Staying in Control

Bridging the Gaps in Autonomous Vehicle Safety

A Research Synthesis
by Transportation Resource Associates, Inc.

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About the Authors

Transportation Resource Associates (TRA), Inc., is a specialty, privately held consulting firm focused on public transportation and infrastructure safety and security projects throughout the United States. Public transportation providers, departments of transportation (DOTs), and related private-sector companies rely on TRA for pragmatic approaches to complex safety, security, operations, and maintenance issues. TRA's 25-year history of experience provides a unique, valuable, and much-needed perspective as fully autonomous vehicles develop. TRA has extensive expertise in the creation, implementation, and assessment of safety and security programs for transportation providers as they grow and evolve. The company's routine work entails the identification and resolution of hazards and unintended consequences from areas of system safety and security. Transit safety topics such as accident/incident investigation, hazard management, and safety certification inform TRA's synthesis of the research toward evaluating a potential regulatory framework for autonomous vehicles, and ultimately a safer future for automobile travel.

For more information, contact:

James Young, Project Manager
Phone: 215-546-9110
E-mail: TRA-AV@traonline.com
1608 Walnut Street, Suite 1602
Philadelphia, PA 19103

Transportation Resource Associates, Inc.
www.traonline.com

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Challenges and Opportunities

Like other innovative transportation modes and technologies throughout history, autonomous vehicle (AV) technology is developing at a rapid pace, and consumer-available AV technologies are already embedded in the fabric of the automobile industry and society. People quickly adapt to advancements in automotive technologies. Despite this growth, however, existing regulatory and safety frameworks remain suited only for conventional auto environments; regulations and standards are not flexible enough to accommodate technological changes, fail to address safety challenges inherent in the latest innovations, and are inconsistent across states, companies, and industries.

While AVs may resemble conventional automobiles in certain ways, they exhibit a range of capabilities that distinguish them from vehicles as a mode in any traditional sense. Regulators face the significant challenge of responding to potential shortcomings of this new mode of travel, which has strained the use of existing regulations and standards for automobiles that lack AV considerations. The complex nature of AV technology necessitates substantial regulatory and safety changes to address gaps that are currently underexplored. Federal and state regulators, researchers, fleet operators, manufacturers, emergency responders, and infrastructure providers each have a stake in development of plans, policies, and management structures to address safety issues.

Safety/regulatory frameworks from other modes and past auto transportation developments may offer transferrable lessons that could improve safety performance and regulatory efficiency for all major players in AV development, manufacturing, operations, regulation, and research. With proactive leadership from federal and state agencies and close coordination with private industry stakeholders, a safety and security oversight regime could be established for the AV industry that strengthens organizational accountability, protects interoperability, perpetually adapts to technology innovations, and enables swift and informed resolution of AV safety and security hazards.

Existing Conditions

Fully self-driving vehicles are still a subject of research and development. Many currently-available vehicles offer semi-autonomous features like adaptive cruise control and braking assist, but still require driver input in certain situations; a smaller selection of high-priced vehicles approach full autonomous operation in highway environments. AV developers have achieved these capabilities with varying technologies and software tools. Beyond vehicles themselves, there are many other AV-related components under development, including infrastructure technologies that may eventually form an integral part of automobile operating environments. Vehicle-to-infrastructure communication devices, road materials, roadway design techniques, and data-driven operations control centers are among the most prominent AV-related infrastructure components, but it is still not clear to what extent infrastructure must be upgraded to accommodate safety-critical AV operation and who would pay for those improvements. Cost and compatibility issues for vehicles and infrastructure will require significant coordination between private parties as well as federal guidance on responsibility for policy making, development, operation, and maintenance.

Widespread AV deployment is projected to significantly reduce accidents and fatalities, and investigations during current test operations show that most accidents involving existing AVs are attributable to human drivers in other vehicles. However, driver behavior has played a role in a few recent semi-autonomous vehicle accidents, highlighting a gulf in expectations for driver attentiveness from vehicle manufacturers and end users. The relationship between AV and non-autonomous vehicles in mixed environments, along with requirements for driver engagement during vehicle use, may negatively influence AV accident performance for decades unless mitigated through AV technology, infrastructure changes, training, and/or public education. Consistent regulatory requirements for enhanced data gathering, reporting, and corrective action planning will help ensure that incident risks are systematically assessed, monitored, and mitigated.

Testing and licensing requirements, liability laws, operating rules, and engineering standards for AVs vary widely by state, and policy guidelines issued by the National Highway Traffic Safety Administration represent the only significant federal move toward creation of a national regulatory framework. Substantial changes in these areas are underway; for example, as AV technology evolves, liability burdens will shift partially from individual drivers to manufacturers and technology companies. Existing regulations enable or constrain certain aspects of AV development and deployment, and though states are encouraged to conform to National Highway Traffic Safety Administration (NHTSA) guidelines, the absence of overarching federal standards may allow increasingly diverse and fragmented AV regulations to flourish. Additionally, regulatory inconsistency impairs swift movement by states to understand safety implications of new developments and manage potential safety risks.

Models for Comparison

Well-developed regulatory and safety frameworks governing other long-extant modes like railroads and motor carriers shed light on the limitations of existing methods for managing AV safety. Given that AV technology essentially creates a new transportation "mode" that has not previously existed, new frameworks must be developed to understand it and ensure its safety. Safety and security could be enhanced through implementation of new programs and techniques governing planning, training, systems integration, rules compliance, engineering, and data collection/analysis at the federal and state levels. The AV industry is fragmented, and many of these techniques are not currently in use, but clear models exist for deployment of many new measures such as safety plans, data sharing tools, engineering requirements, and incident investigation processes which would significantly improve the way AV stakeholders manage risks. Due to the rapid and creative work in AV with high potential for profitability, the AV industry is presently fragmented because separate parties are focusing on critical elements of a bigger transformation in transportation without coordination.

> Smooth, successful AV deployment on a large scale will require consideration of AV safety from a systems perspective.

AVs are being tested by researchers and manufacturers in a range of real-world and engineered scenarios, but research into environmental safety and security risks has been limited mostly to identification of problem scenarios through testing. Preliminary Hazard Assessments (PHAs), a framework for hazard identification, evaluation, and mitigation in transportation operating environments, can serve as a preemptive, exploratory tool to supplement real-world testing and improve management of unknown safety and security risks across broad geographic scales.

Strong parallels also exist between AVs and a variety of related industries and predecessor safety technologies. Fleet management for private trucking fleets and car sharing organizations, for example, incorporates best practices in operations, maintenance, training, security, and systems integration. Such practices should be analyzed for applicability to AV development, including the potential pitfalls of deployment. The adoption and integration of past safety enhancements for automobiles may illustrate how AV safety technologies can be effectively implemented.

Looking Ahead

Smooth, successful AV deployment on a large scale will require consideration of AV safety from a systems perspective. Many of the institutions, tools, and conceptual frameworks necessary for deployment do not currently exist, and others have been developed only in response to the risks and hazards presented by conventional automobiles. Research into safety and security frameworks governing other modes, hazard analysis of AV operations, historic auto safety developments, and other transportation industry innovations reveal how AV stakeholders can close this gap to strengthen safety and security and help all parties manage risk more effectively.

Federal and state agencies, along with input of industry stakeholders, could take a more substantial leadership role in comprehensively evaluating and eliminating these gaps by developing a stronger, unified safety and security oversight program for AV deployment. By taking an engaged and proactive stance toward AV innovation, these public agencies may successfully hold private AV stakeholders accountable for safety analysis, hazard management, consumer education, and related activities during AV design, testing, operation, modification, and repair.

Many changes must take place to accommodate AV technological growth. State-level regulations and safety requirements that are currently fragmented or largely nonexistent must reflect the rapidly changing AV industry and be harmonized to support its safe integration into existing transportation networks. Data-sharing channels must be established, and stakeholders of all types must make efforts to collect comprehensive and uniform data which will inform efforts to evaluate, manage, and reduce risk and improve the quality of new research. Regulatory consistency must be achieved, with the flexibility to accommodate new technological development and the comprehensiveness to control unaddressed safety and security risks. These changes, and more, will support safe and secure expansion and integration of AV technology on roads throughout the United States.

Acronyms

AAR	Association of American Railroads
AASHTO	American Association of State Highway and Transportation Officials
ABS	Anti-Lock Braking System
ACC	Adaptive Cruise Control
ANSI	American National Standards Institute
ASI	Autonomous Solutions, Inc.
AVs	Autonomous Vehicles
CFR	Code of Federal Regulations
CPUC	California Public Utilities Commission
DARPA	Defense Advanced Research Project Agency
DOT	Department of Transportation
DMV	Department of Motor Vehicles
DSRC	Dedicated Short Range Communications
EPA	Environmental Protection Agency
ETRI	Electronics and Telecommunications Research Institute
FARS	Fatal Analysis Reporting System
FCA	Fiat Chrysler Automobiles
FMVSS	Federal Motor Vehicle Safety Standards
FRA	Federal Railroad Administration
FRSA	Full Speed Range Adaptive Cruise Control
FTA	Federal Transit Administration
HRI	Hazard/Security Risk Index
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
LIDAR	Light Detection and Ranging
LRV	Light Rail Vehicle
NHTSA	National Highway Traffic Safety Administration
NREC	National Robotics Engineering Center
OSHA	Occupational Safety and Health Administration
PHA	Preliminary Hazard Assessment
PTC	Positive Train Control
SAE	Society of Automotive Engineers
SCI	Special Crash Investigations
SEPP	Security and Emergency Preparedness Plan
SLAM	Simultaneous Localization and Mapping
SMS	Safety Management Systems
SSO	State Safety Oversight
SSPP	System Safety Program Plan
TNC	Transportation Network Company
TRB	Transportation Research Board
V2I	Vehicle-to-Infrastructure
VMT	Vehicle Miles Traveled
VTA	Valley Transportation Authority

1 Existing Conditions

1.1 Development and Deployment

Growing interest in market-ready autonomous vehicles (AVs) suggests a significant transition toward a new mode of transportation that will eventually supplant the current mode of manually-operated vehicles prevalent today. Some of the key catalysts and factors that are driving this emerging market are the presumed benefits and efficiencies associated with vehicle automation and connectivity. The anticipated benefits of improving safety, mitigating traffic congestion, reducing ecological impacts, and lowering operational costs associated with autonomous technology extend beyond the passenger car market. Manufacturers, ride-sharing services, and other organizations are exploring and applying autonomous technology. Its application is not limited to private vehicles but may also apply to other modes of surface transportation, including public transportation and commercial carrier fleets.

These advancements suggest that there are significant opportunities for autonomous technology to transcend traditional concepts of mobility and common carriage across various sectors of the transportation industry. A host of prototypes, product initiatives, and partnerships are in various stages of testing, implementation, and deployment. As of April 2016, over 30 major automobile industry and technology companies were investing in driverless research and development.[1] Market forecasts project that a variety of semi-autonomous and fully-autonomous vehicles will be widely available to consumers and surface transportation service providers within the next five to ten years.

1.1.1 Existing and Emerging Technology Adoption

AVs rely on a complex network of sensors, navigation and communication systems, and automated controls. The integration and connectivity of these automated components and technologies allow the vehicle to operate without a driver. In May 2013, the U.S. Department of Transportation's NHTSA issued a classification system for AVs based on their functional operating capacity ranging from no automation (Level 0) to fully-automated, self-driving capabilities (Level 4).

Drivers may already be familiar with semi-autonomous features like adaptive cruise control, lane departure warnings, collision avoidance, parking-assist systems, and on-board navigation. These types of vehicle features provide specific and/or combined automated functions (Levels 1 and 2). NHTSA is exploring the standardized offering of some autonomous capabilities, since many of these safety options are more often available in mid- to high-end vehicles than more affordable models. For example, NHTSA recently mandated that back-up cameras will be a standard safety

[1] CB Insights. "30 Corporations Working On Autonomous Vehicles". Web blog post. CB Insights. April 18 2016. https://www.cbinsights.com/blog/autonomous-driverless-vehicles-corporations-list/

feature on any new car sold after 2018.[2] In March 2016, 20 automakers reached an agreement with NHTSA and the Insurance Institute for Highway Safety, mandating that autonomous braking technology be mandatory in vehicles by 2022.[3] While semi-autonomous features are becoming more common, the next generation of automation that automobile manufacturers are focusing on falls within the classifications of limited and full self-driving automation (Levels 3 and 4), where the vehicle is capable of operating without driver intervention or ultimately even driverless.

NHTSA defines vehicle automation as follows:

- **No-Automation (Level 0):** The driver is in complete and sole control of the primary vehicle controls – brake, steering, throttle, and motive power – at all times.

- **Function-specific Automation (Level 1):** Automation at this level involves one or more specific control functions. Examples include electronic stability control or pre-charged brakes, where the vehicle automatically assists with braking to enable the driver to regain control of the vehicle or stop faster than by acting alone.

- **Combined Function Automation (Level 2):** This level involves automation of at least two primary control functions designed to work in unison to relieve the driver of control of those functions. An example of combined functions enabling a Level 2 system is adaptive cruise control in combination with lane centering.

- **Limited Self-Driving Automation (Level 3):** Vehicles at this level of automation enable the driver to cede full control of all safety-critical functions under certain traffic or environmental conditions and in those conditions to rely heavily on the vehicle to monitor for changes in those conditions requiring transition back to driver control. The driver is expected to be available for occasional control, but with sufficiently comfortable transition time. The Google car is an example of limited self-driving automation.

- **Full Self-Driving Automation (Level 4):** The vehicle is designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip. Such a design anticipates that the driver will provide destination or navigation input, but is not expected to be available for control at any time during the trip. This includes both occupied and unoccupied vehicles.

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[2] Iozzio, Corrine. “4 Driverless Car Features Going Standard: Today's safety features foreshadow the robotic cars of tomorrow.” Web blog post. Scientific American. April 1 2015. http://www.scientificamerican.com/article/4-driverless-car-features-going-standard/

[3] Peltz, James F. "Automakers Agree to Make Automatic Braking a Standard Feature by 2022." *Los Angeles Times*. Los Angeles Times, 17 Mar. 2016. Web. 14 July 2016.

1.1.2 Research and Development

Several resources cited the Defense Advanced Research Project Agency (DARPA) Grand Challenge as a significant catalyst for AV research and development in the last decade. The competition was launched in 2004 and invited innovators to compete for substantial research funding based on the technical muster of their AV prototypes. In the inaugural year of the competition, none of the 15 entrants were able to complete the competition's test course without crashing. However, in 2005 five of the 21 entries were successful. In 2007 DARPA concluded the Grand Challenge with the "Urban Competition" test course, and six of the 89 competitors successfully completed the course.[4] Throughout the various phases of this competition there was increased participation and significant advancement in the capabilities of autonomous technology. This momentum has since transferred to the research and development engines among auto and technology industry heavyweights.

Since the Grand Challenge, several major players in auto manufacturing, technology, and academia have emerged. While European-based enterprises are arguably leading research and development concerning autonomous vehicle products, policies, and implementation, investment in autonomous vehicle initiatives is growing worldwide.[5] In April of 2016, CB Insights identified 30 corporate groups pursuing AV research and development.[6] In the United States, this research and development is often the result of high-profile partnerships. Tech industry leaders like Google, Apple, Uber, and Lyft, as well as academic research engines like the Massachusetts Institute of Technology, Stanford University, Carnegie Mellon University, and the University of Michigan have joined forces with leading auto industry manufacturers for a variety of collaborative initiatives. Table 1 in Appendix 1 provides a more comprehensive list of auto industry manufacturers and collaborations that are at the forefront of research and development. These partnerships are sometimes formed with more than just traditional vehicle ownership in mind. BMW, Intel, and Mobileye have announced a partnership with the goal of releasing fleets of AVs for sale by 2021.[7] Comprised of an automaker, developer of computer processors, and a camera manufacturer, the group reflects an application of AV technology that will likely transform many industries such as ride-sharing, delivery service, or shuttle providers. Uber has already begun testing AVs in Pittsburgh, hoping to develop a fleet of AVs for its ridesharing service.[8]

Several manufacturers are in the testing phases of their driverless system technologies and have announced release dates. Consistently across the industry, many automobile manufacturers expect to have "commercially viable autonomous-driving capabilities by 2020 in multiple vehicle

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[4] Blazek, Thomas R. "Autonomous Vehicles". *Defense Transportation Journal*, 71, 5 (October 2015); 16-21.
[5] Ibid
[6] CB Insights. "30 Corporations Working On Autonomous Vehicles". Web blog post. CB Insights. April 18 2016. https://www.cbinsights.com/blog/autonomous-driverless-vehicles-corporations-list/
[7] Abuelsamid, Sam. "BMW, Intel And Mobileye Join Forces To Bring Autonomous Vehicle Fleets To Road By 2021." *Forbes*. Forbes Magazine, 1 July 2016. Web. 12 July 2016.
[8] Liberatore, Stacy. "Uber Drivers, Beware: Taxi App Tests Self-driving Car in Pittsburgh That Could Put All of Its 'contractors' out of Work." *Mail Online*. Associated Newspapers, 19 May 2016. Web. 12 July 2016.

models."[9] This includes Audi, BMW, Daimler, Ford, General Motors, Google, Kia, Mercedes-Benz, Nissan, Renault, Tesla, and Toyota. The semi-autonomous Tesla Model S is already used by consumers today. In the meantime, there are several manufacturers that are working on multiple AV-related prototypes, products, and services.

For example, as part of its "Audi Piloted Driving" campaign, Audi plans to release the A8 model as the brand's flagship vehicle designed with semi-autonomous capabilities (Level 2 or 3). Audi also partnered with Delphi – a legacy auto parts manufacturer that has begun developing AV software and sensors – to integrate AV technology to be retrofitted with their existing vehicle models. The Audi SQ5 model was outfitted with Delphi technology and test-driven for 3,000 miles across the United States in January 2016. The vehicle operated autonomously for 99 percent of the test. Considering the gap in transition between semi- and fully-autonomous cars in the marketplace and on the road, retrofit solutions like these may help drivers become more familiar and comfortable with the technology.

Given the emerging status of autonomous technology, there are still critical unknowns pertaining to safety.

As part of their Super Cruise Technology initiative, General Motors, like Audi, is developing its own technology with a planned 2017 release of the Cadillac CT6 with semi-autonomous Super Cruise technology. Earlier this year, GM acquired Cruise Automation (a self-driving car start up; in March) and Sidecar (a ride-sharing service; in January), and made a significant investment in Lyft. According to some articles, providing on-demand mobility options with a self-driving fleet would lower operating costs (compared to current prices under Uber or Lyft). As a result, driverless ride-sharing services may potentially become the most inexpensive and convenient means of transportation offered to consumers.[10]

Other sectors of the transportation industry are applying autonomous technology to commercial and public transportation vehicles. For example, Daimler (the manufacturer of Freightliner trucks) is testing the "Inspiration," which is the first model of semi-trailer truck with autonomous functions.[11] The truck company has been testing these vehicles in Nevada since May of 2015. Daimler also partnered with DAF, Iveco, MAN, Scania, and Volvo to conduct a truck platooning experiment in Europe in April 2016. Truck platooning involves multiple vehicles with autonomous technology communicating and driving in close proximity behind one another.[12] Truck platooning can improve the safety, cost effectiveness, and efficiency of motor carrier fleets. During the testing,

[9] Fagnant, Daniel J.; and Kara Kockelman. "Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations". Transportation Research Part A 77 (2015): 167-181.
[10] CB Insights. "30 Corporations Working On Autonomous Vehicles". Web blog post. CB Insights. April 18 2016. https://www.cbinsights.com/blog/autonomous-driverless-vehicles-corporations-list/
[11] Blazek, Thomas R. "Autonomous Vehicles". *Defense Transportation Journal*, 71, 5 (October 2015); 16-21.
[12] "What Is Truck Platooning?" *EU Truck Platoon Challenge*. European Union, n.d. Web. 12 July 2016.

six convoys of two semi-autonomous trucks each (with the lead truck controlling the second truck) completed various routes on public roads to test the feasibility of platooning commercial fleets.

Shuttle buses are another example of a transportation service adopting autonomous technology. In June 2016, Local Motors unveiled an autonomous shuttle bus named Ollie that will provide rides to the public in of the National Harbor area in Maryland, near the District of Columbia.[13] It is the first vehicle to use IBM Watson's car-focused cognitive learning platform, Watson Internet of Things (IoT) for Automotive. Local Motors anticipates operating these shuttle vehicles in Las Vegas, Miami-Dade County, and Denmark. In January 2016, the WePod was introduced to Dutch public roads for initial testing in the town of Wageningen.[14] The shuttle pilot project is anticipated to be expanded be used as public transport along a 6-kilometer route in the town.

