Intell. Transp. Syst. Mag. 9 (1), 90–96. https://doi.org/10.1109/MITS.2016.2583491.
Kröger, L., Kuhnimhof, T., Trommer, S., 2019. Does context matter? A comparative study modelling autonomous vehicle impact on travel behaviour for Germany and the USA. Transp. Res. Part A: Policy Practice 122, 146–161. https://doi.org/10.1016/j.tra.2018.03.033.
Lari, A., Douma, F., Onyiah, I., 2015. Self-driving vehicles and policy implications: current status of autonomous vehicle development and Minnesota policy implications. Minn. J. Law Technol. 16, 735–769.
Lim, H., Taeihagh, A., 2018. Autonomous vehicles for smart and sustainable cities: an in-depth exploration of privacy and cybersecurity implications. Energies 11 (5), 1062. https://doi.org/10.3390/en1105106.
Lin, P., 2016. Why ethics matters for autonomous cars. In: Maurer, M., Gerdes, J., Lenz, B., Winner, H. (Eds.), Autonomous Driving: Technical, Legal and Social Aspects. Springer, Berlin, Heidelberg, pp. 69–85.
Litman, T., 2015. Autonomous Vehicle Implementation Predictions: Implications for Transport Planning (No. 15–3326). Victoria Transport Policy Institute. https://vtpi.org/avip.pdf.
Lloyd, J., Chang, H., 2019. Tesla driver appeared to be "fully sleeping" for at least 30 miles on SoCal's 405 freeway. NBC Los Angeles, June 13. https://www.nbclosangeles.com/news/local/Sleeping-Driver-405-Freeway-Los-Angeles-Tesla-Autopilot-511237312.html.
Maurer, M., 2016. Introduction. In: Maurer, M., Gerdes, J., Lenz, B., Winner, H. (Eds.), Autonomous Driving: Technical, Legal and Social Aspects. Springer, Berlin, Heidelberg, pp. 1–7.
Medina, A., Maulana, A., Thompson, D., Shandilya N., Almeida, S., Aapaoka A., Kutila, M., 2017. Public Support Measures for Connected and Automated Driving: Final Report. GROW-SME-15-C-N102. European Commission EC. EU Publications, No. EA-01-17-634-EN-N. https://ec.europa.eu/docsroom/documents/24402/attachments/1/translations/en/renditions/pdf.
National Transport Commission, 2017. Guidelines for Trials of Automated Vehicles in Australia. National Transport Commission. https://www.ntc.gov.au/sites/default/files/assets/files/AV_trial_guidelines.pdf.
National Transport Commission, 2019a. Regulating Government Access to C-ITS and Automated Vehicle Data, Aug. National Transport Commission. https://www.ntc.gov.au/sites/default/files/assets/files/NTC%20Policy%20Paper%20-%20Regulating%20government%20access%20to%20C-ITS%20and%20automated%20vehicle%20data.pdf.
National Transport Commission, 2019b. Motor Accident Injury Insurance and Automated Vehicles, Aug. National Transport Commission. https://www.ntc.gov.au/

sites/default/files/assets/files/Motor-accident-injury-insurance-and-automated-vehicles-August-2019.pdf.
National Transportation Safety Board, 2018. Preliminary Report Highway HWY18MH010. National Transportation Safety Board. https://www.ntsb.gov/investigations/AccidentReports/Reports/HWY18MH010-prelim.pdf.
New South Wales Government, 2017. Transport Legislation Amendment (Automated Vehicle Trials and Innovation) Act 2017 No 41. New South Wales Government. https://legislation.nsw.gov.au/#/view/act/2017/41.
Nowakowski, C., Shladover, S., Chan, C., Tan, H., 2015. Development of California regulations to govern testing and operation of automated driving systems. Transp. Res. Record 2489 (1), 137–144. https://doi.org/10.3141/2489-16.
Parliament of South Australia, 2016. Motor Vehicles Trials of Automotive Technologies) Amendment Act 2016. Parliament of South Australia. https://legislation.sa.gov.au/LZ/V/A/2016/MOTOR%20VEHICLES%20(TRIALS%20OF%20NEW%20AUTOMOTIVE%20TECHNOLOGIES)%20AMENDMENT%20ACT%202016_10/2016.10.UN.PDF.
Parliament of Victoria, 2018. Road Safety Amendment (Automated Vehicles) Act 2018. Parliament of Victoria. http://www.legislation.vic.gov.au/Domino/Web_Notes/LDMS/PubStatbook.nsf/51dea49770555ea6ca256da4001b90cd/6EADABCAD6531AB7CA2582410010E08A/$FILE/18-008aa%20authorised.pdf.
Pearl, T.H., 2018. Hands on the wheel: a call for greater regulation of semi-autonomous cars. Indiana Law J. 93, 713–756.