1.1.3 Forecasts for Deployment

While manufacturers are eager to get their products into the marketplace, there are several factors that will impact market entry, consumer demand, and overall adoption rates. AV advancements are exceeding expectations in product development, particularly as supporting software and technology have become more accessible faster than originally anticipated. As a result, some manufacturers are accelerating their initiatives. Tesla expedited the release date for a potentially fully-autonomous Model 3 by two years but also predicted that various jurisdictions' regulations could take up to five years to catch up.[15][16]

AVs appear to be approaching economies of scale faster than anticipated given the parallel advancements in complementary technology. According to some experts, like Tony Seba, author and Stanford University instructor specializing in disruption and product innovation, "exponentially improving technologies such as Electric Vehicles, Autonomous …Cars, Sensors, and Mobile Internet are turning the industrial-era transportation industry upside down and making the whole public and private transportation infrastructure obsolete." One of the key drivers that Seba cites as an accelerator is the surprisingly fast decrease in technology costs. Many industries are diversifying their research and development and pursuing the market (notably in development of AVs and their corresponding support systems), so consumers witness an aggressive race for

[13] Warren, Tamara. "This Autonomous, 3D-printed Bus Starts Giving Rides in Washington, DC Today." *The Verge*. The Verge, 16 June 2016. Web. 27 July 2016. <http://www.theverge.com/2016/6/16/11952072/local-motors-3d-printed-self-driving-bus-washington-dc-launch>.

[14] Deutsch, Anthony. "Driverless Shuttle Bus to Take to Dutch Public Roads in World First." *Reuters*. Reuters, 28 Jan. 2016. Web. 27 July 2017. <http://www.reuters.com/article/us-netherlands-autos-driverless-bus-idUSKCN0V61J9>.

[15] Heisler, Yoni. "Will the Model 3 really ship on schedule? Some Tesla suppliers are skeptical." Web blog post. Boy Genius Report. 22 May 2016. http://bgr.com/2016/05/22/tesla-model-3-release-date-delay-likely-suppliers/

[16] Korosec, Kirsten. "Elon Musk Says Tesla Vehicles Will Drive Themselves in Two Years." *Fortune Elon Musk Says Tesla Vehicles Will Drive Themselves in Two Years Comments*. Time Inc, 20 Dec. 2015. Web. 12 July 2016.

competitive ready-for-market products. Assuming this competition results in a corresponding level of market saturation, AVs could become affordable much sooner than expected.[17]

There are varying opinions on the anticipated consumer adoption rate of AV technology – some assuming that it will be comparable to traditional auto market penetration, while others forecast a much more aggressive rate of adoption that is more comparable to technology trends at large (i.e. personal computers, mobile phones, and services like Uber). In 2012, the Institute of Electrical and Electronics Engineers (IEEE) estimated that 75 percent of vehicles will be autonomous by 2040, while more conservative forecasts predict 2060 for 75 percent market saturation, based on the rate of market capture from previous technological advancements in the auto industry.[18] Coordinated and consistent development of AV infrastructure, safety regulations, and technology standards may all play a role in the speed of AV adoption by consumers.

1.1.4 Conclusion

The technological advancements and product development for autonomous vehicles have been substantial in the last decade. While market penetration is inevitable, it appears that consumer access to AVs is partially contingent on whether supporting infrastructure and affordable technology can keep up with market demands completely and safely. It is also important that manufacturers and regulators account for the diversity in opportunities for AV technology. The technology will likely have different applications, from private use by families to commercial fleets deployed by ride-sharing or delivery services. As such, the implications for both these deployments may differ.

Given the emerging status of autonomous technology, there are still critical unknowns pertaining to safety. Some of these risks include system failures, security breaches, and passenger privacy concerns.[19] Despite such trepidation, development continues without public or regulator knowledge of steps taken to mitigate these risks.

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[17] Seba, Tony. Keynote at AltCar Expo: 100% Electric Transportation and 100% Solar by 2030. Blog Post. Web. 2014. http://tonyseba.com/

[18] Davidson, Peter; and Anabelle Spinoulas. "Autonomous Vehicles—What Could This Mean for the Future Of Transport?" *AITPM 2015 National Conference* (4 June 2015).

[19] Litman, Todd. *Autonomous Vehicle Implementation Predictions: Implications of Transport Planning.* Victoria Transport Policy Institute. (2015).

1.2 Infrastructure and Technology

AVs exhibit various levels of interoperability with existing fixed and electronic roadway infrastructure. In general, the development of vehicle technology appears to have far outpaced the development of infrastructure optimized for autonomous vehicle use. However, several initiatives are currently underway to develop and deploy infrastructure that improves the safety, reliability, and performance of AVs.

AV infrastructure can be broadly grouped in three major categories: communications technology, road materials, and roadway design. Each is subject to its own regulations and standards, and carries unanswered questions regarding integration with AVs.

Roadways could eventually function more like the fixed guideways on which rail vehicles operate, though these systems bear little resemblance to one another right now. Most AVs are currently designed to operate with existing infrastructure, navigating much like human drivers based on conditions that can be seen or detected from the vehicle itself. In the future, however, the limitations of using only vehicle-based equipment may require significant integration between AVs and nearby infrastructure to the point where vehicles and roads may become a singular, fully-integrated technological system, consistent with current rail systems. There are many infrastructure technologies capable of addressing safety problems inherent to operation of AVs on existing, as-built roads. Though the expense of AV infrastructure deployment means higher per-mile roadway costs relative to existing roadway components, and there are many challenges to maintaining full interoperability between vehicles and the outside environment, certain safety improvements and operational benefits of AVs like widespread platooning and increased intersection throughput may only be achieved through infrastructure linkages described below.

1.2.1 Communications Technology

AVs employ a variety of communications technologies to navigate the built environment. In certain instances, AVs may also interface with one another by way of an intermediary connected infrastructure, using data gathered and distributed by off-site servers and networks. Though development and deployment of AVs has progressed with nearly zero integration between vehicles and infrastructure, infrastructure communications technologies can offer a range of safety benefits and redundancies with vehicle safety systems, aiding in collision avoidance and detection of hazardous situations including construction, weather events, and pedestrians. Communications technology will also play an important role in maximizing the efficiency of AV technology, improving capacity by enabling techniques like vehicle platooning. A 2014 study by the American Association of State Highway and Transportation Officials (AASHTO) identified several core elements of a fully-connected deployment of vehicle infrastructure.[20] They include:

- Fully-networked signal systems governed by controls which manage signal timing, phasing, and coordination

[20] National Connected Vehicle Field Infrastructure Footprint Analysis Final Report. Rep. American Association of State Highway and Transportation Officials (AASHTO), 27 June 2014. Web.

- Wayside communications equipment. This element represents all equipment located in or adjacent to the roadway, plus any related power systems, networks, and enclosures
- Any security-related processes and functions which protect the integrity of communication and data networks
- Map products. Maps utilized to inform movement of AVs range from low-accuracy location data to detailed, street-specific maps of road features and geometry
- Positioning services, including any highly accurate and precise technology to identify vehicle location
- Servers to gather and process data acquired from vehicles, and to communicate weather disturbances, travel information, alerts, advisories, congestion data, and parking info to vehicles[21]

Each of these technologies is currently in operation on roads today in some manner, but few specific plans have been developed to integrate their functions and maximize their benefits through state or national infrastructure investment. The American Association of State Highway and Transportation Officials (AASHTO) and the U.S. Department of Transportation, however, have developed scenarios to help conceptualize future deployment of AV infrastructure. The escalating series of scenarios focuses is based on the road type and its surrounding geography, ranging from limited deployment of core tools on rural roadways to use of many integrated tools in a complex urban corridor.[22]

A selection of these scenarios is listed below in order of complexity from lowest to highest:

- **Rural Roadway**: Key applications of vehicle to infrastructure (V2I) communication technology in a rural setting include basic safety functions of weather alerts, warnings regarding impacts to roadways from natural hazards and wildlife, speed warnings, and applications related to information exchange for navigation through unpredictable conditions such as wind and ice. Technologies deployed would center on Dedicated Short Range Communications (DSRC) devices or cellular networks to gather information on conditions from nearby vehicles, process the data, and broadcast notifications back out to vehicles on the roadway for action.

- **Urban Highway**: Key applications of V2I communication technology on urban highways include those of rural roadways, along with non-safety-critical applications including dynamic traffic control and live updates on traffic conditions. A communications infrastructure scheme in this context would likely involve cellular and DSRC technology. Data gathered from urban highways would likely be integrated into traffic control center functions in existing urban control centers.

- **Urban Intersection**: Augmentation of existing signal controls at complicated urban intersections could ensure a minimum level of safety while also enhancing the operational

[21] Connected and Autonomous Vehicles 2040 Vision. Rep. Pennsylvania Department of Transportation / Carnegie Mellon University, 10 July 2014. Web.
[22] National Connected Vehicle Field Infrastructure Footprint Analysis Final Report. Rep. American Association of State Highway and Transportation Officials (AASHTO), 27 June 2014. Web.

capabilities of AVs. Many existing sensors are pressure-sensitive detectors or inductive loops embedded in the pavement and are sometimes capable of being coordinated with neighboring traffic lights. A range of other cameras, sensors, and emergency response prioritization systems may also be in use. With full deployment of V2I communication technology, additional intersection functions could include gap assist for turns and automated warnings for signal violations by other AVs (or human operators in a mixed-operating environment). This deployment concept also relies on DSRC units interfaced with signal controllers to manage traffic flow through each intersection, gather basic data on traffic movement, and interface with centralized control programs.

- **Urban Corridor**: The urban corridor deployment scenario combines elements of several other scenarios for multiple modes across multiple intersections and road segments in the densest city operating environments. This scenario incorporates alert features and information management technology oriented toward navigation of urban hazards such as unpredictable pedestrian and bike activity, dense traffic, and construction. While they could be deployed in other operating environments, high-bandwidth networks are more likely to be available for communication in an urban setting, providing for enhanced communication capabilities and allowing coordinated movement of vehicles across broader areas.

Other scenarios cover specific applications including freight movement, management of border areas, communication technologies for fee payment, and others. While those technologies would be deployed in smaller areas, they would offer specific niche benefits.

None of these deployment scenarios has been realized. Still, according to AASHTO, many state departments of transportation (DOTs), Metropolitan Planning Organizations, and research institutions have independently tested, planned, or researched connected vehicle technologies with mobility and safety applications.[23]

- **Weather and emergency alerts**: The Washington State DOT equipped snowplows to gather weather data which can be distributed via radio and signage to travelers elsewhere in the road network.

- **Emergency response**: The Arizona DOT and Maricopa County have explored dynamic vehicle routing for emergency response based on traffic condition data.

- **Signal coordination**: Maricopa County, Arizona, has begun efforts to integrate signal sequences with traffic data communicated from vehicles.

- **Eco-friendly driving**: CalTrans implemented a program using signal control devices which respond to vehicle inputs to vary traffic speeds and boost environmental performance by reducing fuel expenditures through less-frequent acceleration and braking.

[23] AASHTO Connected Vehicle Infrastructure Deployment Analysis. Rep. American Association of State Highway and Transportation Officials / U.S. Department of Transportation, 17 June 2011. Web.

- **Commercial and heavy vehicles**: New York State DOT has deployed technologies which allow for communication of driver identification information and commercial vehicle advisory data, and support wireless roadside safety inspections.

- **Road maintenance**: Idaho DOT has developed a concept of operations which includes a dynamic pavement conditions database developed with data gathered from fleet vehicles.

- **Connected vehicles**: In the San Francisco Bay Area, the Metropolitan Transportation Commission has explored how communication technology could enhance information flows related to dynamic pricing and travel times in high-occupancy toll lanes.

Together, these applications hint at the possibilities presented by full deployment of V2I communications equipment to facilitate AV operation. A variety of key issues shape the conversation surrounding V2I communication technologies.

First, it is important to differentiate between safety-critical infrastructure and communications infrastructure that is optimized only for operational benefits. Many V2I communication technologies improve operating efficiency by supporting platooning, increased intersection throughput, and other operational enhancements that are primarily intended to target existing inefficiencies rather than eliminate chronic safety issues. Some communications technologies, however, offer improvements in both areas.

As mapping products and GPS technologies external to individual vehicles become a core component of vehicle navigation systems, maps must be developed and maintained to accurately reflect changing real-world conditions.[24] The integrity of data transmissions between satellites, wayside equipment, and vehicles must be protected in the face of technological challenges and network security issues.

While cities and states monitor and act on real-time road data that is currently generated via existing tools such as cameras and traffic counters, widespread adoption of V2I communication technologies will significantly increase the amount of real-time data available for monitoring, analysis, and action. Real-time information gathered from vehicles is likely to play a more significant role in operational decision-making by local and state authorities in managing weather, congestion, and emergency situations.

As more data becomes available to support real-time decision making, cities and states may opt to establish control centers which allow overseers to gather data inputs in a centralized location, analyze traffic flows, roadway conditions, and hazards, and distribute actionable information back to vehicles and drivers. These control centers, in turn, may require detailed operating procedures, rules, regulations, maintenance standards, and training programs to ensure that staff may properly maintain data quality, facilitate data distribution, and effectively utilize real-time information during active management of AV operating environments. In this context, the functions performed by control centers would far exceed the capabilities of existing traffic monitoring and management facilities.

[24] Anderson, James M., et al. *Autonomous vehicle technology: A guide for policymakers*. Rand Corporation, 2014.

1.2.2 Road Materials

Road materials have a potentially significant influence on the ability of AVs to operate safely. Vehicle-based sensors and technologies for interpreting and navigating the built environment are developing at a rapid pace. However, varied pavement materials and road surfaces, signage materials, and road paints react in unique and sometimes unpredictable ways with the many sensors AVs use to navigate.

AV tests have revealed a range of functional limitations linked with certain road materials. For example, in heavy rain, fog, and other weather conditions, vehicles may lose their ability to detect road surfaces, stay within lines, and interpret signage.[25] Although these failures can be linked to the inability of technologies such as Light Detection and Ranging (LIDAR) to perform under the necessary conditions, existing road materials lack special features to improve their detectability in different types of weather.[26] Assets that are more susceptible to damage from weather and vandalism, such as faded or obscured road signs, may fall outside the normal tolerances for detection by passing vehicles.[27] While some vehicles depend on surface reflectivity to identify navigable roads, pavement types, sign materials, and paints with different reflectivity are in use across different jurisdictions.[28] Finally, these factors are also influenced by changing daylight, surrounding lighting, and missing markings and signage in rural areas, introducing unpredictable effects into a vehicle's attempts to navigate.

There are few efforts currently underway to develop and deploy uniform, AV-optimized materials or infrastructure in response to the issues identified above.[29] Groups such as AASHTO and the Transportation Research Board have completed past studies of road materials related to traction and tire adhesion, endurance, maintenance, and repair in a variety of weather conditions, with a goal of developing road surfaces for different environmental and usage applications. Studies in these areas may provide a framework for future exploration of AV-optimized road materials, and this research may demonstrate a gap between existing objectives for infrastructure development and future AV needs.

Once AVs become the dominant vehicle type on most roadways, organizations responsible for maintaining and developing roadways may consider reevaluating preventive maintenance plans and seasonal maintenance activities to ensure that AVs may interact with the road environment in a predictable manner. Wherever practical, roadway designers and infrastructure providers should seek to use consistent materials in order for vehicles to reliably interpret environmental information with minimal unpredictability.

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[25] Anderson, James M., et al. *Autonomous vehicle technology: A guide for policymakers*. Rand Corporation, 2014.
[26] Ibid
[27] Margolis, Jason. "In Michigan, a Testing Ground for a Future of Driverless Cars." All Tech Considered. National Public Radio, 31 July 2015.
[28] Ibid
[29] Glaser, Sebastien, et al. "Maneuver-based trajectory planning for highly autonomous vehicles on real road with traffic and driver interaction. *"Intelligent Transportation Systems, IEEE Transactions on* 11.3 (2010): 589-606.

1.2.3 Road Design

Roads are engineered in order to safely manage the flow of traffic, correspond to the capabilities of modern vehicles, and respond to the needs of human drivers in a range of situations. AVs capable of platooning with one another at narrow distances, automatically reacting to disturbances in the roadway, and receiving updates on road conditions from remote communications infrastructure will operate more efficiently and safely in an environment optimized for those capabilities. As such, many aspects of road design may change, including:

- Lane widths,
- On- and off-ramp lengths,
- Emergency pull-offs and shoulders,
- Signage and curb placement,
- Curve radii, and
- Speed limits.

Many design changes may not be appropriate for existing roads; while new lane widths and speed limits could be implemented at low cost on existing roadways and offer immediate benefits to capacity and trip duration, existing ramp lengths and curve radii are already navigable using existing AV technologies and would be costly to modify.

Some state DOTs and research institutions have begun to explore the implications of widespread road design changes in response to broader introduction of AVs. One study, conducted by researchers from Carnegie Mellon University and funded by the Pennsylvania Department of Transportation, evaluated expressways and neighborhood core areas for potential design impacts of AV deployment.[30] The study identified several potential design changes intended to reduce community infrastructure investment costs while ensuring safety.

- **Roadway capacity**: Lane widths could be reduced to increase the capacity of tunnels and chokepoints. Variable lane widths could be used, with smaller lanes reserved for smaller vehicles. All vehicles would need to be integrated with platooning technology for benefits to be observed from this scheme.

- **Flow**: The study anticipates more uniform traffic flow and reduced congestion in historically congested chokepoints.

- **Signage**: Signage along certain routes could be reduced or eliminated, as all operating instructions, alerts, and commands could be transmitted directly to vehicles.

- **Parking**: Parking lanes along certain routes could be reduced or eliminated, as AVs are theoretically capable of traveling to remote locations independently for storage. This change impacts road capacity, flow, and the proximity of pedestrians and bicyclists to traffic.

[30] Connected and Autonomous Vehicles 2040 Vision. Rep. Pennsylvania Department of Transportation / Carnegie Mellon University, 10 July 2014. Web.

Significant changes to design standards are unlikely in the near future, yet these questions have immediate relevance as states attempt to forecast traffic and plan future spending on infrastructure, especially given the substantial impact new AV ownership patterns may have on congestion and infrastructure needs.[31] Federal and state regulators have not yet addressed these issues or issued guidance on anticipated changes to long-standing road design practices. The safety implications of lane widths, acceptable speeds, sight lines, weight limits, and other design factors will need to be systematically reassessed, with the results incorporated into engineering standards.

1.2.4 Other Key Infrastructure Issues

Substantial infrastructure changes will have a long implementation timeframe. Safe comingling of AVs, conventional vehicles, bicycles, and pedestrians will likely be a priority for many years to come, and the infrastructure demands for each are significantly different. While certain signage, road markings, and signals may be rendered unnecessary by AV technology, conventional vehicles will continue to be dependent on them. In the immediate future, AVs could be deployed in the existing as-built infrastructure environment, where traffic is a mix of AVs and conventional driver-operated vehicles. However, AVs may operate in designated AV-only environments or road segments with specialized, integrated infrastructure where conventional vehicles are prohibited.

The costs of deploying specialized AV infrastructure everywhere are potentially very high. At first, deployment could be limited to areas that are cost-effective for infrastructure investment. New financial models for financing infrastructure may surface as stakeholders in AV deployment identify new arrangements to shoulder the increased costs of infrastructure development.[32] If public-private partnerships and other innovative infrastructure financing tools become more common, safety implications of new models for providing infrastructure must be assessed. Development of public infrastructure cannot be built solely to safely interface with one manufacturer's vehicle; in an environment with mixed AV models and non-AVs, the infrastructure provider must ensure interoperability with all vehicles.

Further, road construction and maintenance responsibilities are highly fractionalized nationwide. Within any small municipality, a mix of local DOT, state DOT, and private owners are often responsible for intersecting and adjacent roads. Even a single road can repeatedly change in the jurisdiction for upkeep as it passes through several municipalities. These separate entities may want to follow a singular and consistent set of guidance and standards when implementing coordinated enhancements to roads.

Prioritizing infrastructure deployment will be a significant challenge. Infrastructure owners must weigh the risks and safety benefits of deploying infrastructure in certain areas and not in others.[33] The risk-reduction evaluation process should accurately reflect the hazards presented by AV operation in specific locations and the potential safety improvements offered by new technologies. Thorough and accurate cost-benefit analysis for infrastructure investments must also be supported by incident and performance data gathered from across the AV industry, and informed by trend

[31] Ibid
[32] Connected and Autonomous Vehicles 2040 Vision. Rep. Pennsylvania Department of Transportation / Carnegie Mellon University, 10 July 2014. Web.
[33] Ibid

analysis that identifies specific risks of infrastructure deployment scenarios. Infrastructure providers should collaborate with manufacturers, regulators, researchers, and operators to develop a common understanding of anticipated timeframes and needs for infrastructure deployment. A committee of federal and state DOT representatives, together with AV developers, could explore how new technologies can be phased in, consider how each technology will impact mixed-traffic operations, assess potential risks, and evaluate alternatives to identify the safest configuration of new infrastructure.

1.2.5 Conclusion

There is an uneven landscape of AV-linked communications devices, AV-optimized road materials, and potential design changes to improve safety and maximize potential benefits of AV adoption. Existing signal coordination systems, weather alert communications devices, road maintenance data collection programs, and traffic management technologies offer a sense of how infrastructure tools may eventually be integrated and deployed on a larger scale.

While some infrastructure capabilities such as V2I combinations-based hazard alerts promote safety directly, other infrastructure improvements like roadway design changes are largely non-safety-critical (though offering significant operational improvements). In addition, many of the safety benefits offered by AV infrastructure are redundant with the capabilities of the vehicles themselves, which have been the subject of significant research and investment by manufacturers. Once a baseline of safety-related technologies is in place, AV infrastructure development efforts may shift to incorporate technologies that enable higher speeds, shorter stopping distances, and greater intersection throughput. A comprehensive optimization of road materials and road design in the Federal Highway Administration's Manual on Uniform Traffic Control Devices for AV usage is a logical step toward maximizing the operational advantages of AV technology.

> The decentralized nature of infrastructure development presents a significant challenge to implementation of many new technologies.

The decentralized nature of infrastructure development and regulation presents a significant challenge to implementation of many new technologies. The complex nature of AV infrastructure technologies will require development of thorough safety regulations, and existing regulatory frameworks lag far behind recent technological developments. Furthermore, infrastructure is planned, constructed, and maintained by many separate entities and according to different regulatory requirements; coordination among states, operators, vehicle manufacturers, and researchers is relatively limited. Implementation of complex infrastructure scenarios incorporating multiple technologies will require enhanced planning, research, coordinated investment, and communication regarding the engineering parameters and operational capabilities of infrastructure elements. Lastly, as with other nascent technologies, there is lingering uncertainty regarding which new devices, techniques, and strategies are most suitable for widespread use on roads throughout the country.

1.3 Accidents/Incidents and Known Hazards

One of the greatest projected benefits of AVs is the positive contribution self-driving cars will have on improved road safety. More than 90 percent of conventional motor vehicle accidents result from human error.[34] As AV technology is enhanced and made more prevalent on public roadways, AVs will have significant impacts on driver safety, which is predicted to result in a decline of human-induced motor vehicle-related injuries and fatalities. This, however, will be challenging, as drivers of conventional vehicles will need to adapt to a new driving style when sharing the road with AVs. Additionally, there is a need for owners of vehicles with semi-autonomous features to learn and adopt new driving skills. Manufacturers of semi-autonomous vehicles should educate drivers about their capabilities and limitations. Specific measures, such as AV accident tracking and analyses, should be established in order to better understand the root cause of incidents and minimize the risk of future incidents from occurring.

Because AVs can be programmed to abide by traffic laws, and are expected to greatly reduce risks from intoxicated, fatigued, and distracted drivers, human factors that contribute to accidents could be virtually eliminated. In addition, AV performance standards could be better than those of human drivers because of enhanced perception, decision making, and execution.[35] As self-driving vehicles in testing become more prevalent on public roadways, however, it is important that potential hazards are identified and remediated in early stages before large-scale commercial deployment.

> As AV accidents occur, public perception of AVs may adopt a negative tone, as public reaction may lean toward blaming the technology rather than human error.

Even with the large-scale use of AVs, some crashes will be unavoidable. Therefore it is critical that AVs possess the proper decision-making technology to recognize a path that results in the least amount of harm. For instance, an AV may encounter a person who darts in front of the moving vehicle, and the AV does not have sufficient time or stopping distance before striking the individual. The AV may need to choose between striking the person or swerving into another lane of traffic, which could yield a more or less severe outcome.

As AV accidents occur during testing and future deployment, public perception of AVs may adopt a negative tone, as public reaction may lean toward blaming the technology rather than human error. This perception may negatively impact large-scale AV deployment. This is exemplified by a collision that occurred in February 2016, when a Google AV test vehicle collided with a Santa

[34] National Highway Traffic Safety Administration. Critical Reasons for Crashes Investigated in the National Motor Vehicle Crash Causation Survey. February 2015. http://www-nrd.nhtsa.dot.gov/pubs/812115.pdf

[35] Kalra, Nidhi and Susan M. Paddock. Driving to Safety: How Many Miles of Driving Would It Take to Demonstrate Autonomous Vehicle Reliability?. Santa Monica, CA: RAND Corporation, 2016. http://www.rand.org/pubs/research_reports/RR1478.html.

Clara Valley Transit Authority bus. Although the accident was not solely the fault of the AV in testing, the incident contributed to AV skepticism from a variety of parties.[36]

1.3.1 Conventional Vehicle Accident Trends

According to NHTSA's Fatal Analysis Reporting System (FARS) records, 32,675 people died in motor vehicle crashes in 2014 in the United States.[37] Along with drunk driving, which constitutes roughly one-third of the fatalities, fatigue and distracted driving were reported in crashes that killed 13,992 people (43 percent of all fatalities). Of the total number of fatalities, 4,884 pedestrians and 726 cyclists were killed in motor vehicle crashes in 2014. In addition, roughly 2.3 million people were injured in crashes in 2014. On average, motor vehicle crashes in the United States can account for economic and social costs of more than $800 billion a year.[38] As AV technology improves and AVs are deployed for use on public roads, the quantity of motor vehicle crashes resulting from human error is projected to decline. Drivers' ability to adapt to programmable AV driving styles will play a large role in the expected safety outcomes.

Conventional vehicle incidents are typically investigated by local and state police to determine the need for penalties or criminal charges, and/or to assign liability. Automobile insurance companies and specialized investigation teams also investigate accident claims depending on the nature and severity of each accident. Accident investigations, however, can also be part of a comprehensive hazard management process to identify, report, classify, resolve, and track safety hazards in a planned and consistent manner. Currently, NHTSA's National Center for Statistics and Analysis Special Crash Investigations (SCI) department compiles and analyzes special accident and incident investigation data related to conventional vehicle cases.[39] These cases are intended to aid in determining contributing factors in special crash circumstances or outcomes from an engineering perspective. The goal of the program is to improve performance of advanced safety systems by identifying outcomes through in-depth investigations of unique cases throughout the United States.

1.3.2 Accident and Incident Investigations and Current AV Data Tracking Methods

As technology plays a larger role in vehicle use, a greater focus will be placed on identifying software and technical malfunctions as part of investigations. Investigation efforts should seek to identify primary and contributory causes for incidents and hazards, and to develop corrective actions to minimize the likelihood of recurrence. Through ongoing review of individual incidents, incident trends, and hazards, state and/or federal agencies can determine root causes and work with

[36] Cabanatuan, Michael. "Google Self-driving Car in Fender-bender with VTA Bus." *SFGate*. N.p., 29 Feb. 2016. Web. 05 July 2016.
[37] National Highway Traffic Safety Administration. Traffic safety facts: 2014 crash data key findings. DOT HS 812 2119. Washington, DC: National Highway Traffic Safety Administration; November 2015. http://www-nrd.nhtsa.dot.gov/Pubs/812219.pdf
[38] Blincoe, Lawrence, Ted R. Miller, Eduard Zaloshnja, and Bruce A. Lawrence, The Economic and Societal Impact of Motor Vehicle Crashes 2010 (Revised), Washington, D.C.: National Highway Traffic Safety Administration, DOT HS 812 013, 2014, revised May 2015. http://www-nrd.nhtsa.dot.gov/pubs/812013.pdf
[39] National Highway Traffic Safety Administration. Special Crash Investigations (SCI). http://www.nhtsa.gov/SCI Accessed June 7, 2016

AV manufacturers or infrastructure providers to prevent future incidents. As of July 2016, in-depth technical investigations by AV manufacturers or independent parties such as law enforcement have not been required throughout initial testing phases of fully autonomous vehicles or the public use of Level 2 AVs. However, some initiatives have been taken to better understand and track accidents that have occurred.

California is currently the only state that has adopted regulations to require vehicle testing manufacturers to record accident and incidents. As of July 2016, the California Department of Motor Vehicles (DMV) has issued Autonomous Vehicle Testing Permits to 14 vehicle manufacturers.[40] Under the testing regulations, manufacturers are required to provide the California DMV with a *Report of Traffic Accident Involving an Autonomous Vehicle* (form OL 316) within 10 business days of the incident. It is unclear whether these requirements include accidents that occur with semi-autonomous vehicles using autopilot mode, but none have been reported to California to date.

In addition, the California Autonomous Vehicle Testing Regulations require every manufacturer authorized to test AVs on public roads to submit an annual report summarizing disengagements during testing. Disengagements are defined as deactivations of the AVs when a failure of the autonomous technology is detected or when the safe operation of the vehicle requires that the autonomous vehicle test driver disengage the autonomous mode and take immediate control of the vehicle. From December 2014 to November 2015, there were 1,840 disengagements reported from seven different testing manufacturers in January 2016. Manufacturers who reported disengagements tested a variety of vehicles periodically throughout this time frame.

Table 2 in Appendix 2 details the 16 autonomous vehicle accidents and incidents reported in California from January 2014 to July 2016. They included three different accident types: angle (one case), sideswipe (four cases), and rear-end (11 cases).[41] In California, there have been a total of four recorded injuries that resulted from one accident in particular. All 16 accidents involved at least one other motor vehicle, and the majority (12) of accidents occurred as the self-driving car was either stopped or travelling at a low speed (at or below 5 mph). As of June 2016, AVs were only at fault for one of the 16 accidents recorded in California.

Another growing concern is accidents and incidents occurring with semi-autonomous vehicles, in the Level 2 stage, that have already been made available for the public. A May 2016, incident involving a Tesla Model S in Williston, Florida, involved the first known death in more than 130 million miles driven in Autopilot mode.[42] The semi-autonomous vehicle collided with a tractor-trailer rig, killing the Model S driver. Shortly after the incident, NHTSA opened an investigation to determine the design and performance of Tesla's Autopilot system. Preliminary investigations indicate the crash occurred when the tractor-trailer rig made a left turn in front of the Tesla Model S vehicle at an intersection of a divided highway, and neither the driver nor the Autopilot noticed

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[40] California Department of Motor Vehicles. Autonomous Vehicles in California. https://www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/testing Accessed June 7, 2016
[41] Ibid
[42] Lowy, Joan, and Tom Krishner. "Driver Killed in Self-driving Car Accident for First Time." PBS. PBS, 30 June 2016. Web. 05 July 2016.

the white side of the trailer compared to the sky.[43] This fatality gained widespread media attention, but it is difficult to determine how many non-fatal semi-autonomous vehicle incidents have occurred because regulations do not require specific AV accident reporting nationwide. NHTSA was also investigating a Tesla Model S rollover accident on the Pennsylvania Turnpike in July 2016 to determine whether Autopilot was engaged and, if so, what actions the technology and the driver took.[44]

1.3.3 Data Limitations and Known Hazards to Safe AV Implementation

As of July 2016, the overall severity of crash-related injuries involving AVs has been less than conventional vehicles based on number of miles travelled. AV testing has been limited, however, to specific regions and less demanding driving conditions versus those experienced by human drivers in conventional motor vehicles (e.g., severe weather conditions or dense urban environments).[45] These testing conditions limit the viability of AV incident statistics.

In relation to conventional vehicles, AVs have accumulated considerably fewer vehicle miles traveled (VMT) in the United States. For comparison, since initial testing started in 2009 to June 2016, Google's AV fleet has accrued nearly 1.5 million vehicle miles in autonomous mode.[46] This is a small fraction of the nearly 3 trillion miles travelled by conventional vehicles in the United States in 2014 alone.[47] This large disparity in driving mileage makes the number of accidents from conventional vehicles seem relatively small based on the large number of miles, which translates to roughly one fatality for 100 million miles traveled, or one injury for 1.3 million miles traveled.[48] Researchers at the RAND Corporation have recently determined that AVs would have to be driven hundreds of millions of miles, and in some cases hundreds of billions of miles, to demonstrate their reliability in terms of fatalities and injuries.

One of the largest obstacles to safe and secure AV implementation is linked to how conventional vehicle drivers will adapt to self-driving vehicles.

[43] Ibid.

[44] Boudette, Neal E., Bill Vlasic, and Annalyn Kurtz. "U.S. Safety Agency Investigates Another Tesla Crash Involving Autopilot." The New York Times. The New York Times, 06 July 2016. Web. 08 July 2016. http://www.nytimes.com/2016/07/07/business/us-safety-agency-investigates-another-tesla-crash-involving-autopilot.html.

[45] Schoetle, Brandon and Sivak, Mihcael. A Preliminary Analysis of Real World Crash Involving Self-Driving Vehicles. Ann Arbor, MI: University of Michigan Transportation Research Institute; 2015

[46] "Google Self-Driving Car Project." *Google Self-Driving Car Project*. Google, n.d. Web. 07 July 2016.

[47] U.S. Department of Transportation, Federal Highway Administration, Highway Statistics (Washington, DC: Annual Issues), table VM-1. Feb. 23, 2016. http://www.fhwa.dot.gov/policyinformation/statistics.cfm

[48] Kalra, Nidhi and Susan M. Paddock. Driving to Safety: How Many Miles of Driving Would It Take to Demonstrate Autonomous Vehicle Reliability?. Santa Monica, CA: RAND Corporation, 2016.

One of the largest obstacles to safe and secure AV implementation is linked to how conventional vehicle drivers will adapt to self-driving vehicles. Some researchers have suggested that risks may increase during the transition period in which AVs and conventional vehicles share the road. As more AVs are added to public roads, and conventional vehicle drivers become accustomed to their presence, researchers at the University of Michigan Transportation Research Institute suggest that the number of accidents will decrease over time.[49] Because of limited testing, the ways in which conventional drivers will react to AVs is largely unknown. Policy strategies such as designated AV lanes and the use of public awareness and outreach campaigns could encourage safe vehicle interactions; however, they can also be costly endeavors and difficult to deploy from state to state.

Accident and incident classification and tracking can assist in identifying trends and preventing specific incidents from recurring. Incidents can be categorized by type, and depending on specific thresholds, such as severity and monetary damages, should be reported to federal and/or state agencies. Appendix 2 outlines the 13 road vehicle accident categories for conventional vehicles as identified by the American National Standards Institute. This list could be adopted for AV accident categorizations adopted by states and AV manufactures in order to track and identify hazards throughout testing stages and early implementation. Further, existing NHTSA reporting could be expanded or categorized to specifically capture accidents that occur within each level of automation for AVs.

1.3.4 Conclusion

Although it is largely accepted that AVs will reduce the number of human-induced accidents and fatalities, there are still some uncertainties on how conventional vehicle drivers will adjust to AV implementation. States, under NHTSA guidance, should closely examine accident investigation and reporting policies now to contribute to a smooth transition between AVs and conventional vehicles. In conjunction with proactive hazard management strategies, regulators should consider requiring AV manufacturers to develop clear processes for addressing any potential deficiencies and hazards identified through future investigations. This should be seen as a proactive measure that could be helpful as more AVs are designed and deployed. A comprehensive database of accident and incidents, tracked by both states and AV manufactures, could help manufacturers be conscious of design flaws, and how to prevent future incidents from occurring.

[49] Sivak M, Schoettle B. Road safety with self-driving vehicles: General limitations and road sharing with conventional vehicles. Ann Arbor, MI: University of Michigan Transportation Research Institute; 2015

1.4 State and Federal Regulations

On January 14, 2016, the federal government pledged support for development and deployment of AV technology.[50] While the federal government has invested $4 billion toward furthering this technology, it has not yet released any comprehensive regulatory framework concerning AVs as the technology rapidly develops. The only action taken at the federal level concerning such a framework came in the form of NHTSA issuing policy guidelines [51] [52] on the development of state regulations. This guidance consists of recommendations covering myriad aspects of AV usage such as licensing, restrictions on operation, minimizing risk to other drivers, and ensuring that pertinent data is recorded. As of July 2016, 19 states have introduced AV legislation that is either in the various stages of legislative vetting, or has failed.[53] Only the District of Columbia and five states – California, Florida, Michigan, Tennessee and Nevada[54] – have passed substantive legislation regarding AV operation on public streets and highways. Tennessee's legislation regulating AV operations will take effect in January 2017.[55] Some of the other 19 states like Utah and North Dakota have passed legislation calling for the state to study AVs and their safety.[56,57] Louisiana has passed legislation defining AV technology, but it has no requirements.[58] Some of the state regulations follow NHTSA's policy guidance, but the state regulation landscape remains a patchwork of different requirements. Several reports in June 2016 indicated that NHTSA would release more specific guidance or proposed federal regulation in July 2016.[59,60]

The following sections will examine existing state regulations and compare them to NHTSA policy guidance. These states define AVs as vehicles with the capability to drive without the active physical control of a human driver. This definition of an AV is usually interpreted by legislatures to exclude vehicles equipped with semi-autonomous technology (Levels 1 and 2), such as those available to the public today. Unless otherwise noted, references to "AVs" refer to Level 3 and 4 autonomy, and references to "states" regard the District of Columbia, California, Florida, Michigan, Nevada, and Tennessee.

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50 "Secretary Foxx Unveils President Obama's FY17 Budget Proposal of Nearly $4 Billion for Automated Vehicles and Announces DOT Initiatives to Accelerate Vehicle Safety Innovations." U.S. Department of Transportation, 14 Jan. 2016. Web. 08 June 2016.

51 "National Highway Traffic Safety Administration Preliminary Statement of Policy Concerning Automated Vehicles". U.S. Department of Transportation, 30 May. 2013. Web. 8 Jan. 2016.

52 "DOT/NHTSA Policy Statement Concerning Automated Vehicles" 2016 Update to "Preliminary Statement Of Policy Concerning Automated Vehicles". U.S. Department of Transportation, 14 Jan. 2016. Web. 8 June 2016.

53 "Autonomous | Self-Driving Vehicle Legislation." Http://www.ncsl.org/research/transportation/autonomous-vehicles-legislation.aspx. National Conference of State Legislatures, 1 July 2016. Web. 6 July 2016.

54 For purposes of this analysis, readers should assume that references to these states includes the District of Columbia.

55 TN SB 1561 (2016).

56 UT HB 280 (2016).

57 ND HB 1065 (2016).

58 LA HB 1143 (2016).

59 "DOT/NHTSA Policy Statement Concerning Automated Vehicles" 2016 Update to "Preliminary Statement Of Policy Concerning Automated Vehicles". U.S. Department of Transportation, 14 Jan. 2016. Web. 8 June 2016.

60 "Michigan Department of Transportation Public Act 231 of 2013; Section 665(3) Testing and Operation of Automated Vehicles." Michigan Department of Transportation. Web. 6 July 2016.

1.4.1 Testing and Licensing Requirements

Given the experimental nature of AV technology, some states have approached licensing carefully. Getting behind the wheel of an AV in three of the states which have passed AV legislation requires additional licensing requirements beyond a regular driver's license. These additional requirements are intended to provide assurances that AVs are "operated" by individuals who understand the capabilities and limitations of the technology. California and Nevada both require AV technology manufacturers submit driver training plans – which include, but are not limited to, instruction on the autonomous technology and assurance that each driver has completed or will complete the training.[61] [62] In Nevada, a driver must apply for an AV-specific license endorsement.[63] Furthermore, Nevada requires two people to be present in the vehicle during operations.[64] This adds an additional layer of protection and licensure as both people must be licensed to operate AVs. Tennessee's legislation requires the Tennessee Department of Safety, in consultation with the Tennessee Department of Transportation, to promulgate rules regarding the licensing of "Operator-required autonomous vehicles" based on "the class of vehicle based on weight rating or number of passengers" for those vehicles[65].

California does not make use of special endorsements like Nevada, but does require that the driver operating an AV maintain a testing certificate and meet certain thresholds. In addition to completing a manufacturer's training course, drivers in California seeking to operate AVs must possess a regular driver's license, with no accident history for 10 years, and no driving violations for at least three years.[66] These special licensing and training requirements do not apply to the semi-autonomous vehicles already on the market.

While California and Nevada both take a cautious approach to licensing drivers, not all states that have passed AV legislation require any additional licensing requirements. Michigan, for instance, only requires that AVs bear special license plates[67] (Nevada also has this requirement[68]). The District of Columbia and Florida have no special licensing requirements beyond a basic, valid driver's license.