Petit, J., Shladover, S.E., 2015. Potential cyberattacks on automated vehicles. IEEE T. Intell. Transp. Syst. 16 (2), 546–556. https://doi.org/10.1109/TITS.2014.2342271.
Pütz, F., Murphy, F., Mullins, M., Maier, K., Friel, R., Rohlfs, T., 2018. Reasonable, adequate and efficient allocation of liability costs for automated vehicles: a case study of the German liability and insurance framework. Eur. J. Risk Reg. 9 (3), 1–16.
Rijksoverheid, 2016. Declaration of Amsterdam "Cooperation in the Field of Connected and Automated Driving". Rijksoverheid https://www.rijksoverheid.nl/documenten/rapporten/2016/04/29/declaration-of-amsterdam-cooperation-in-the-field-of-connected-and-automated-driving.
Rios-Torres, J., Malikopoulos, A., 2016. A survey on the coordination of connected and automated vehicles at intersections and merging at highway on-ramps. IEEE T. Intell. Transp. Syst. 18 (5), 1066–1077. https://doi.org/10.1109/TITS.2016.2600504.
Road Vehicle Certification System, 2019. Vehicle Certification in Australia. RVCS. http://rvcs.infrastructure.gov.au/cert.html.
SAE International, 2018. Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles. SAE International. https://saemobilus.sae.org/content/J3016_201806/.
Schreurs, M., Steuwer, S., 2016. Autonomous driving - political, legal, social, and sustainability dimensions. In: Maurer, M., Gerdes, J., Lenz, B., Winner, H. (Eds.), Autonomous Driving: Technical, Legal and Social Aspects. Springer, Berlin, Heidelberg, pp. 149–171.
Schroll, C., 2014. Splitting the bill: creating a national car insurance fund to pay for accidents in autonomous vehicles. Northwestern U. Law Rev. 109 (3), 803–833.
Sheehan, B., Murphy, F., Mullins, M., Ryan, C., 2019. Connected and autonomous vehicles: a cyber-risk classification framework. Transp. Res. Part A: Policy Practice 124, 523–536.
Shladover, S.E., 2018. Connected and automated vehicle systems: introduction and overview. J. Intell. Transp. Syst. 22 (3), 190–200. https://doi.org/10.1016/j.tra.2018.06.033.
Shladover, S.E., Nowakowski, C., 2019. Regulatory challenges for road vehicle automation: lessons from the California experience. Transp. Res. Part A: Policy Practice 122, 125–133. https://doi.org/10.1016/j.tra.2017.10.006.
Singh, S., 2015. Critical Reasons for Crashes Investigated in the National Motor Vehicle Crash Causation Survey—DOT HS 812 115. US Department of Transportation. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812115.
State of California Department of Motor Vehicles, 2015. Express Terms Title 13, Division 1, Chapter 1 Article 3.7 – Autonomous Vehicles. State of California Department of Motor Vehicles. https://www.dmv.ca.gov/portal/wcm/connect/ed6f78fe-fe38-4100-b5c2-1656f555e841/AV_Express_Terms.pdf?MOD=AJPERES&CVID=.
State of California Department of Motor Vehicles, 2016. DMV statement on federal automated vehicle policy. State of California Department of Motor Vehicles. https://www.dmv.ca.gov/portal/dmv/detail/pubs/newsrel/newsrel16/2016_29.
State of California Department of Motor Vehicles, 2018a. Order to adopt. Title 13, Division1, Chapter 1, Article 3.7 testing of autonomous vehicles. State of California Department of Motor Vehicles. https://www.dmv.ca.gov/portal/wcm/connect/a6ea01e0-072f-4f93-aa6c-e12b844443cc/DriverlessAV_Adopted_Regulatory_Text.pdf?MOD=AJPERES.
State of California Department of Motor Vehicles, 2018b. Autonomous vehicle disengagement reports 2018. State of California Department of Motor Vehicles. https://www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/disengagement_report_2018.
State of California Department of Motor Vehicles, 2018c. Driverless testing and public use rules for autonomous vehicles approved. State of California Department of Motor Vehicles. https://www.dmv.ca.gov/portal/dmv/detail/pubs/newsrel/2018/2018_17.
State of California Department of Motor Vehicles, 2019. Autonomous vehicles in California. State of California Department of Motor Vehicles. https://www.dmv.ca.gov/portal/dmv/?1dmy&urile=wcm:path:/dmv_content_en/dmv/vr/autonomous/bkgd.
State of California Department of Motor Vehicles, 2020. Report of Traffic Collision Involving an Autonomous Vehicle. State of California Department of Motor Vehicles. https://www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/autonomousveh_ol316.
Straub, E.R., Schaefer, K.E., 2019. It takes two to tango: automated vehicles and human beings do the dance of driving–four social considerations for policy. Transp. Res. Part A: Policy Practice 122, 173–183. https://doi.org/10.1016/j.tra.2018.03.005.