NHTSA's 2013 preliminary policy statement on AVs contains two suggestions for licensing drivers. First, NHTSA recommends that "[a] driver licensing program should provide for driver's license endorsements (or separate driver's licenses) that authorize the operation of self-driving vehicles."[69] Nevada is the only state to implement a separate endorsement for the operation of self-driving vehicles, whereas California, while not mandating a separate license or endorsement, captures the spirit of this suggestion by requiring an application for a certificate to operate AVs. Next, NHTSA recommends that issuing such a license or endorsement should be conditioned upon

[61] Nev. Admin. Code § 482A.110 (2014), and 13 Cal. Code Regs. § 227.22 (2014).
[62] Ibid
[63] Nev. Admin. Code § 482A.040 (2014).
[64] Nev. Admin. Code § 482A.130(2) (2014).
[65] TN SB 1561 (2016).
[66] 13 Cal. Code Regs. § 227.20 (2014).
[67] Mich. Comp. Laws § 257.244(3).
[68] Nev. Admin. Code § 482A.140 (2014).
[69] "National Highway Traffic Safety Administration Preliminary Statement of Policy Concerning Automated Vehicles". U.S. Department of Transportation, 30 May. 2013. Web. 8 Jan. 2016.

"certain prerequisites, such as that person's passage of a test concerning the safe operation of a self-driving vehicle and presentation of a certification by a manufacturer of self-driving vehicles… that the person has successfully completed a training course provided by that manufacturer (or representative), or a certification by that manufacturer (or representative) that the person has operated a self-driving vehicle for a certain minimum number of hours."[70] Both California and Nevada follow suit with this recommendation by requiring that manufacturers provide either a training plan or proof that drivers have completed such training.

As of July 2016, Michigan, Florida, and the District of Columbia lack any requirements on formal testing or licensure beyond that of a normal driver's license. This stands in contrast to NHTSA's policy guidance. While these jurisdictions may find their current rules sufficient, as most states with regulations currently limit operations to testing, additional licensing and testing requirements could be beneficial as operations expand beyond testing and ultimately to public operations. NHTSA's guidance states that such testing should "include providing an understanding of the basic operation and limits of self-driving vehicles, and knowledge of how to resume control of such a vehicle in the event that it cannot continue to operate automatically."[71] Understanding the limitations of any vehicle is paramount to its safe operation, especially in emergent technology such as AVs.

1.4.2 Driver Requirements

Five of the six jurisdictions with substantive AV legislation currently require a human to be present in, and be ready to assume control over, the vehicle. California, for instance, requires that a "…driver shall be seated in the driver's seat, monitoring the safe operation of the autonomous vehicle, and capable of taking over immediate manual control of the autonomous vehicle in the event of an autonomous technology failure or other emergency."[72] Similarly, Tennessee will condition operation of AVs upon a driver being seated in the driver's seat.[73] Nevada's statutory language requires that a driver "be seated in a position which allows the person to take complete control of the vehicle, including, without limitation, control of the steering, throttle and brakes."[74] While Nevada does not specify where a person must be seated in the vehicle, it does require two people to be in the vehicle while the vehicle is operating and that at least one be ready to take control of the vehicle.[75] Michigan and the District of Columbia employ similar language that requires that a person merely be present in the car ready to assume control of the vehicle's movements. Recently, Florida passed legislation making it the only state which explicitly does not require a human driver to be present in the vehicle.[76] Florida's legislation permits the operation of AVs on public roads, and only requires that the vehicle be "operated" (i.e. causes the vehicle's AV technology to be engaged[77]) by a licensed driver.

[70] Ibid
[71] "National Highway Traffic Safety Administration Preliminary Statement of Policy Concerning Automated Vehicles". U.S. Department of Transportation, 30 May. 2013. Web. 8 Jan. 2016.
[72] Cal. Veh. Code § 38750(b)(2) (2014).
[73] TN SB 1561 (2016).
[74] Nev. Admin. Code § 482A.130(1) (2014).
[75] Ibid
[76] FL HB 7027 (2016).
[77] Florida Uniform Traffic Control Law, Fla. Stat. § 316.85(2) (2014).

Additionally, California and Michigan require that the driver is an employee or contractor of the company testing the autonomous technology. These regulations as currently written would prohibit a company from releasing a Level 3 or 4 vehicle to the public. Michigan, for instance, requires that "[t]he vehicle is operated only by an employee, contractor, or other person designated or otherwise authorized by that manufacturer of automated technology."[78] Similarly, California requires the "autonomous vehicle is being operated on roads in this state solely by employees, contractors, or other persons designated by the manufacturer of the autonomous technology."[79] These regulations substantially limit the operation of AVs by essentially prohibiting consumer use of Level 3 or 4 AVs.

NHTSA policy guidance is written from a perspective that envisions operations limited to testing purposes only, and assumes there is a relationship between the manufacturer or testing institution and the driver. NHTSA recommends that states require a "properly licensed driver be seated in the driver's seat and ready to take control of the vehicle while the vehicle is operating in self-driving mode on public roads."[80] Here, we see that some states follow this advice; yet, statutory language from Nevada, Michigan and the District of Columbia only require that the driver be seated in a position where they are capable of taking immediate control of the vehicle's movements. This raises the question of how these regulations define "control." By not requiring the individual to be seated behind the driver's seat, one could assume that control simply means being able to stop the vehicle.

As AV technology becomes more prevalent the public will be presented with a paradigm shift on who or what a driver is.

While some states have taken steps to define the vehicle driver as a human[81], as AV technology becomes more prevalent the public will be presented with a paradigm shift on who or what a driver is. Most laws as written assume that the "driver" is constantly controlling the vehicle. Will the driver continue to be the person in the vehicle, or will the autonomous technology at some point become the de facto driver? This concept is analogous to automated people mover systems (prevalent at airports) where the vehicle "driver" is really the software itself and/or an "operator" in a remote control center. Until such a concept is redefined for automobiles, humans are still operators of these vehicles. While autonomous technology is still being developed, states should consider requiring a human be seated behind the wheel ready to assume control over the vehicle. Once there is a transition phase where more AVs operate alongside traditional motor vehicles, there will be a number of unknown factors involving human driving behavior. In order to ensure the safety of all those on the road, states should take a cautious approach consistent with NHTSA's recommendations.

78 Mich. Comp. Laws § 257.665(2)(a) (2014).
79 Cal. Ved. Code § 38750(b)(1) (2014).
80 "National Highway Traffic Safety Administration Preliminary Statement of Policy Concerning Automated Vehicles". U.S. Department of Transportation, 30 May. 2013. Web. 8 Jan. 2016.
81 Nev. Admin. Code § 482A.020 (2014), and Cal. Veh. Code § 38750(a)(4) (2014).

1.4.3 Limits on Liability

In an effort to encourage development and innovation in autonomous vehicle technology, the District of Columbia, Florida, Michigan, Tennessee, and Nevada limit liability for manufacturers and testers when third parties outfit their vehicles with AV technology.

Nevada expressly limits the liability for vehicle manufactures when a third party installs autonomous technology in one of their vehicles, with liability falling to the third party that performed the modification. Nevada's statute provides that "the manufacturer of a motor vehicle that has been converted by a third party into an autonomous vehicle is not liable for damages to any person injured due to a defect caused by the conversion of the motor vehicle or by any equipment installed to facilitate the conversion unless the defect that caused the injury was present in the vehicle as originally manufactured."[82] Michigan, the District of Columbia, Tennessee, and Florida all use similar language. Currently, California is the only state with AV regulation that does not expressly limit liability for original vehicle manufacturers whose vehicles are retrofitted with autonomous technology.

Liability limits, combined with limiting operations to testing and requiring certain amounts of insurance (discussed in more detail below), offer an incentive for technology testing while protecting safety interests of the general public. Holding original vehicle manufacturers liable for events caused by third parties could have a chilling effect on experimentation and innovation in developing this technology.

Likewise, NHTSA has recognized at this early stage of autonomous technology's development that over-regulation could stifle the advancement of this technology. In their policy statement, NHTSA indicated that "premature regulation can run the risk of putting the brakes on the evolution toward increasingly better vehicle safety technologies."[83] The NHTSA policy statement provides no guidance on limiting liability; this was entirely a development of the states. NHTSA does, however, state that its intention is to promote the "safe development and implementation of autonomous technology."[84] If regulations are too prescriptive, development and innovation could be stifled. If, on the other hand, regulations shield manufacturers more than necessary, states run the risk of allowing companies to engage in practices that could compromise safety because they would be protected from damages for valid claims. It is important for states to consider this balance when crafting regulations on the use of AVs.

1.4.4 Limits on Operations

Only Michigan limits AV operation to testing purposes only. While Michigan, California, and Tennessee allow testing on public highways, Nevada appears to take the most geographically limiting approach of all the states by limiting testing operations to certain identified zones.[85] Parties wishing to test an AV in an additional zone must submit an application for a testing permit to the

[82] Nev. Rev. Stat. § 482A.090 (2014).
[83] "National Highway Traffic Safety Administration Preliminary Statement of Policy Concerning Automated Vehicles". U.S. Department of Transportation, 30 May. 2013. Web. 8 Jan. 2016.
[84] Ibid.
[85] Nev. Admin. Code § 482A.120 (2014).

Nevada Department of Motor Vehicles. Within that application, the party must submit proof that the vehicle they wish to test has the technological capabilities to perform according to the road conditions and comply with applicable traffic laws of that geographic zone.[86] Nevada evaluates these applications on a case-by-case basis and requires a demonstration of the vehicle's capabilities.

NHTSA has strongly recommended that the operation of AVs currently be limited to testing purposes only. NHTSA has expressly stated that it "does not recommend at this time that states permit the operation of self-driving vehicles for purposes other than testing."[87] While this is in line with the current state of the technology's usage, a uniform and updated policy from the federal level reflecting widespread public use will be needed as the technology quickly develops. Further, safety policy is virtually nonexistent regarding semi-autonomous vehicles already on the road today.

1.4.5 Insurance Requirements

Nevada, Michigan, Tennessee, and California require AV testers to show proof of insurance coverage, often in the form of multi-million dollar policies, beyond what is required by regular insurance laws. While insurance is not a safety precaution, it can mitigate harm done by a tester's vehicle. Like limited liability, insurance is an area that is not expressly recommended in NHTSA's policy statement, and is entirely a creation of state legislatures. Most jurisdictions with AV legislation take a similar approach in their insurance requirements.

California, Nevada, and Tennessee require testers to submit proof of insurance or surety bond covering up to $5 million.[88] Testers must submit their deposit or proof of insurance prior to testing their vehicles on public roads. While Florida once required the same amount, it has recently amended its law to require a policy amount of about $1 million.[89] Both Michigan and the District of Columbia have no special insurance requirements for AV testers beyond regular insurance.

1.4.6 Vehicle Requirements

NHTSA has recommended a set of four principles that states should adhere to when crafting a regulatory framework governing this technology:

- Ensure that the process for transitioning from self-driving mode to driver control is safe, simple, and timely;
- Self-driving test vehicles should have the capability of detecting, recording, and informing the driver that the system of automated technologies has malfunctioned;
- Ensure that installation and operation of any self-driving vehicle technologies does not disable any federally required safety features or systems; and

[86] Ibid
[87] "National Highway Traffic Safety Administration Preliminary Statement of Policy Concerning Automated Vehicles". U.S. Department of Transportation, 30 May. 2013. Web. 8 Jan. 2016.
[88] Nev. Rev. Stat. § 482A.060 (2014), CAL. VEH. CODE § 38750(c)(3) (2014), and TN SB 1561 (2016).
[89] "Interview with FL State Senator Brandes." Telephone interview. 18 Mar. 2016.

- Ensure that self-driving test vehicles record information about the status of the automated control technologies in the event of a crash or loss of vehicle control[90]

The first principle includes ensuring that drivers are familiar with a vehicle's controls; that the vehicle's autonomous/manual transition defers to the driver through various mechanisms which allow the human driver to assume control; and requiring a vehicle to alert the driver when they must assume manual control of the vehicle. California and Nevada require that the driver be able to assume manual control of the vehicle through multiple means "including, without limitation, through the use of the brake, the accelerator pedal, or the steering wheel, and it shall alert the operator that the autonomous technology has been disengaged."[91] The District of Columbia has a similar requirement that the vehicle has a "manual override feature that allows a driver to assume control of the autonomous vehicle at any time."[92] Tennessee has also employed comparable language in its legislation.[93]

The second principle NHTSA recommends is that AVs should have the capability of detecting when the autonomous technology has failed, recording the failure, and alerting the driver accordingly. None of the states appear to capture this principle in their regulations. Even states such as California and Nevada with robust safety frameworks do not require recording of this data. They do, however, require the capture of crash data (the fourth principle).

Next, NHTSA recommends that state law forbid the disabling of federally required safety features; emphasize that disabling these systems is prohibited by federal law; and require that autonomous technology should not degrade or interfere with the performance of these systems. California, Tennessee, and Nevada's legislation require this.

The final principle is for recording data from an AV in the event of a collision or loss of vehicle control. For this principle NHTSA recommends that all pertinent data prior to a collision or loss of control, including whether the autonomous technology was engaged at the time of the event, be recorded for analysis. Furthermore, NHTSA recommends requiring that this data be made available to the state. California and Nevada capture this principle in their regulations. In fact, California and Nevada use nearly identical language in their respective regulations, requiring that:

> "[t]he autonomous vehicle has a separate mechanism… to capture and store the autonomous technology sensor data for at least 30 seconds before a collision occurs… while the vehicle is operating in autonomous mode. The autonomous technology sensor data shall be captured and stored in a read-only format … The data shall be preserved for three years after the date of the collision…"[94]

Tennessee's legislation also contains this requirement but differs by requiring storage of data 90 seconds before a collision.[95] All three states require the recording and storage of collision data.

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[90] "National Highway Traffic Safety Administration Preliminary Statement of Policy Concerning Automated Vehicles". U.S. Department of Transportation, 30 May. 2013. Web. 8 Jan. 2016.
[91] Ibid
[92] D.C. Code §§ 50-2352(2) (2013).
[93] TN SB 1561 (2016).
[94] Nev. Admin. Code § 482A.110 (2014), and Cal. Veh. Code § 38750(c)(1) (2014).
[95] TN SB 1561 (2016).

Yet, nothing in these regulations appears to require manufacturers to provide this data to law enforcement or the states. This information could provide critical safety data to identify the causes of accidents. States developing AV legislation may want to consider requiring manufacturers and testers to provide this information to the state.

1.4.7 Conclusion

Overall, the few jurisdictions with AV regulations are in line with NHTSA's policy guidelines. These states have taken further steps including mandating requirements for insurance and liability. Some states such as California and Nevada have delegated further rulemaking responsibilities to their respective Departments of Motor Vehicles, and these bodies have instituted requirements for accident and data reporting. Tennessee has also delegated rulemaking to state agencies on the effective date of its legislation.[96] With the exception of Michigan, which has strictly limited operations to testing purposes only, most states have either set the stage for eventual deployment or allowed for their widespread use.

Of all the states which have passed legislation authorizing the use of AVs, California and Nevada's regulations are by far the most robust. Both sets of regulations are nearly identical to each other and require many aspects of NHTSA's recommended principles. While this technology is still in the early stages of development, detailed regulations may not be feasible. Safety, however, should be lawmakers' primary concern, and as such NHTSA's recommended principles offer a balanced approach.

Without overarching federal regulations, states are free to develop AV regulations as they see fit. Compared to Nevada and California, Florida and the District of Columbia have taken a more permissive approach to their regulations. Florida's initial AV regulations, while not as prescriptive, resembled California's and Nevada's. A 2016 bill eased many of those restrictions and transformed Florida's laws into some of the most relaxed regarding AV usage.[97] By easing many of these restrictions, Florida has attempted to encourage AV testing in the state while anticipating regulations to be driven by insurance requirements.[98] Recognizing the lack of federal regulations regarding AVs, Florida is seeking a market-based solution by relying on insurance companies to set standards for AV use.[99]

In early 2016, NHTSA released an update to its 2013 preliminary policy statement. While this update does not provide any new substantive guidelines like those found in the 2013 statement, it does reflect NHTSA's commitment to remaining flexible and promises to "propose best-practice guidance to industry on establishing principles of safe operation for fully autonomous vehicles."[100] More policy guidance, and eventually regulations – in order to ensure consistent motor vehicle standards for AVs – was expected in summer 2016. Until such a time as more guidance is issued from the federal level, states seeking to craft regulatory frameworks should adhere to the principles described in the 2013 preliminary statement. Additionally, states will have to tackle issues not

[96] Ibid.
[97] Florida State Senate, HB 7027 (2016).
[98] "Interview with FL State Senator Brandes." supra note 39.
[99] Ibid.
[100] "National Highway Traffic Safety Administration Preliminary Statement of Policy Concerning Automated Vehicles". U.S. Department of Transportation, 30 May. 2013. Web. 8 Jan. 2016.

covered in the preliminary statement such as liability and insurance. Lawmakers should look to states like California and Nevada which currently offer the most comprehensive models of regulatory framework. As discussed in more detail below, lawmakers can also draw on other areas of highly regulated transportation modes when drafting AV legislation.

1.5 Industry Standards

Just as AV development will have an impact on new and existing regulations, it will influence industry standards. Unlike regulations and statutes, industry standards are not law, but rather are recommendations for best practices that have primarily been developed by manufacturers or other private industry trade groups, such as the Alliance of Automobile Manufacturers. They are not necessarily mandatory, but can be adopted by governing bodies to assist in developing regulations. There are many industry standards that apply to automobiles, as well as a number that pertain to connected technologies already in place. However, there are relatively few standards that cover instances in which both automobiles and AV technologies overlap. While some AV standards will result from the revision of existing industry standards pertaining to all automobiles, new standards may be needed to accommodate new AV technology. Because industry standards differ from government-mandated requirements, the responsibility will be on private organizations and industry trade groups, such as the International Organization for Standardization (ISO) and the Society of Automotive Engineers (SAE) International, to revise existing standards and help draft new ones.

1.5.1 Existing Industry Standards

Of the industry standards in place that involve AVs, almost all only pertain to Level 1 or 2 autonomous technology. For example, the ISO has certain industry standards that involve the performance requirements and test procedures for Full Speed Range Adaptive (FSRA) cruise control systems, which use on board sensors to maintain a consistent distance behind the car in front of the vehicle they are controlling.[101] These systems are currently classified under Level 1 AV technology. The SAE has also created standards that address adaptive cruise control systems, specifically for operating characteristics and user interface.[102] Both of these standards include original equipment and aftermarket sales, which is an important factor when creating new standards related to AVs. As the technology continues to develop, systems could be implemented in existing vehicles rather than solely in new vehicles.

While many existing industry standards may be applicable to fully-functional AVs, in certain areas, these standards may also be constrained by traditional definitions of automobiles that oftentimes may not necessarily pertain to AVs. One such area is functional safety, which is addressed by existing standards from the International Electrotechnical Commission (IEC) and ISO.[103] [104] In 2012 ISO created ISO 26262, which addresses safety issues that may arise from electrical system malfunctions. This standard was created with newer, more connected vehicles in mind,[105] but still exhibits some limitations due to the progression of AV technology. One such limitation is in internal hazard analysis, or the ability of a system to diagnose and prevent potential

[101] Intelligent Transport Systems -- Full Speed Range Adaptive Cruise Control (FSRA) Systems -- Performance Requirements and Test Procedures. ISO 22179:2009. Geneva, Switzerland: ISO
[102] Adaptive Cruise Control (ACC) Operating Characteristics and User Interface. SAE J2399_200312. Troy, Michigan: SAE
[103] Functional Safety. IEC 61508. London, United Kingdom: IEC
[104] Road vehicles -- Functional safety. ISO 26262. Geneva, Switzerland : ISO
[105] Lazarte, Maria. "High-tech Vehicles - High-tech ISO Safety Standards." ISO.com. International Organization for Standardization, 10 Jan. 2012. Web.

risks. A large component of functional safety and hazard analysis will be an important factor in the development of AV safety standards.[106] While these vehicles are still in the earlier stages of development, it is important for standardization organizations to consider future technological advances when developing AV industry standards.

While many automakers have their own connected technology that relays information on such diagnostics employed in each vehicle, the interoperability of these technologies may become increasingly important. Vehicles may need to communicate basic diagnostic information with each other in order to prevent accidents, just as a human driver may put their hazard lights on in the event of an equipment failure. Vehicle design standards must address the problem of hazard management, even if human operators do not maintain awareness of potential hazards. The issue of controllability is also an area in which functional safety standards may need to be revised. Existing standards examine whether drivers can take action to correct possible failures with the vehicle; these may become outdated, as human drivers will no longer be expected to remain in control of Level 4 AVs. This, in turn, may affect standards related to the physical specifications and interface of the car, such as dashboard, pedals, and even steering wheel.

In addition to standards developed by private sector organizations, those developed through governmental agencies will also need to be revised to reflect developments in AV technology. The most prominent safety standards developed by a government agency are the Federal Motor Vehicle Safety Standards (FMVSS), which are created by NHTSA. The FMVSS cover the design, construction and performance of motor vehicles, as well as such vehicles' safety-related components. In March 2016, the U.S. DOT released a report detailing portions of standards that may need to be changed to prevent barriers in the development of AVs.[107] The report centers on how the definition of the "driver" will likely have to be changed to reflect newer vehicles' autonomous driving capabilities. As stated earlier in this report, the current concept of a driver will become partially obsolete in some current regulations. Much like many current state regulations, industry standards may also need to be revised in order to allow for autonomous technology to continue developing without stifling or confusing standards. The FMVSS defines a driver as "the occupant of the motor vehicle seated immediately behind the steering control system."[108] This definition, however, assumes cars will have steering control systems, something that may become obsolete as vehicles gain more autonomous capabilities. In the meantime, the definition of a driver such as this one raises many interesting questions. Will cars developed for the purpose of full autonomy need steering wheels or other control systems? How will automobile design standards change as the idea of the driver changes? Questions such as these indicate just how much standards may change as widely accepted terms, such as the concept of a "driver," change with the rise of AVs. In its report, the U.S. DOT found that 33 FMVSS standards contained references to human drivers. While these references may not necessarily prevent AV development, the definition of a driver will most likely need to be changed to reflect changes in AV technology.

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[106] Nathan, Stuart. "Safety of Autonomous Vehicles." TheEngineer.com. The Engineer Magazine, 21 Jan. 2016. Web. (15 May 2016).
[107] Kim, Anita, et. Al. Review of Federal Motor Vehicle Safety Standards(FMVSS) for Automated Vehicles. Volpe National Transportation Systems Center, US Department of Transportation. (March 2016).
[108] Ibid

Along with references to drivers, FMVSS standards contain other, more specific aspects that may hinder the use of AVs. For example, standards regarding theft protection or rollaway protection are written with the assumption that only a human being will be available to physically start the car. Although some existing automobiles have recently developed remote starting capabilities, NHTSA interprets these capabilities the same way as if the driver was physically in the car inserting a key.[109] However, future driverless vehicles may be started not through a secure, two-way connection, but rather through a device using wireless networks or other multi-party connections. Additionally, FMVSS standards maintain that service brakes should be implemented through foot control, which may make it difficult for future driverless vehicles to meet the standard.

In addition to providing safe and secure vehicles, industry standards can benefit consumers by streamlining AV development. Without a single specification for development, different companies may produce cars that are not interoperable, largely negating a potential benefit of AVs. Automakers have recognized that providing uniform opportunities for research and development can allow AVs to develop faster and more effectively.[110] For example, automakers agreed to standardize the locations of pedals and shifters in the 1920s.[111] Current AV manufacturers may want to develop design standards for new technology in order to make AV operation consistent, which will it turn make them easier and safer to use. Additionally, stakeholders will need to work together to determine which technology allows for optimal development of AVs in order to avoid a situation in which different companies produce vehicles that need completely different infrastructure and cannot communicate with each other.

In addition to providing safe and secure vehicles, industry standards can benefit consumers by streamlining AV development.

1.5.2 Developing New Industry Standards

In addition to existing standards, organizations such as ISO and SAE International are beginning to develop standards that involve addressing potential new problems as AV technology continues to advance. For example, the problem of cyber security could become more significant as connected AVs become more commonplace. Some experts have raised concerns that AVs that are network-connected will be more vulnerable to security threats such as hackers. In 2015, hackers took control of a Jeep Cherokee while the vehicle was in operation in order to expose potential security lapses in new connected vehicles. While the 2014 Jeep Cherokee was not an autonomous vehicle, it employed Chrysler's Uconnect technology, an internet-connected feature, which allowed hackers to remotely control the vehicle. This incident caused Jeep's parent company, Fiat Chrysler Automobiles (FCA), to more closely examine potential security threats in new vehicles and issue a software update for 10 of their models.[112] Additionally, Sen. Ed Markey, D-Mass., and

[109] Ibid
[110] Thurlow, Andrew. "As Autonomous Vehicles Gain Traction, Industry Needs One Standard, Experts Urge." Automotive News. Automotive News, 25 Sept. 2013. Web. (02 June 2016.)
[111] Fierman, William. "This Is Why the 1920s Were the Golden Age of Car Design." Business Insider. Business Insider, Inc, 19 Apr. 2016. Web. (05 July 2016.)
[112] Levin, Doron. "More Disturbing Details about the Jeep Hack." Fortune.com. Fortune Magazine, 23 July 2015. Web. (20 May 2016).

Sen. Richard Blumenthal, D-Conn., introduced new legislation after the hack, urging NHTSA and the Federal Trade Commission to develop standards that better protect connected vehicles from cyber-attacks.[113] In order to maintain the security of new AVs, SAE International also created a new industry standard in November 2015 that provides guidelines for creating systems that preserve the security of automobiles[114] and prevent cyber-attacks.

The issue of privacy also will become increasingly relevant as AVs continue to develop. Some experts have raised concerns that the data collected from autonomous technology, such as common destinations or other personal information, will be used by companies as potential advertising information.[115] In 2014, the Government Accountability Office examined the data mining practices of 10 automotive companies and advised them on methods to help develop industry best practices regarding privacy in AVs.[116] Automakers have collected data on drivers before the development of AVs; however, now that advertising-based technology companies such as Google are entering the automotive industry, some organizations are wary that they may allow potential advertisement buyers to use consumer data.[117] SAE International has developed a Cybersecurity Guidebook for Cyber-Physical Vehicle Systems, which aims to develop new industry standards concerning autonomous vehicle privacy that are adaptable for future autonomous vehicle applications.[118] Despite the progress that is being made in the development of AV standards, they will likely need more changes as the technology itself continues to develop both in its ability and its application.

1.5.3 Conclusion

Much like state and federal regulations, many existing standards may need to be revised so as not to hinder the development of AVs and reduce confusion involving their operation. New, comprehensive standards that address many different aspects of AV technology may also need to be drafted. AVs will likely require guidance on elements that traditional cars do not, such as data privacy, security in communication between vehicles, or design specifications (such as button locations) for vehicles without human drivers. Industry standards can allow for interoperability and ease of use in vehicles that are produced by different manufacturers. Without new and revised standards, AVs could be manufactured in ways that are incompatible with each other, their environment, or the expectations of human users.

[113] Greenberg, Andy. "Senate Bill Seeks Standards For Cars' Defenses From Hackers." Wired.com. Conde Nast Digital, 21 July 2015. Web. (01 June 2016).
[114] "The World's First Standard on Automotive Cybersecurity." SAE International. Society of Automotive Engineers, 25 Nov. 2015. Web. (20 May 2016).
[115] Dorothy J. Glancy, Symposium, Privacy in Autonomous Vehicles, 52 Santa Clara L. Rev. 1171 (2012).
[116] Bigelow, Pete. "Car Companies Are Collecting Drivers' Location Data."Autoblog.com. Autoblog, 7 Jan. 2014. Web. (01 June 2016).
[117] Bigelow, Pete. "For Self-driving Cars, Privacy May Be Bigger Concern than Safety." Autoblog.com. Autoblog, 12 May 2015. Web. (01 June 2016).
[118] Cybersecurity Guidebook for Cyber-Physical Vehicle Systems. SAE J3061. Troy, Michigan: SAE

2 Safety Models for Comparison

2.1 Safety Management in Rail Transit, Motor Carrier, and Railroads

As technology becomes more responsible for vehicle operation than human drivers, there will be a profound shift in public expectations for motor vehicle safety. Any major incidents or deaths other than suicides are heavily scrutinized. As a result, there is a need to reconsider and strengthen the safety framework the public expects from automobile manufacturers and rideshare providers.

There are strong parallels between some gaps in the regulatory landscape surrounding AVs and the processes governing safety of other transportation modes in which few or no fatalities are expected. Safe deployment of AVs, like rail transit vehicles, railroads, commercial freight and coach vehicles, and other transportation modes, necessitates complex demands for standardization, vehicle operating rules, preventive and corrective maintenance, driver training, engineering requirements, hazard management, accident investigation, recordkeeping, and communication. Voids in existing safety requirements for AV technology can be informed by adaptable, highly reliable, pre-existing safety methodologies that have been pioneered in other transportation modes.

Widespread AV use will blur current perceptions between public and private transport. On-demand driverless vehicles will pick up passengers for either a private ride or to pick up and drop off other passengers on the way, functioning much like UberPool and Lyft Line ride-sharing services do today (only with a human driver). Fleet operation without the overhead cost of drivers may make AV availability so common that response time will be quick enough to obviate the need for even suburban residents to have one or more privately owned automobiles. Conceptually, even private trips begin to function more like public transportation, and as such it makes sense to examine practices in modes of common carriage for transferrable lessons.

In the following sections, elements from a variety of rail and motor vehicle regulations are grouped according to key themes, and implications for AV development are discussed. This comparison provides lessons for a variety of stakeholders on potential future regulatory requirements, communications needs, organizational changes, and technical challenges.

Federal Motor Carrier Safety Administration (FMCSA) regulations: These regulations, outlined in 49 Code of Federal Regulations (CFR) Parts 300-399, subject commercial motor carriers in the United States to a variety of safety requirements. Because they pertain to motor vehicles, parallels can be drawn between FMCSA regulations and the eventual landscape of regulations that will govern AV operation.

Federal Transit Administration (FTA) requirements: Public rail and bus transportation agencies are required by the federal government to develop and implement safety and security plans to manage their operations. The FTA works in concert with individual State Safety Oversight agencies to ensure that rail transit properties operate in compliance with all applicable standards as defined in their safety and security plans. These plans must include certain elements (i.e. training responsibilities, maintenance regimen) as described below. The aviation industry uses, and the rail transit industry is transitioning to, a new safety framework based on the Safety Management

Systems (SMS) approach. SMS emphasizes safety policy, safety risk management, safety assurance, and safety promotion at all organizational levels. These other modes of common carriage provide safety frameworks that should be considered in the AV industry, especially if the public's tolerance for accidents and fatalities decreases significantly due to expectations of technology performance.

Federal Railroad Administration (FRA) regulations: 40 CFR Parts 200-299 define specific regulations pertaining to freight and passenger railroads in the United States. These regulations establish safety rules and requirements, enforcement techniques, reporting relationships, and engineering standards for rail vehicles and structures. In an AV context, these regulations are useful in revealing how complex transportation systems involving major private companies and public entities can be managed and monitored to improve coordination and reduce safety risks nationwide. Rail vehicles, like AVs, must operate and interact on shared, interconnected networks that are developed and maintained by many different parties, making interoperability, consistency, and communication especially important.

2.1.1 Plans, Policies, and Organizational Structure

AV development, manufacturing, operation, and regulation involve a wide range of organizations, each with independent plans, operating procedures, and organizational structures optimized for certain purposes. While each of these organizations may independently specify safety goals and policies under an organization-specific management regime, most AV stakeholders have not coordinated to develop specific safety objectives and targets or detailed safety goals for the entire AV industry. Organizational responsibilities are also sometimes unclear, particularly when attempting to determine who is accountable for maintaining the safety and security of AV operating environments and assets. Without a concerted effort, both within these organizations and between them, to develop safety plans, align policies toward safety objectives, and optimize management of safety issues, AV stakeholders will face challenges in unifying safety goals and risk allowing unaddressed hazards to result in fatalities, injuries, and major property damage.

Federal and state regulators, fleet operators, manufacturers, and infrastructure providers each have a stake in development of plans, policies, and management structures to address safety issues. Regulators, for example, may seek to improve safety by encouraging consistency across the AV industry relative to how safety hazards and risks are managed. Manufacturers and operators, meanwhile, should systematically manage all hazards for which they could be found accountable, which could require strengthening existing management frameworks, setting new goals, and improving accountability. For infrastructure providers, safety plans and policies offer a framework to confirm agency responsibilities for safety and outline the standards that will be followed. With AV technology becoming more advanced, stakeholders throughout the industry should consider developing detailed safety plans with organization-specific goals, objectives, and milestones.

As with the safety plans maintained by rail transit agencies, a federal regulatory body could address the uncertainty and complexity inherent in AV development by requiring stakeholders to create and implement safety plans, and overseeing their compliance with such plans. Each plan and policy developed by AV stakeholders could clearly define the safety responsibilities of all members of the organization, and steps to be taken to ensure that employees of manufacturers, fleet operators, and infrastructure providers are aware of their responsibilities. Finally, as emphasized in the SMS framework, organizations involved in AV development must communicate to ensure that all professional staff members, including management and executives, are held accountable for safety during planning, design, manufacturing, operation, and maintenance activities. Notably, depending on the dominant vehicle ownership patterns, individual owners, lessors, or users of AVs may not feasibly be subjected to similar organizational requirements.

AV stakeholders should coordinate to ensure that vehicle, communications, software, and infrastructure technologies from different providers work smoothly together.

FRA regulations raise questions about the preparedness of AV stakeholders for management of the complex hazards arising out of AV operation for individual users as well as AV deployment on a fleet-wide scale. 49 CFR Part 244, for example, establishes requirements for integration of technologies, plans, procedures, and equipment as major railroad companies merge and consolidate. Similarly, AV manufacturers, software and hardware companies, maintenance and operations groups, parts suppliers, data providers, and infrastructure developers are likely to expand, merge, and/or cease to exist as the industry grows, yet there are no clear requirements for integration of safety activities or general vehicle functions during these major transitions. Positive Train Control (PTC) technology parameters established by FRA in 49 CFR Part 236 feature extensive requirements for interoperability between rail system components independent of the vendor, railway owner, or operator; the absence of similar requirements in the AV industry could introduce safety risks to major systems and impact operational performance as key players change.

2.1.2 Management of Change

Vehicle manufacturers already maintain internal programs for ensuring that engineering changes are documented, built with approved materials, tested for safety, and communicated to all relevant parties[119]. But unlike the existing automobile industry, the integrated yet diffuse landscape of AV technologies means that engineering changes to one component of vehicles or infrastructure may introduce unanticipated hazards to the system if not properly tested, documented, and communicated to other stakeholders. These topics pertain directly to vehicle manufacturers and fleet operators, but state and federal regulatory bodies may someday play a role in establishing requirements surrounding procurement, safety certification, system modification, and configuration management.

[119] Ström, Mikael. Redesign of the Engineering Change Process of a Supplier in the Automotive Industry. 2nd Nordic Conference on Product Lifecycle Management, 2009.

AV stakeholders should coordinate to ensure that vehicle, communications, software, and infrastructure technologies from different providers work smoothly together at all times, as each breakdown between vehicle systems could allow hazardous conditions to surface. In both the motor carrier and railroad industries, providers have worked with regulators to develop minimum engineering standards embodied in regulations for vehicles and equipment of all types, protecting the interoperability of each system and ensuring consistency in engineering. Regulations in 49 CFR Part 393 require that vehicles be equipped with lamps, reflectors, brakes, windows, fuel tanks, horns, exhaust systems, and other components of certain materials and dimensions. Similarly, FRA regulation 49 CFR Part 215 establishes minimum engineering standards for required rail vehicle safety equipment including brakes, brake-line air pressure monitoring devices, crash-resistant passenger rail vehicle compartments, and tank car walls and valves; these standards demonstrate successful collaboration between federal regulators and private industry to establish and ensure safety with safety-oriented design criteria. By taking similar steps, AV manufacturers and operators could ensure that safety-related components with consistent engineering parameters and materials are integrated throughout complex AV operating environments.

In the railroad industry, regulations such as 49 CFR Part 235 govern material modification to signal and communication systems, and require that rail infrastructure providers report major modifications made to safety-sensitive technological systems. Furthermore, this regulation establishes a mechanism for relief from specific engineering requirements, requiring that all deviations from industry norms are reviewed and documented. As with other aspects of passenger vehicle regulation, many vehicle infrastructure systems are controlled and regulated by individual states.

AV manufacturers and operators may, with the involvement of regulators, elect to implement minimum standards beyond those that already exist for testing, approval, and documentation of engineering changes, along with restricting the types of materials and suppliers that may be involved in such a change. Currently, automobile culture sometimes emphasizes customization, aftermarket modifications, and interoperability of parts, signifying that vehicle re-engineering does not present significant safety risks. In the rail transit industry, however, even minor engineering changes are tightly controlled, and are subjected to rigorous tests and monitoring before being applied across a transit vehicle fleet. Individuals could be prohibited from modifying AVs which are leased or rented under new ownership schemes, but could have more autonomy if vehicles are privately owned; each situation presents unique challenges for regulators seeking to control the configuration of vehicles. AV stakeholders may benefit from ensuring that similar processes control the flow of materials and the implementation of significant changes in the increasingly complex AV technological landscape.

2.1.3 Safety Data Analysis

Recent movements in the transportation safety field, particularly the adoption of the SMS framework in aviation and rail, point to the importance of data gathering, tracking, and trend analysis in combating safety hazards. AV developers currently collect safety data related to accidents, defects, and daily operations. But in most cases no external agency responsible for safety receives this information or has input on accident investigations. There is no overarching safety data analysis program or proactive, data-based hazard management framework specifically in the

AV industry, and the data collected by stakeholders is not uniform. State and federal regulators, researchers, vehicle manufacturers, fleet operators, and others stand to gain from data management and analysis techniques that can capture safety trends both large and small, allowing stakeholders to conduct trend analysis and mitigate hazards before a serious incident can occur. If the mass-market deployment of AVs incorporates widespread networked connectivity, this could facilitate more comprehensive data gathering by fleet operators, infrastructure owners, and other stakeholders.

Full adoption of data analysis best practices would involve centralized data gathering and trend analysis at a federal level. Currently, NHTSA maintains data on traffic fatalities, incident types, safety devices, and other key factors in safe motor vehicle operation. AV safety data could be gathered, analyzed, and disseminated through the NHTSA's existing mechanism. Other data gathering, such as the data collection that supports recalls for defective and noncompliant vehicles, is conducted largely by motor vehicle manufacturers with mandatory reporting to the federal government.[120] Under an enhanced data collection regime, after compiling safety statistics and identifying key issues, the responsible agency could distribute critical information to impacted manufacturers and operators. Furthermore, NHTSA or other federal regulators may deploy investigative teams in certain cases, set guidelines for local investigators, or require that vehicle and infrastructure providers employ staff investigators to ensure that adequate data is collected. Outside of formal requirements, all stakeholders may benefit from more extensive hazard tracking to inform corrective actions.

Many federal motor carrier and railroad regulations cover data gathering and analysis in detail. In one example, 49 CFR Part 379 mandates that motor carriers retain and preserve certain records related to operations for a defined period of time, often between 1 and 3 years, in part to ensure that historic safety-related data remains available. In another example, 49 CFR Part 225 explains how railroad incidents are classified, reported, and investigated, with specific incident-related data generated and shared during each phase. Though a great deal of data regarding AV safety is currently being generated by developers, the true value of such data, including trend-analysis-informed infrastructure designs, road designs, safety devices, training courses, and operating procedures, will remain unexplored until a proper system allows stakeholders to compile, share, and analyze safety data to inform future actions.

2.1.4 Operating Rules and Standards

Operating rules and standards, while varying substantially by mode, are sometimes established by transportation regulators to govern high-risk situations. FRA regulations 49 CFR Parts 222 and 224, for example, require locomotive operators to sound the horn at certain intersections or crossings to reduce the likelihood of a collision, and establish other parameters for intersection safety. Operating rules of this variety are typically based on a thorough knowledge of historic safety trends and incidents, and rule compliance checks are conducted by the transit agencies and sometimes oversight bodies to ensure rules are consistently followed. In the case of AVs, many operating rules for safe performance can be drawn from the existing standards that govern conventional vehicles.

[120] 49 C.F.R. § 573

As vehicle functions become increasingly automated and human operators cease to perform key functions, information on operating rules must be integrated into software and hardware components of vehicles and infrastructure. For example, AV standards may require visual or auditory warnings to be issued automatically in certain situations. The horn may automatically sound the moment a potential pedestrian collision is detected. Mixed operating environments with vehicles and pedestrians may require specific operating rules to accommodate hearing-, sight-, and mobility-impaired pedestrians with special auditory or visual signals on the AV exterior. AVs need programming to accommodate traffic laws and customs that vary by state or region, such as those governing right turns on red, U-turns, and school zones, as well as the varying signage and signals indicating such restrictions to motorists. Furthermore, AVs may require programming on desired response during emergency operations, such as following a minor accident; there is likely to be a transitional period during which AVs may not function as anticipated in emergencies and may need a human to take control. As new sensors, communications devices, and other components proliferate, automobiles must continue to behave according to uniform, widely-understood rules.