Taeihagh, A., Lim, H., 2019. Governing autonomous vehicles: emerging responses for safety, liability, privacy, cybersecurity, and industry risks. Transp. Rev. 39 (1), 103–128. https://doi.org/10.1080/01441647.2018.1494640.
Talebpour, A., Mahmassani, H.S., 2016. Influence of connected and autonomous vehicles on traffic flow stability and throughput. Transp. Res. C-Emerg. 71, 143–163. https://doi.org/10.1016/j.trc.2016.07.007.
The Nation, 2019. Rapid driverless vehicle rollout projected in Australia by 2020. The Nation, Jan. 8. https://nation.com.pk/08-Jan-2019/rapid-driverless-vehicle-rollout-projected-in-australia-by-2020.
United Nations Economic Commission for Europe, 2016. Report of the Seventy-second Session of the Working Party on Road Traffic Safety. United Nations Economic and Social Council. Geneva, 29 march – 1 April 2016. https://www.unece.org/fileadmin/DAM/trans/doc/2016/wp1/ECE-TRANS-WP.1-153e.pdf.
United Nations Economic Commission for Europe, 2018a. Draft Recommendation on Cyber Security of the Task Force on Cyber Security and Over-the-air Issues of UNECE WP.29 GRVA. Working Party on Automated/Autonomous and Connected Vehicles. United Nations Economic and Social Council. 25-28 September 2018. https://www.unece.org/fileadmin/DAM/trans/doc/2018/wp29grva/GRVA-01-17.pdf.
United Nations Economic Commission for Europe, 2018b. Priority Topics for Automated and Connected Vehicles (Based on WP.29-176-28). United Nations Economic and Social Council. 21 December 2018. https://www.unece.org/fileadmin/DAM/trans/doc/2019/wp29/ECE-TRANS-WP29-2019-2e.pdf.
United Nations Economic Commission for Europe, 2019. Report of the Global Forum for Road Traffic Safety on its Seventh-Eighth session. United Nations Economic and Social Council. 25-29 March 2019. https://www.unece.org/fileadmin/DAM/trans/doc/2019/wp1/ECE-TRANS-WP1-167e.pdf.
U.S. Department of Transportation, 2016. Federal Automated Vehicles Policy: Accelerating the Next Revolution in Roadway Safety. National Highway Traffic Safety Administration, September 2016. https://www.transportation.gov/AV/federal-automated-vehicles-policy-september-2016.
U.S. Department of Transportation, 2017. Automated Driving Systems 2.0: A Vision for Safety. National Highway Traffic Safety Administration DOT HS 812 442, September. https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/13069a-ads2.0_090617_v9a_tag.pdf.
U.S. Department of Transportation, 2018. Preparing for the Future of Transportation: Automated Vehicles 3.0. National Highway Traffic Safety Administration October. https://www.transportation.gov/av/3.
Verband der Automobilindustrie, 2015. Automatisierung. Von Fahrerassistenzsystemen zum automatisierten Fahren. https://www.vda.de/dam/vda/publications/2015/automatisierung.pdf.
VicRoads, 2018. Automated driving system (ADS) permit scheme: information for permit applicants, permit holders and vehicle supervisors. VicRoads and Transport for Victoria. https://www.vicroads.vic.gov.au/-/media/files/documents/safety-and-road-rules/connected-and-automated-vehicles/automated-driving-system-ads-permit-scheme.ashx?la=en&hash=08DCCF0FAF9AA5EE2DB48E14C418FB74.

Wachenfeld, W., Winner, H., 2016. The release of autonomous vehicles. In: Maurer, M., Gerdes, J., Lenz, B., Winner, H. (Eds.), Autonomous Driving: Technical, Legal and Social Aspects. Springer, Berlin, Heidelberg, pp. 425–449.
Wheelahan, F., Phillip, C., Westbrook, G., 2018. Australia: Steering the Future: Victoria to welcome driverless cars. Mondaq, June 27. http://www.mondaq.com/australia/x/713926/cycling+rail+road/STEERING+THE+FUTURE+VICTORIA+TO+WELCOME+DRIVERLESS+CARS.
Young, K., Regan, M., Hammer, M., 2007. Driver distraction: a review of the literature. In: Faulks, I.J., Regan, M., Stevenson, M., Brown, J., Porter, A., Irwin, J.D. (Eds.), Distracted Driving. Australasian College of Road Safety, Sydney, pp. 379–405.

David J. Hess is the James Thornton Fant Chair in Sustainability Studies and Professor of Sociology at Vanderbilt University, where he is also the Associate Director of the Vanderbilt Institute for Energy and Environment and the Director of the Program in Environmental and Sustainability Studies (www.davidjhess.net).

Dasom Lee holds a bachelor's degree in sociology from London School of Economics and a master's degree in economics from Kyoto University, and she is currently a Ph.D. candidate in sociology at Vanderbilt. Her dissertation research is on corporate social and environmental responsibility.