2.1.5 Training and Rules Compliance

Requirements dealing with AV training and programs to ensure compliance with applicable laws exist to a certain extent. For instance, states like Nevada and California require AV manufacturers to train operators on their technology and provide assurances to the state that their vehicles meet certain safety requirements. While this may suffice for testing of fully-autonomous vehicles in a corporate research context on a limited scale, stakeholders will need to address the issue of training as vehicles with autonomous features become available to the public. Currently, training and licensing requirements for traditional vehicles vary among states. This training generally requires a state administered test, and in some cases a certain level of instruction from a certified provider. While traditional vehicles vary in terms of features and capabilities, their operation is fairly consistent and uncomplicated. The operation and capabilities of AVs will be brand new and more complicated to people using them for the first time.

Due to a lack of federal regulations and the variations in AV technology and capabilities, aspects of training may begin to fall to manufacturers and retailers. Nevada is seeking to incorporate information on AV limitations and capabilities into their regulations. To this end, they are currently working with AV manufacturers to provide training to the consumer.[121] A parallel example exists in rail transit and people mover systems with automatic operation: the operators and remote controllers are required to complete a full training regime regardless of how much they may need to take control, if at all. Such a requirement could apply to manufacturers, fleet operators, retailers, and/or governments in order to ensure that "operators" are adequately trained in the operation of particular vehicles. FRA regulations also establish detailed requirements for training of operators, establishing mandatory minimum qualifications, certification requirements, and testing and licensing programs to validate training. FMCSA establishes standards for states to follow in development of state-level certification and licensing processes.

[121] "Interview with NV Department of Motor Vehicles Management Services & Programs Division Administrator." Telephone interview. 4 Mar. 2016.

Regarding compliance with applicable traffic laws, both California and Nevada hold that the human driver of the vehicle is responsible for adhering to traffic laws while the autonomous technology is activated.[122] California and Nevada define the "operator" as the person who causes the autonomous technology to engage. This raises a question for scenarios where ride-sharing services launch AV fleets for passenger operations: Would a passenger be responsible for adhering to traffic laws, or would this fall on the fleet operator? Using the above definition, this question depends on who engages the autonomous technology. Should it be determined that fleet operators are the ones who engage the technology, they will need to ensure that AVs can navigate roadways in accordance with applicable traffic laws. Here, a rules compliance requirement framework similar to that required by rail transit regulations can offer guidance. These regulations require a process to ensure compliance with rules and procedures having a safety impact, including identifying such rules, a method to assess the implementation of these rules and procedures, and assessing their supervision. This process would work differently from within rail transit, in which a human operator is being assessed. In addressing issues such as compliance with traffic laws, this type of requirement could apply to manufacturers, fleet operators, and others to implement a review process of spot checks that ensures autonomous technology is consistently performing as designed. This process would account for traffic laws applicable to a fleet's unique operating environment, evaluating compliance with these laws, and developing plans to address infrastructure or technology improvements needed to maintain compliance.

2.1.6 Audits and Inspections

As AVs become more prevalent, there will be an increased demand for inspection and maintenance of evolved vehicles and supporting infrastructure. Because AVs could become interoperable with other AVs and roadway infrastructure, existing regulations governing vehicle and infrastructure maintenance may be inadequate. In order to improve these processes in response to new technology, lawmakers at the state and federal level can draw lessons from existing transit regulations. Additionally, fleet operators and AV manufacturers could enhance internal processes by applying aspects of these regulations to organizational practices. Fleet operators and manufacturers could benefit from a framework that ensures vehicle maintenance, maintenance facilities, and quality control/assurance are updated to new recommendations and are functioning as designed. To this end, language from existing state and federal transit regulations can offer model frameworks.

Among other practices, these existing regulations require a process to identify "functions subject to review; a process for conducting reviews; and tracking the status of implemented recommendations…"[123] Such internal reviews ensure that all elements of maintenance processes, including mechanic training and quality assurance, are performing as intended. Industry standards and/or state regulations can apply similar benchmarks to ensure that a robust inspection program keeps AVs and support infrastructure in safe condition.

[122] Chapter 2, Section D, supra note 1.
[123] 49 C.F.R. §659.19(l).

2.1.7 Cybersecurity

AV technology presents an opportunity for malicious actors to cause harm to the public. While some states are taking steps to address AV security, security requirements appear to be missing from state regulations and NHTSA policy guidance. NHTSA has stated in its preliminary policy statement, that research has begun on "vehicle cybersecurity, with the goal of developing an initial baseline set of requirements."[124] To this end, NHTSA has identified the following topic areas within cybersecurity which will need to be examined: Security; Risks; Performance; Unintended Consequences; and Certification.[125]

State and federal rail transit regulations offer guidance on cybersecurity for AVs. These requirements include among others: a process for managing threats and vulnerabilities during operations, controls for passenger and employee security, and a process for internally reviewing security and compliance with the security program. While focusing on securing the physical environment of a transit system, these requirements address many of the topic areas identified by NHTSA. Through these regulations, transit agencies compile data on security measures currently in place, identify gaps that need to be addressed, and respond with actionable steps that strengthen the most vulnerable areas. Applying a similar regulatory regime to AVs would provide stakeholders with a framework for quantifying cybersecurity vulnerabilities, such as hacking, and a process to address gaps in cybersecurity measures.

2.1.8 Preliminary Hazard Analyses

Vehicle manufacturers should be expected to implement high standards of safety and system assurance throughout the planning, design, fabrication, testing, pre-operational, and operational system phases of all autonomous vehicle manufacturing and deployment projects. A Preliminary Hazard Analysis (PHA) is a systematic, high-level examination of the proposed design to identify hazards that may exist. The primary purpose of PHAs is to detect and define hazards that might arise from defects and fault conditions in the design and operation of a system or subsystem. PHAs help develop safety design requirements and establish the framework for subsequent safety analyses. Drawing on the expertise of subject matter experts from diverse disciplines, PHAs are qualitative examinations that identify potential hazards, assign hazard severity and probability categories, and list measures to reduce and/or eliminate the hazards.

To ensure safe and secure roadways, stakeholders should consider all possible hazards before large-scale AV deployment. A PHA is used in rail transit, for example, to identify potential risks resulting from failure of system elements, and determine their impact on the overall system, persons, property, and the environment. According to the Federal Transit Administration (FTA), the PHA "identifies critical areas, hazards and criteria being used, and considers hazardous components, interfaces, environmental constraints, as well as operating, maintenance, and emergency procedures."[126] Hazards and vulnerabilities that cannot be eliminated through physical

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[124] "National Highway Traffic Safety Administration Preliminary Statement of Policy Concerning Automated Vehicles". U.S. Department of Transportation, 30 May. 2013. Web. 8 Jan. 2016.
[125] Ibid
[126] Adduci, R. J., W. T. Hathaway, and L. J. Meadow. *Hazard Analysis Guidelines for Transit Projects*. Rep. FTA-MA-26-5005-00-01, Jan. 2000. Web.

measures can be controlled by providing safety warning strategies, written procedures or public education, and coordination among other AV stakeholders. In addition, adequate training and knowledge of rules for AV users will help prevent accidents and minimize hazards.

It is evident that state and local governments, as well as AV manufacturers in testing phases, are working to consider different scenarios and potential hazards when deploying new technology. In California, for example, manufacturers in testing are required to report and classify disengagements. Disengagements constitute any deactivation from autonomous mode when a failure of autonomous technology occurs or when the safe operation of the vehicle requires the test driver to take manual control of the vehicle.[127] Disengagements are a critical component of testing driver-vehicle interaction with current levels of technology, and are useful in determining the degree to which technology can be altered to reduce potential risks and identify problematic locations. Vehicle manufacturers and technology developers are clearly investing heavily in development and testing, but it is unknown what hazards they have identified and mitigated and which hazards remain unexplored and/or unmitigated. State and local governments should continue to work with AV manufacturers to perform analyses to better understand potential hazards and develop strategies to prevent incidents from occurring.

Appendix 4 details a sample PHA conducted in a roughly 25-square mile area in Santa Clara County, California. This simulated PHA identifies items that should be considered when assessing potential AV hazards, and how AV manufacturers or technology providers could be expected to show their due diligence in identifying and mitigating all potential hazards. Potential safety and security hazards are dependent upon a combination of pre-existing geographic, physical, and environmental conditions, that includes severe weather conditions, interactions with existing transit and pedestrians, speed restrictions, and unexpected road conditions. The benefit of conducting a PHA in a controlled setting is that results of the analysis on a sample area can be translated to surrounding areas with similar physical and natural characteristics throughout the country.

2.1.9 Conclusion

It is likely that the existing AV regulatory landscape could be significantly improved by incorporating standards or requirements from other regulatory frameworks regarding planning, data analysis, safety oversight, management of change, training, security, auditing, and preliminary hazard analyses. Some steps to improve AV safety and security could be taken immediately; others will become possible as relationships and responsibilities between manufacturers, fleet operators, users, infrastructure providers, regulators, and research bodies become clearer. State and federal agencies could collaborate with researchers and look to other modes to identify and resolve unaddressed gaps in safety regulations. Manufacturers, operators, and infrastructure providers, in turn, should acknowledge the unique challenges posed by AVs and infrastructure, and adapt both business processes and industry standards to account for new safety requirements.

[127] California Department of Motor Vehicles. Autonomous Vehicles in California. https://www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/testing Accessed June 7, 2016

2.2 Fleet Management and Regulatory Lessons

2.2.1 Motor Carrier and Car-Share Management

Fleet operators could be among the first members of the transportation industry to adopt AVs on a large scale. Fleet operators already employ practices outlining maintenance schedules and optimizing operational efficiency. Fleet telematics allow for the tracking of vehicles, in order to ensure their location, safe driving habits, and help diagnose any potential maintenance issues. Additionally, as more vehicles develop connected capabilities, remote vehicle disabling systems can prevent security threats from remote, central locations. Many existing practices such as these, as well as fleet management practices from trucking and interstate bus modes, can provide insight for helpful safety and security practices within AV fleet management.

In its report *Fleet Management Program — Productivity, Quality and Safety,* CNA Financial recommends that companies identify drivers' differing skill levels in order to properly assign them.[128] Before vehicles become completely autonomous, companies may want to distinguish between the abilities of human drivers versus driverless vehicles. Some routes or conditions may prove too challenging for early-stage AVs and should remain exclusively operated by human drivers. Companies may want to employ mechanics with expertise in the field of AVs in order to train drivers who could be doing inspections or diagnosing problems during stops on the vehicle's journey. As conventional vehicles transition to AVs, drivers' knowledge and training also will need to change during the transition from Level 1 to Level 4 automation. Training will remain an important element in fleet management, but the focus will change, requiring employees to better understand new technology so that they can assist in preventative and on-the-road maintenance of AVs, rather than operating the vehicles.

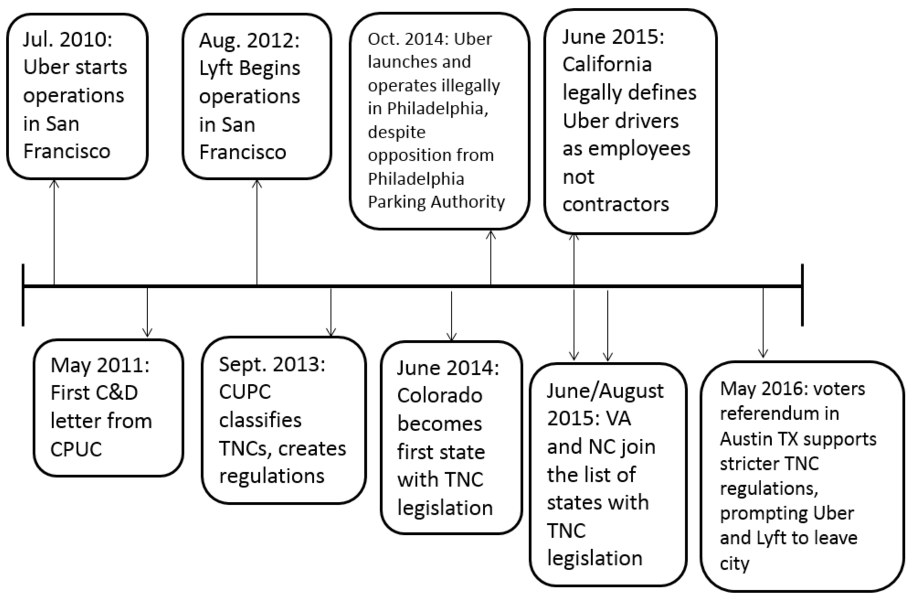
The current policies of car-sharing services offer additional aspects of fleet management and maintenance that will be relevant in AV fleets. Companies such as Zipcar still rely on human customers to inspect, refuel, and clean vehicles in between their periodic employee inspections. Zipcar uses a self-reporting maintenance system in which customers report any problems with the vehicle before or after use. Zipcar's vehicles are tracked using a physical "Zipcard" that all customers use to lock and unlock their vehicles.[129] The Zipcard indicates which customer was using the vehicle at a given time, allowing the company to determine who may have caused any damage or was responsible for a missing vehicle. These procedures provide examples for AV fleet operators but will likely need to be altered as higher-level AVs are integrated into car-sharing fleets. Because a driverless car will be able to pick up passengers at virtually any location, oftentimes no one will be able to inspect the vehicle prior to it driving to pick up the customer. Car-sharing services may want their vehicle storage facilities to be in locations that are monitored by staff members who can inspect cars between occasional trips. Additionally, persons who are not licensed drivers may eventually be able to use car-sharing services with driverless cars as current licensing regulations regarding AVs change. These passengers may not know what problems to look for in a vehicle, which could present a challenge for self-reporting inspection systems such as the one that Zipcar employs.

[128] Fleet Management Program — Productivity, Quality and Safety. CNA. Web. 2016.
[129] Ibid

2.2.2 Ride-sharing Services

Transportation network companies (TNCs) such as Uber and Lyft can provide a case study for instances in which technology outpaced regulations. Unlike with traditional taxicab services, there were initially few, if any, laws that regulated Uber, Lyft and other similar organizations. Although these services have left some markets due to local regulations,[130] they have also continued to operate illegally in certain jurisdictions.[131] While operating both legally and illegally, the TNCs are able to create their own policies concerning training, vehicle inspection, safety, and security, instead of following existing regulations.

UberCab was founded in March of 2009 and began operations in San Francisco during July 2010. In May 2011, however, the company received a cease and desist letter from the San Francisco Municipal Transportation Agency and California Public Utilities Commission (CPUC), claiming it was operating an unlicensed taxi service. This letter caused UberCab to change its name to Uber. In September 2013, the CPUC unanimously voted to lift sanctions imposed by previous cease and desist letters sent to Uber and Lyft (which started in August 2012). The commission also created the TNC classification for the services, which had previously been in the ride-sharing category.



In June 2014, Colorado became the first state to regulate TNCs through legislation.[132] As of May 2016, there were 33 states with legislation pertaining to TNCs,[133] although the topics of this legislation varied from insurance liability to employee status and testing. There are also some cities that, independent of state law, have outlawed ride-sharing services as they exist today or have remained in a state of flux, inviting protests and unequal practices between ridesharing and taxi services.

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130 http://www.npr.org/sections/thetwo-way/2016/05/09/477310339/uber-lyft-vow-to-stop-driving-in-austin-after-voters-affirm-regulations
131 http://www.bizjournals.com/philadelphia/news/2016/01/29/uber-ppa-taxi-industry-illegal-operate-philly.html
132 http://www.denverpost.com/2014/06/05/colorado-first-to-authorize-lyft-and-ubers-ridesharing-services/
133 http://www.pciaa.net/industry-issues/transportation-network-companies

Ensuring that drivers are properly licensed and in good legal standing has been a challenge for local governments, where taxi licensing and certification regulations are largely developed. Unlike traditional taxi services in which drivers are instructed on how to drive the vehicle and must pass a test certifying them as ready, TNCs employ regular drivers as contractors with no additional license required. TNCs have made some effort to address training internally, however. For example, Lyft has implemented a "mentor program" in which experienced Lyft drivers meet new drivers in order to train them on how to drive and inspect their vehicles; Uber offers a short video course to train their drivers.[134] The regulatory controversies are not limited to training or inspections, however, as much of the debate has centered on background checks. Taxi and limousine companies use fingerprinting during background checks, giving them access to drivers' Identity History Summaries, which provide information on past driving violations and convictions.[135] Many of the TNCs are regulated as for-hire drivers, rather than ride-sharing services, allowing them to only use names and Social Security numbers to perform background checks. This method has a much larger rate of failure than the fingerprinting method employed by taxis.[136] Both Uber and Lyft perform their background checks through a third-party service, which is not standardized, making it easier for certain drivers with prior traffic citations or convictions to drive for the services.[137] The regulatory delay in making TNCs legal and implementing associated safety requirements could reoccur with the advent of AVs. AVs remain unregulated in most states, and it will be more challenging to retroactively regulate them consistently once they are already on the road. Regulators should proactively develop comprehensive regulations regarding testing and operation in order to ensure that all AVs are safe for consumers to drive before, rather than after, they are already being operated.

Other challenges stemming from the unclear or more relaxed ride-sharing service regulations may also affect AVs. For example, under U.S. Occupational Safety and Health Administration (OSHA) regulations, taxi and limousine companies are required to publish data on safety incidents involving their drivers. Since TNC drivers are classified as subcontractors rather than employees, they are not covered by OSHA practices, and Uber and Lyft do not make their statistics on driver incidents public.[138] However, there may come a time when there are no taxis operated by humans, and existing safety data will be lost. Incidents involving single-person carriage by a third-party vehicle will enter the same category as those under Uber and Lyft and therefore be lost. Additionally, there are few regulations in place that require companies testing AVs to release data on accidents or incidents involving the vehicles they are testing.[139] Just as OSHA provides a best practice for taxi and limousine companies to report incidents involving employees, regulators could consider drafting standard procedures for reporting accidents and incidents in which employees are involved in AV testing.

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134 http://www.forbes.com/sites/ellenhuet/2014/10/08/uber-skimps-on-driver-training-then-charges-drivers-65-for-basic-driver-skills-course/#2ac412d06015

135 Daus, Matthew W. *One Standard For All. Criminal Background Checks for Taxicab, For-Hire, and Transportation Network Company (TNC) Drivers*. Rep. New York: City College of New York, 2015. Print. pp. 73-75

136 Ibid

137 http://archives.sfexaminer.com/sanfrancisco/lax-background-checks-compromise-safety-of-ride-hail-apps-study-says/Content?oid=2931669

138 http://www.wired.com/2016/03/uber-lyft-can-much-keep-drivers-safe/

139

Another aspect of ride-sharing regulation that is increasingly relevant to AVs is the security of customers' private information. Although Uber has maintained that the technology used through its service protects customer privacy and security, there have been breaches in security regarding customer data.[140] Contrary to company policy, there have been instances in which TNC drivers were able to access non-encrypted customer phone numbers, allowing them to contact former customers even after they had completed the ride. Additionally, reports have been published alleging that Uber had access to customers' locations in real time, and were able to track users' movements.[141] Concerns over privacy for riders of AVs have already been raised.[142] The tracking of users' movements through AVs would allow many companies access to customers' private data. Companies could theoretically pay automakers to reprogram AVs to take specific routes that direct passengers to their stores or services. A more serious implication of AV data use is the potential for blackmail or other coercion; customer journey information could be gathered and published. It is essential that regulators require protections for customer data as AVs develop, as security breaches possible with TNCs could be worse with AV data accessibility.

2.2.3 Positive Train Control

In contrast to ride-sharing services such as Uber and Lyft, the implementation of positive train control (PTC) in railroads reflects an instance in which an unfunded mandate, or a federal requirement without accompanying funds caused negative consequences for implementation. Using connected technology, PTC allows a train to receive information on the location and operating parameters of other trains, and therefore where and how fast it can safely travel. The technology prevents trains from making unsafe movements and helps to ensure trains do not collide. The U.S. Rail Safety Improvement Act of 2008 mandated that PTC technology be implemented on most of the United States railway system by 2015, including both passenger and freight rail systems. Although part of the 2008 law provided some funding to assist with the implementation of PTC, the overall costs of implementing such technology is very high. Large-scale resistance from railroad companies due to the high cost of implementation caused many systems to miss the 2015 deadline.[143] In October 2015, Congress passed a bill extending the deadline to 2018.[144]

Since the technology must be interoperable in order to be effective, some railroads needed to simultaneously upgrade the connected technology and connected infrastructure, causing the cost of implementation to rise. The Association of American Railroads (AAR) estimates that freight lines altogether will end up spending over $10 billion to integrate the connected technology into their systems.[145] Despite Congress providing some funds when the law was first enacted in 2008,

140 http://www.financierworldwide.com/ubers-privacy-violations-a-cautionary-tale-for-others/#.VzpVUhWDGko
141 http://www.wired.com/insights/2015/01/uber-privacy-woes-cautionary-tale/
142 http://www.autoblog.com/2015/05/12/self-driving-cars-privacy-bigger-concern-than-safety/
143 http://www.npr.org/2015/10/23/450833762/few-railroads-on-track-to-meet-end-of-year-safety-deadline
144 http://thehill.com/policy/transportation/257566-agreement-reached-on-automated-train-extension
145 *Positive Train Control*. Rep. American Association of Railroads, June 2016. Web. 6 July 2016.

in many cases funding for implementation has been provided from the railroads themselves, making it more difficult to meet the required deadlines.[146] This problem could become increasingly relevant to AV manufacturers. By placing the funding burden on AV manufacturers for infrastructure enhancements, as was done with railroad companies and PTC, regulators may unintentionally invite such companies to cut corners in the interest of saving costs. As PTC illustrates, retroactively equipping such vehicles or infrastructure with new technology can create challenges in costs as well as delays. Developing new standardized safety measures in the initial design of AV deployment may be more cost-efficient and effective than retrofitting existing vehicles and infrastructure.

While the cost of implementing an unfunded mandate may have been a large obstacle in implementing PTC, much of the resistance from railroad companies reflects a possible challenge in regulating AVs. Congress implemented the U.S. Rail Safety Improvement Act of 2008 in order to set firm deadlines for the implementation of PTC, but it has fallen short of the deadline once and is in danger of doing so again. Many railroads continue to lobby Congress in order to extend the implementation deadline two additional years, until 2020.[147] This resistance largely originates from the high cost of implementation, but also reflects the natural opposition to regulation that is present in many industries. The 2015 train derailment of Amtrak train 188 in Philadelphia, which killed eight passengers and injured over 200 more, could have been prevented by a functioning PTC system.[148] While the delay in PTC implementation is not necessarily the fault of regulators, lawmakers in the AV industry should view the accident as a reminder of the negative consequences that can stem from a lack of regulation. The negative consequences of the delay in PTC implementation may provide AV regulators with an incentive to mandate AV testing regulations in a proactive and measured manner. Like with PTC, AV infrastructure and technology must be interoperable across manufacturers, which will raise the costs as well as industry resistance if safety regulations come too late.

2.2.4 Past Safety Enhancements: Air Bags and Seat Belts

The implementation of air bags and seat belts show how new safety measures in automobiles can have a large positive impact on automotive safety, while also providing a valuable lesson in ways to ensure that such technology is properly implemented and its usage enforced. Both of these enhancements experienced large opposition from automakers. Additionally, problems in implementation caused some regulatory delay, especially in the case of air bags. Studying the history of these two enhancements provides some insight into manufacturer and consumer behavior regarding AV safety measures.

The Motor Vehicle Safety Standard, in 49 USC 301, was the first United States seat belt law. Enacted on January 1, 1968, the standard made it mandatory for all vehicles except for buses to

[146] http://www.npr.org/2015/10/23/450833762/few-railroads-on-track-to-meet-end-of-year-safety-deadline
[147] Milkulka, Justin. "Positive Train Control, Critical Rail Safety Improvement, Delayed for Decades." *DeSmogBlog*. DeSmog Blog, 16 Feb. 2016. Web. 06 July 2016.
[148] Graham, David A. "'Preventable Tragedy': Amtrak 188 and the Case for Positive Train Control." *The Atlantic*. Atlantic Media Company, 17 May 2016. Web. 06 July 2016.

have seat belts.[149] However, many automakers pushed back on this standard due to the potential of increased production costs, causing NHTSA to remove the seat belt standard in 1981. However, New York became the first state to make seat belts mandatory in December 1984. In the years following this change, many states began to see the potential of seat belts to save lives, culminating in 34 states making their use mandatory by 1989.[150] Although seat belts have had an overwhelmingly positive effect on the number of automobile fatalities, there were an estimated 32,300 automobile fatalities in 2015. One of the reasons for this is non-universal use by drivers and passengers. According to a recent study by the Center for Disease Control, one in seven people still do not use a seat belt when driving or riding as a passenger.[151] Recently, state lawmakers have tried to increase seat belt use, implementing primary enforcement strategies in which authorities can pull vehicles over and issue citations simply because occupants are not wearing seat belts. Today, 35 states and the District of Columbia have seat belt primary enforcement laws, helping increase the effectiveness of seat belt requirements.[152]

Although airbags could be implemented in vehicles as early as 1971, it was not until 1990 that the first legislation was enacted making them mandatory in all vehicles.[153] Many automakers led the movement in opposition to airbags, seeing their costs as too high and noting an overall public disinterest.[154] Another large reason for delay in airbag regulations was unforeseen challenges in implementation. When deployed, air bags were found to cause potential for serious injury to children and elderly passengers, shifting safety concerns to these groups.[155] This experience indicates the importance of comprehensive hazard assessment, and considering all possible impacts and stakeholders, before AV technology is available for sale to the public. For example, as AV technology continues to develop, regulators and developers should ensure that other groups, such as pedestrians or cyclists for example, are not negatively affected.

Oftentimes, when new technology enters the market, manufacturers naturally resist regulations that may hinder development. AVs will likely be no different. Automakers may naturally resist regulation of AV technology due to cost much like they did with air bags,[156] which may lead to implementation of a product that can still cause injuries and fatalities.

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[149] Part 571 - Federal Motor Vehicle Safety Standards: Crash Avoidance. National Highway Traffic Safety Administration, US Department of Transportation. Web. 2016.

[150] Williams, John Moore. "The Hotly Contested History of the Seat Belt." Blog.Esurance.com. Esurance, 23 May 2011. Web. 8 June 2016.

[151] Policy Impact: Seat belts. Issue brief. Center for Disease Control, Jan. 2011. Web. 14 May 2016.

[152] Policy Impact: Seat belts. Issue brief. Center for Disease Control, Jan. 2011. Web. 14 May 2016.

[153] Ni, Richard, and Jason Leung. Safety and Liability of Autonomous Vehicle Technologies. Rep. Massachusetts Institute of Technology, n.d. Web. 14 May 2016.

[154] "Cushioning the Blow: History of Automotive Airbags."Secondchancegarage.com. Second Chance Garage, n.d. Web. 08 June 2016.

[155] Ni, Richard, and Jason Leung. Safety and Liability of Autonomous Vehicle Technologies. Rep. Massachusetts Institute of Technology, n.d. Web. 14 May 2016.

[156] *"Middle Lane: Bags, Belts, and a Loophole". TIME. 1984-07-23. Archived from the original on October 29, 2010. Retrieved 2016-07-06.*

Other automobile technology has been made mandatory in recent years, such as anti-lock braking systems (ABS),[157] electronic stability control[158] and back-up cameras.[159] Like seatbelts and airbags, these technologies vary in their passive or active nature. Most vehicles allow drivers to turn off electronic stability control,[160] while ABS can only be disabled through tampering. AV manufacturers and regulators may want to work collaboratively to decide which new aspects of technology drivers should be able to disable and which aspects should remain absolutely mandatory. Regulators may also wish to incentivize not tampering with AV technology in new vehicles through warranty regulations. Many warranties are voided if a consumer tampers with a product; for example, tampering with an odometer can void a vehicle warranty.[161] Regulators may wish to ensure AV technology is being used properly by mandating that AV warranties be cancelled if evidence of tampering is found. Like other technological advances in the automotive industry, AVs can have a positive impact on safety. Regulators should study past advances in order to anticipate potential gaps in regulations and ensure the technology develops in a way that preserves consumer safety.

2.2.5 Conclusion

Many of the best practices for fleet management may provide new opportunities for procedures regarding fleets of AVs. However, some existing practices regarding vehicle inspections, driving history, and accident reporting may need to be revisited as the technology continues to develop. By ensuring that drivers, mechanics, and users are competent and trained on how to manage autonomous technology, companies with autonomous fleets can provide safe, reliable services.

TNCs can provide an example of why comprehensive regulations are necessary ahead of time for new technology such as AVs. Once AVs are on the road, it becomes more difficult to develop comprehensive rules regarding licensing, testing, security, and other important considerations. By not doing so, such regulators may allow for business practices that put consumers' safety and privacy at risk. Further, overlooking the costs and challenges of implementing new technology, as regulators did with PTC, may cause unforeseen challenges and litigation. Federal, state, and local governments should aim to work with vehicle manufacturers to develop comprehensive regulations and provide adequate infrastructure funding that allows technology to develop without compromising the safety and privacy of customers.

Although both airbags and seat belts provide a valuable lesson on the implementation of vehicular safety advancements, they also outline the different paths that regulation of AV technology could take. Seat belts were made mandatory, but their nature as an active restraint requires a human driver to physically put one on every time he or she rides in a car. Although by the early 1990s

[157] PARTS AND ACCESSORIES NECESSARY FOR SAFE OPERATION 63 FR 24465, May 4, 1998, as amended at 75 FR 57396, Sept. 21, 2010
[158] Federal Motor Vehicle Safety Standards; Electronic Stability Control Systems 49 CFR Parts 571 & 585
[159] Woodyard, Chris. "NHTSA to Require Backup Cameras on All Vehicles." *USA Today*. Gannett, 01 Apr. 2014. Web. 06 July 2016.
[160] Baruth, Jack. "Don't Touch That Button: Turning Off Stability Control Is Dumb and Dangerous." *Road & Track*. Hearst Communications Inc., 05 Apr. 2016. Web. 06 July 2016.
[161] Montoya, Ronald. "What Voids Your Vehicle's Warranty? -- Edmunds.com." *Edmunds*. Edmunds.com Inc., 25 Aug. 2009. Web. 06 July 2016.

automakers did develop automatic seatbelts, which were classified as a passive restraint, they were eventually eliminated from most models after regulators made the implementation of airbags mandatory for manufacturers. This effectively made their use mandatory for drivers and passengers, due to airbags being a passive restraint that is automatically deployed with no driver action. AVs will provide an opportunity for regulators to decide which path they would like the technology to follow. If regulators wish to make fully-autonomous vehicles mandatory for all drivers and passengers, they could require manufacturers to develop passive technology that does not allow humans to drive the car, except in special circumstances. However, if regulators want to treat technology the same way as seat belts, they could allow autonomous technology to be an active measure, only available if the user enables it, and retroactively punish drivers who were not using it at the time of an accident or traffic violation. Such questions will become more relevant as the technology continues to develop.

3 Findings and Recommendations

AV developers have already released early versions of their technology to the general public, and fully autonomous vehicles will come within years. The transition to this new type of transportation has presented many questions regarding safety requirements and logistics. However, lessons from other modes of transportation and past transportation enhancements can help stakeholders identify and address the safety and security gaps of AV deployment. It is unclear whether current infrastructure, regulations, and safety standards will keep pace with the release of AV technology to ensure safe, secure, efficient, and reliable transportation. What follows is a summary of current safety and security gaps in AV implementation identified in the preceding research, along with potential strategies, next steps, and areas of for further research to fill these gaps.

3.1 Safety Gaps and Solutions

Overall, AV technology development is outpacing the implementation of safety requirements.

Although developers are currently testing AVs on public streets and semi-autonomous technology has already been released to the public, only a handful of states have specific safety regulations for AVs. The implementation of laws requiring airbags, seat belts, and anti-lock braking systems – examples discussed earlier in this report – provide valuable lessons in ways to ensure that new technology is properly implemented. The nearly 20-year gap between airbag availability and the legal requirement shows how lobbying efforts can prevent the implementation of safety improvements and ensure they are not tested thoroughly for all potential hazards before release. Additionally, the proliferation ride-sharing highlights the difficulties that occur when regulations lag behind technology. Although these services have left a few markets due to local regulations, they have also continued to operate illegally in certain jurisdictions. They have created their own – sometimes less stringent and sometimes more stringent – policies for safety items. In other forms of transportation where individual users do not control operation, requirements are mandated by government agencies and standards are designed by industry trade groups to ensure a minimum level of safety assurance.

The regulatory landscape is becoming a patchwork of varying requirements that could hinder effective development of AV technology.

As this patchwork grows, it will be difficult for manufacturers to comply with so many competing regulations in different states. There may be more laws pertaining to human operation that will vary considerably between states. Compliance with these rules can be treated much the way rules vary now between states for laws such as cell phone usage or motorcycle helmets. Others may have a stifling effect on the ability for seamless interstate operation of fully autonomous vehicles; for these reasons, it will be important for states to enact safety laws within a range of reasonable variability for more continuous compliance by the public and manufacturers.

The interpretation of existing AV laws will become confusing as the semi-autonomous vehicles on the road now and in the near future escalate to a higher level of autonomy.

Some current vehicle models, such as the Tesla Model S, can receive a software update to gain newly released features. There are some state laws that prohibit autonomous vehicle use outside of testing, or have specific driver requirements. Existing vehicles with partially autonomous features do not appear to be affected by these regulations, but it is unclear whether there is a point where their use would be prohibited in certain states. It will be important to plan ahead for the safe use of AV technology on both existing vehicles and those produced in the future.

Most states do not follow NHTSA's guidance for numerous areas of AV safety assurance.

NHTSA recommends that states improve driver licensing programs and ensure that transitioning from autonomous operations to manual control is a seamless process; that AVs record data on the vehicle's operation including any crash data; and that installation of autonomous vehicle technology does not interfere with any federally required safety features. Only five jurisdictions have some level of regulation for AV use; the others may have testing occurring without any imposed safety requirements. California and Nevada have captured many of NHTSA's recommended items in their legislation, as discussed earlier in this report. NHTSA has publicly stated that it may launch regulations or additional guidance in July 2016, which would be helpful for states creating their own requirements. Lawmakers could also look to states like California and Nevada for examples of initial models of a regulatory framework, though even those frameworks will need to be revised as the technology quickly evolves.

Substantial infrastructure changes will have a long and costly implementation timeframe.

There are varying opinions on whether infrastructure must be improved to meet the needs of AVs, or whether AV technology will be refined so that it functions completely with existing streets. For example, there is currently no threshold for what defines pavement markings or signage that is in too poor a condition to be detected by AV sensors. Further, already cash-strapped states and municipalities are currently unlikely to accept the financial burden of widespread infrastructure improvements without external funding. There will likely be a need for new financial models and innovative financing tools for infrastructure improvements and ongoing maintenance. An AV industry trade group should reach a consensus about the level to which existing infrastructure needs to be upgraded, if at all, and then discuss with departments of transportation whether development of dedicated roads with upgraded AV infrastructure needs to occur. Infrastructure providers must collaborate with manufacturers, regulators, researchers, and operators to develop a common understanding of anticipated timeframes and costs for infrastructure deployment.

It is important to differentiate between safety-critical infrastructure – which is necessary for safe AV operation – and infrastructure that simply enhances AV capabilities.

Communication technologies for a connected AV deployment are currently in operation on roads today, but few specific plans exist to integrate their functions and maximize their benefits through investment in infrastructure. Further, while some of this infrastructure is important, much of it is not as safety-critical as non-communications infrastructure needs such as consistent pavement marking treatments and signage. The needs versus enhancements should be catalogued in order to prioritize public and/or private investment.

There is not a specific measure of assurance that the general public and local governments will receive from AV manufacturers demonstrating that all possible hazards have been considered while in the testing phase.

It does not appear that manufacturers have yet begun to address the challenge of autonomous driving in exigent conditions, including poor weather. Snow, in particular, hides many of the cues that AV technology uses for navigation as well as deviation from typical braking scenarios due to decreased friction. Once developers have found a workaround for such challenges, they should be required to prove the safety of the workaround through a testing regimen. Hazards and vulnerabilities that cannot be eliminated through physical measures could be controlled by providing safety devices and warning strategies, written operating, emergency and maintenance procedures, and adequate training and knowledge of rules for AV users to help prevent the occurrence of accidents and minimize security vulnerabilities. Preliminary hazard analyses of some scale could be a prerequisite to determine the needs for particular cities and states, or simply to show the manufacturers have done their homework, before AV implementation is realized on a large scale.

There are no set expectations for driver involvement or engagement in current and future phases of AV technology.

Until then, drivers may be unaware of how to use AV mode safely. For example, a YouTube video surfaced in June 2016 of a driver asleep while his semi-autonomous vehicle cruised along a highway; this and other unsafe behaviors can be expected and are evident in other publicly available videos as well. At some point, humans cannot be reasonably expected to pay attention if the vehicle does not require their input after a significant amount of time. Safety policy decisions will need to be made regarding the point at which it is acceptable for the driver to, for example, take a phone call or send a text message, or to be intoxicated and have the AV drive them safely home, or where the passengers can be seated. There will eventually be dissonance between what is required and what can reasonably be expected of human behavior. As learned from past cases, technology outpacing regulation can have undesired effects. In this case, people could become more likely to undertake prohibited behaviors if they feel it is safe. Expectations need to be set and made clear to all users as the technology progresses. Regardless of whether such behaviors are permitted, there could be a simultaneous AV industry expenditure on a public education campaign and/or training for consumers regarding what is safe and legal, especially if states have different and confusing requirements regarding these elements. Industry stakeholders and regulators must conduct research to create realistic, logical, and enforceable expectations for driver engagement that can feasibly be implemented.

NHTSA policy guidance is written from a perspective that envisions operations limited to testing purposes only, and assumes the driver is an agent of the manufacturer or testing institution rather than a private consumer.

As such, the guidance offers little on driver limitations. Driver use of AVs has arrived and will continue to escalate more quickly than governments have imagined, and there could be a gap between deployment and the intentions of NHTSA. States could take a cautious approach during this phase where there will be a number of unknown factors involving human driving behavior. Such an approach may employ requirements for specially licensed or trained drivers, as some states currently require.

Industry standards do not yet address AV technology beyond Level 1 or 2 (semi-autonomous) vehicles and are becoming obsolete.

One issue impacting standards and motor vehicle laws is that the public will be presented with a paradigm shift on who or what is classified as the driver. Will the driver continue to be the person in the vehicle, or will the autonomous technology become the driver? The United States Department of Transportation released a report detailing portions of standards that may need to be changed to prevent barriers to the development of AVs. The same issue is applicable to state motor vehicle laws regarding drivers. Industry organizations may want to work with NHTSA to ensure that guidance such as the Federal Motor Vehicles Safety Standards are updated to reflect the current state of AV technology. It would also benefit AV developers to band together and develop standards that meet or exceed emerging regulations at the state level. Industry standards may bring some cohesiveness and continuity to the AV marketplace, since jurisdictions could in many cases defer to adopting standards as their requirements.

Engineering changes to one component of vehicles or infrastructure may introduce unanticipated hazards to the system if not properly tested, documented, and communicated to other stakeholders through a change management process.

AV manufacturers and industry guidelines can borrow from safety certification and change management concepts more common to other modes of transportation. Regulations from agencies that oversee other modes of transportation, such as FRA, FTA, and FMCSA, provide requirements for configuration management when infrastructure developers expand, change, merge, and/or cease to exist, in order to ensure engineering changes are vetted through a cycle of safety review and approval by relevant parties. A more rigorous management of chance process will be needed as slight alterations to software and communications components can have intended negative consequences. AV stakeholders could coordinate to ensure that vehicle, communication, software, and infrastructure technologies from different providers work smoothly together at all times in order to prevent an unintended hazard, including in the case of alteration or upgrades.

There is no consistent method for notifying manufacturers or safety authorities regarding accidents that may have been caused by use of AV technology.

Furthermore, there are no consistent definitions regarding critical accident-related data for tracking and analysis of incident trends. In any mode of common carriage where a person’s transportation safety is placed in the hands of someone else (in this case, a computer), they expect zero tolerance for potential injuries and deaths. Nearly any incident results in lawsuits at a minimum, and tightened safety regulation or temporary decommissioning at a maximum. Several studies have conflicting results about self-driving crash rates. In order to identify potential hazards and prevent futures incidents from occurring, federal or state governments could consider working with AV manufacturers to develop a uniform method for accident/incident reporting and investigation. Regulators could consider requiring AV manufacturers to develop corrective action plans as a result of safety deficiencies identified during investigations.

Law enforcement procedures for accident investigation and motorist rule compliance will become partially obsolete; new methods will need to be developed.

When an accident occurs, fault is typically assigned to one or none of the parties involved, and one party may receive a citation. However, the involvement of an AV in an accident may require a more detailed and possibly technical investigation, and at the very least a way to assign fault to the technology itself rather than the human occupants. States will also need to develop new motor vehicle laws relevant to AV operation that can be practically enforced, and the methods for detecting or enforcing them. It will important for compliance to be high in order for AVs to function as designed.

3.2 Summary of Recommended Actions

The following is a concise list of recommendations presented above that specific stakeholders should implement for a safe, coordinated transition to AVs:

1. Government agencies should work with trade groups to design and mandate detailed, comprehensive safety requirements that are maintained by a group that can adapt requirements in sync with the rapid changes to the industry.
2. Regulators should plan ahead for the safe deployment of AV technologies on both existing, semi-autonomous vehicles and fully autonomous vehicles produced in the future.
3. NHTSA policy guidance should be adapted for AV operating environments other than testing and should extend to requirements for individual private consumers as well as manufacturers or testing agency personnel.
4. The federal government should craft motor vehicle laws for AV operation that reflect the increasing technical complexity of AVs, yet remain enforceable, and consider how enforcement campaigns could be modified to promote compliance with these laws.
5. Absent federal regulation, states should enhance regulations to allow safe use of AVs but attempt to minimize variability across jurisdictions to facilitate compliance by the public and manufacturers.
6. States should improve driver licensing programs to incorporate training on transitioning from autonomous operations to manual control in vehicles that are not fully autonomous.
7. Regulators should consider requiring AV stakeholders to adopt plans and policies which govern organizational responsibilities and management of safety and security issues.
8. Regulators and manufacturers should agree to a minimum safe level of operator engagement during AV use, and consider a consumer training campaign regarding these requirements.
9. Regulators and manufacturers should ensure that AVs record data on the vehicle's operation, including any crash data.
10. Regulators should ensure that installation of autonomous vehicle technology does not interfere with any federally-required safety features.
11. Industry organizations and NHTSA should ensure that guidance including the Federal Motor Vehicles Safety Standards is updated to reflect the current state of AV technology.
12. AV manufacturers and their industry trade groups should consider developing industry standards that meet or exceed emerging regulations at the state level.
13. AV trade groups should evaluate infrastructure upgrades required for AV operation and collaborate with departments of transportation if development of dedicated roads with upgraded AV infrastructure needs to occur.

14. Infrastructure providers should work with manufacturers, regulators, researchers, and operators to develop a common understanding of anticipated timeframes and costs for infrastructure deployment.
15. Regulators should require manufacturers to evaluate safety and security hazards during testing according to uniform standards, and demonstrate that hazards have been eliminated or mitigated before vehicles enter service.
16. Regulators should require stakeholders to develop change management processes covering vehicles, infrastructure, communications technology, and software.
17. Regulators should work with AV manufacturers to develop uniform accident/incident reporting processes, investigation requirements, and corrective actions steps for safety deficiencies.

Transportation Resource Associates, Inc.

Transportation Resource Associates, Inc. (TRA) is a premier specialty consulting firm built to serve the transportation industry with unparalleled expertise, extensive experience and practical work products. Founded in 1990 by President and CEO Kenneth Korach, TRA offers technical and management consulting services in the areas of multimodal transit operations, transit maintenance program planning, capital investment programming, asset management, and system safety and security. TRA is widely recognized in the world of public transit, and is one of the industry's most trusted consulting firms, having conducted work related to nearly every major transit agency and numerous smaller providers in North America. TRA is the nation's top consultant in State Safety Oversight of rail transit agencies. TRA also consults directly for bus, rail, and commuter agencies as well as public and private infrastructure companies of all sizes. TRA's consulting team has a range of multi-disciplinary backgrounds and multimodal transit experience. The firm's unique combination of expertise serves the individual needs of each client with innovative, effective, and efficient consulting services. TRA is also the parent company of IndustrySafe, a web-based safety management software product that enables organizations to track, manage, and comply with environmental, health, and safety regulations.

For more information, contact:

James Young, Project Manager
Phone: 215-546-9110
E-mail: TRA-AV@traonline.com
1608 Walnut Street, Suite 1602
Philadelphia, PA 19103
www.traonline.com

4 Appendices

4.1 Appendix 1: AV Development and Deployment Summary Tables

Table 1 – AV Research and Development Leaders & Collaborations

Source: Driverless Car Market Watch – Key Players. Driverless-future.com 2016.

R&D Initiative	Location	Description
Google Driverless Car Project	United States	Headed by Chris Urmson, this project now operates more than 20 AVs which accumulate about 10.000km of urban autonomous driving per week in Mountain View (as of 5/2015). The project began in 2009 under the direction of DARPA Grand Challenge winner Sebastian Thrun. Another key member of the project is Anthony Levandowski, who has built a self-driving motorcycle.
GM-Carnegie Mellon Autonomous Driving Collaborative Research Lab	United States	Headed by Raj Rajkumar who won the 2007 Urban Driving Grand Challenge with the 'Boss' autonomous car based on a modified Chevy Tahoe. The collaborative research lab was established in 2008.
Uber Advanced Technologies Center	United States	Located in Pittsburgh, near the Carnegie Mellon University Campus, this center focuses on research in the areas of AVs, vehicle safety technologies and mapping. This includes a collaboration with CMU's National Robotics Engineering Center (NREC).

R&D Initiative	Location	Description
University of Berlin	Germany	The Autonomous car team is headed by Raúl Rojas. The team has sent a prototype to the 2007 Urban Grand Challenge (where it reached the semi-finals) and currently tests the "Made in Germany" driverless vehicle public on roads in Germany (it has obtained an official test license). The team has developed an autonomous car taxi service and also has demonstrated an early brain-computer interface for steering a car.
Technical University of Braunschweig	Germany	Participated in Darpa Urban Challenge. Under the direction of Markus Maurer, has successfully operated an autonomous Volkswagen Passat in the city of Braunschweig in 2010 (Project: Stadpilot).
Karlsruhe Institute of Technology	Germany	Participated in Urban Challenge 2005 and 2007. Headed by Christoph Stiller. Cooperated with Daimler in 2013 to have a Mercedes drive autonomously more than 100km through Southern Germany using only close-to-market sensors (no LIDAR). Also involved in localization for autonomous railways. A spinoff (Atlatec) focuses on vision-based 3D mapping and map-based localization.
Universität der Bundeswehr	Germany	Develops MuCAR-3, a modified Volkswagen Toureg. Headed by Hans-Joachim Wünsche. Repeated participation in the European Land Robot Trials (see an example video). Focus on expectation-based perception (4D, Saccadic vision) and off-road navigation and driving.
VisLab, University of Parma	Italy	VisLab is a spin-off of the University of Parma headed by Alberto Broggi and has been involved in automated vehicles research for more than 15 years. Instead of using LIDAR sensors, his approach is based on computer vision. In July 2013 his BRAiVE prototype successfully navigated rural, urban and freeway traffic in Parma, Italy. In 2010 his team completed a 13000 km journey with two AVs from Italy to China. Supplied vision technology to Oshkosh automated vehicle that participated in the Grand Challenge.

R&D Initiative	Location	Description
Oxford Mobile Robotics Group	United Kingdom	Headed by Paul Newmann, the group develops the Wildcat autonomous vehicle. Key research areas are large scale navigation and scene understanding, going far beyond traditional algorithms for simultaneous localization and mapping (SLAM). The group is also involved in the Europa project to build an autonomous robotic pedestrian assistant.
INRIA IMARA	France	French research group. Key projects: Cybercar and cybercars2. Currently involved in LaRA project, which looks at intelligent transport systems.
Easymile	France	Joint venture between a Ligier Group, a vehicle manufacturer, and Robosoft, a robotics software company. Their main product is a driverless shuttle, the EZ-10, which is tested in several European cities as part of the Citymobil2 project.
NavyaTechnology	France	Autonomous solution provider (Formerly: Induct). Offers a driverless shuttle called ‘Navya’ Currently trialed in Greenwich, UK.
Griffith University, Intelligent Control Systems Lab	Australia	This lab is headed by Ljubo Vlacic. Research in cooperative driverless vehicles and an autonomous research platform.
Singapore-MIT-Alliance for Research and Technology	Singapore	Aims to develop new paradigms for urban mobility. The future urban mobility group experiments with autonomous golf carts to improve last mile transportation and builds simulation models for predicting mobility demands in transportation networks.
Electronics and Telecommunications Research Institute (ETRI)	Korea	The institute works on various aspects of robot/cognitive convergence, including navigation, 3D depth sensing and is working on an autonomous vehicle shuttle for outdoor environments (ESTRO).
RobotTaxi	Japan	A joint venture of ZMP and DeNA which aims to develop an autonomous taxi service. RobotTaxi wants to have the first autonomous taxis available for the Tokyo Olympics in 2020.

R&D Initiative	Location	Description
Autonomous car research	China	It is difficult to get detailed information about the autonomous car prototypes on China. But China Daily has reported highway trials auf driverless car prototypes involving the Military Transportation University (Tianjin) (120 km highway drive in 2012) and the National University of Defense (Beijing) (286 km highway drive in 2011). An article claims that the National University of Defense plans to cooperate with China's First Auto Works to bring the technology into commercial vehicles. The National Natural Science Foundation of China plans a longer 2400km drive from Beijing to Shenzhen in 2015.
Yutong Bus Company	China	Develops a self-driving city bus. In September 2015 their prototype autonomous bus completed a 32km trip in regular traffic on an intercity road, including lane changes, over-taking etc.
Autonomous Solutions, Inc. (ASI)	United States	Offers a vehicle automation kit which can be used to convert traditional vehicles for autonomous operation. ASI has equipped many types of vehicles including mining trucks for autonomous operation.

4.2 Appendix 2: AV Testing Accidents and Incidents

Table 2 – List of Reported AV Testing Accidents/Incidents in California[162]
California DMV – July 2016

Date	Vehicle Testing Company	Time of Occurrence	Location	Vehicles Involved	AV Moving/ Stopped in Traffic	Injuries	Accident Detail - Description
7/15/2016	Google	15:26	Cuesta Drive and Springer Road, Los Altos	2	AV Stopped in Traffic	0	A Google AV operating in autonomous mode travelling westbound on Cuesta Drive in Lost Altos was involved in an accident. The Google AV was stopped at the stop sign at the intersection of Cuesta Drive and Springer Road when a vehicle approaching from behind in the same lane collided with the Google AV. The other vehicle was travelling at approximately 7 mph when it struck the Google AV. There were no injuries reported at the scene.
5/10/2016	Nissan	15:00	101 Highway South Bound, Sunnyvale	2	AV Moving	0	The AV Driver was on Highway 101 South between Nasa Ames Research Center and Exit 237. The AV was in conventional mode and the car travelling directly ahead of the subject vehicle stopped suddenly. The AV subject vehicle made contact with the car in front of it at low speed. No injuries were reported by either vehicle occupant.
4/28/2016	Google	17:35	Nita Avenue and San Antonio Road, Palo Alto	2	AV Stopped in Traffic	0	The AV was travelling westbound on Anita Avenue in autonomous mode. The AV was stopped at a red light at the intersection of San Antonio Road. As it was making a right turn, the AV proceeded to move forward to check traffic. As it approached, it came to a stop, and the vehicle behind the AV collided with the rear bumper.
4/7/2016	Google	AM	Bryant Street at Oregon Expressway, Palo Alto	2	AV Stopped in Traffic	0	The AV was travelling southbound on Bryant Street in autonomous mode in the far right lane. The AV stopped at a red signal and a vehicle attempted to pass. The mirror of the vehicle made slight contact with the side of the AV.

162 Report of Traffic Accident Involving an Autonomous Vehicle (OL 316), California Department of Motor Vehicles. 2016. https://www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/autonomousveh_ol316

Date	Vehicle Testing Company	Time of Occurrence	Location	Vehicles Involved	AV Moving/ Stopped in Traffic	Injuries	Accident Detail - Description
2/14/2016	Google	PM	El Camino Real and Castro Street	2	AV Moving	0	The AV was travelling eastbound in autonomous mode in the far right lane. The AV had to go around sand bags that were positioned over a storm drain, and returned to the center lane. At that moment a transit bus was approaching and did not react. The AV made contact with the bus and was traveling less than 2mph.
1/8/2016	Cruise Automation	13:41	7th and Bryant, SF	2	AV Moving	0	The AV was travelling north at approximately 20 MPH in the right lane of 7th Street. The AV began moving within its lane to the left, and then began correcting to the right, at which point the driver decided to take over manual control. The operator did not change the path of the AV and collided with an unoccupied conventional vehicle that was parked on 7th Street, approximately 20 feet before the intersection with Bryant Street.
11/2/2015	Google	14:30	Clark Ave. and El Camino Rd., Mountain View	2	AV Stopped in Traffic	0	A Google AV in autonomous mode travelling northbound on Clark Avenue was involved in an accident. As the AV approached the intersection of Clark Avenue and El Camino it activated its right turn signal. The AV came to a complete stop at a red traffic signal and began to slowly advance to get a better view of cross traffic approaching from the left. A vehicle from behind stopped and then rolled forward and collided with the rear bumper of the AV. The approximate speed of the conventional vehicle was 4 MPH. The speed of the AV was below 1 MPH at the time of impact.
8/20/2015	Google	9:36	Shoreline Blvd. and High School Way, Mountain View	2	AV Moving	0	A Google AV in autonomous mode travelling northbound on Shoreline Blvd was involved in an accident. As the AV approached the intersection, a pedestrian began to cross the northbound lanes of Shoreline Blvd. The AV slowed to yield as it approached the crosswalk, and out of caution, the AV test driver disengaged the autonomous technology and took control of the vehicle. A vehicle in the process of changing lanes from lane one into lane two and approaching from the rear struck the AV. The AV was travelling 5 MPH at the

Date	Vehicle Testing Company	Time of Occurrence	Location	Vehicles Involved	AV Moving/ Stopped in Traffic	Injuries	Accident Detail - Description
							time of the impact. The conventional vehicle was traveling approximately 10 MPH.
7/1/2015	Google	17:16	Grant Rd., Mountain View	2	AV Stopped in Traffic	4	A Google AV was travelling northbound on Grant Rd. approaching the intersection of Phyliss Ave. and Martens. In autonomous mode. The two vehicles in front of the AV, the AV, and a vehicle behind the AV were all travelling at a steady speed of 15 MP. As the vehicles approached stopped traffic the two vehicles in front of the AV and the AV decelerated and stopped with adequate and similar stopping distances. About 1 second later, the vehicle approaching from the rear struck the AV at approximately 17 MPH. The driver and two passengers in the AV reported whip lash and were taken to the hospital. The driver of the conventional vehicle reported minor neck and back pain.
6/18/2015	Google	11:15	California and Bryant, Mountain View	2	AV Stopped in Traffic	0	A Google AV was travelling northbound on California St. in autonomous mode and was stopped at a red light in the straight-only lane. The lane to the left of the AV was a left-only lane. When the left turn signal appeared, the vehicle behind the AV began to move forward and collided with the rear bumper of the AV. The other vehicle was travelling about 5 MPH at the time of impact.
6/4/2015	Google	8:54	California Ave. and Rengstorff Ave, Mountain View	2	AV Stopped in Traffic	0	A Google AV was travelling westbound in autonomous mode and was stopped behind traffic at a red light at the intersection of California St. and Rengstorff Ave. A vehicle approaching from behind collided with the rear bumper of the AV. The AV was stopped for approximately 17 seconds prior to the collision. The approximate speed of the other vehicle at the time of impact was < 1 MPH.

Date	Vehicle Testing Company	Time of Occurrence	Location	Vehicles Involved	AV Moving/ Stopped in Traffic	Injuries	Accident Detail - Description
5/30/2015	Google	12:00	720 Shoreline Blvd., Mountain View	2	AV Stopped in Traffic	0	A Google AV was travelling southbound on Shoreline Blvd in autonomous mode and was stopped behind traffic at a red traffic light. A conventional vehicle approaching from behind collided with the rear bumper and sensor of the AV. The approximate speed of the conventional vehicle at the time of impact was 1 MPH.
4/27/2015	Google	16:27	California St. and Shoreline Blvd.	2	AV Stopped in Traffic	0	A Google AV in autonomous mode heading southbound on California St. was stopped at a red light in the right lane. A conventional vehicle immediately behind the AV attempted to pass the AV on its right in the bike lane to make a right turn. While passing the AV, the vehicle's side mirror brushed on of the AV's sensors located on the passenger's side of the AV.
4/7/2015	Google	n/a	Castro and El Camino	2	AV Moving	0	A Google AV was travelling northbound on Castro St. and making a right turn onto El Camino eastbound. The AV was operating in autonomous mode. The AV came to a complete stop at the intersection for a red light. The AV proceeded to make a right turn by creeping forward to obtain a better view of oncoming traffic. The AV noticed a vehicle moving eastbound and came to a stop, and the vehicle behind failed to break sufficiently and struck the AV's bumper at approximately 5 MPH.
2/26/2015	Google	n/a	El Camino Rd. and View St.	2	AV Moving	0	A Google AV was traveling northbound on El Camino Rd. in autonomous mode when a conventional vehicle failed to come to a stop at the stop-sign at the intersection and struck the right rear quarter panel and wheel of the AV. The AV began applying the brakes due to the detection of the conventional vehicle's speed and trajectory and the driver disengaged autonomous mode.
10/14/2014	Delphi	19:27	San Antonio Rd.	2	AV Stopped in Traffic	Not reported	In conventional mode, the Delphi AV transitioned from one lane to another and waited in the lane pocket for traffic to clear. A conventional vehicle bypassed a traffic island and hit the AV travelling at approximately 25 - 30 MPH.

Road Vehicle Accident Types (ANSI D16.1-2007)[163]

1.1 Overturning accident: An overturning accident is a road vehicle accident in which the first harmful event is the overturning of a road vehicle.

1.2 Collision accident: A collision accident is a road vehicle accident other than an overturning accident in which the first harmful event is a collision of a road vehicle in-transport with another road vehicle, other property or pedestrians.

1.3 Non-collision accident: A non-collision accident is any road vehicle accident other than a collision accident.

Inclusions:

- Overturning accident (See 1.1)
- Jackknife accident (See 1.4)
- Accidental poisoning from carbon monoxide generated by a road vehicle in-transport
- Breakage of any part of a road vehicle in-transport, resulting in injury or in further property damage
- Explosion of any part of a road vehicle in-transport
- Fire starting in a road vehicle in-transport
- Fall or jump from a road vehicle in-transport
- Occupant hit by an object in, or thrown against some part of a road vehicle in-transport
- Injury or damage from moving part of a road vehicle in-transport
- Object falling from, or in, a road vehicle in-transport
- Object falling on a road vehicle in-transport
- Toxic or corrosive chemicals leaking out of a road vehicle in-transport

[163] ANSI D16.1-2007, Manual on Classification of Motor Vehicle Traffic Accidents, American National Standards Institute, Inc. 2007. http://www-nrd.nhtsa.dot.gov/Pubs/07D16.pdf

- Injury or damage involving only the road vehicle that is of a noncollision nature, such as a bridge giving way under the weight of a road vehicle, striking holes or bumps on the surface of the trafficway, or driving into water, without overturning or collision

1.4 Jackknife accident: A jackknife accident is a noncollision accident in which the first harmful event results from unintended contact between any two units of a multi-unit road vehicle such as a truck combination.

1.5 Collision involving pedestrian: A collision involving pedestrian is a collision accident in which the first harmful event is the collision of a pedestrian and a road vehicle in-transport.

1.6 Collision involving motor vehicle in-transport: A collision involving motor vehicle in-transport is an accident that is both a motor vehicle accident and a collision accident in which the first harmful event is the collision of two or more motor vehicles in-transport.

1.7 Collision involving other road vehicle in-transport: A collision involving other road vehicle in-transport is an accident that is both another-road-vehicle accident and a collision accident in which the first harmful event is the collision of two or more other road vehicles in-transport.

1.8 Collision involving parked motor vehicle: A collision involving parked motor vehicle is a collision accident in which the first harmful event is the striking of a motor vehicle not in-transport by a road vehicle in-transport.

1.9 Collision involving railway vehicle: A collision involving railway vehicle is a collision accident in which the first harmful event is the collision of a road vehicle in-transport and a railway vehicle.

1.10 Collision involving pedalcycle: A collision involving pedalcycle is an accident that is both a motor vehicle accident and a collision accident in which the first harmful event is the collision of a pedalcycle in-transport and a motor vehicle in-transport.

1.11 Collision involving animal: A collision involving animal is a collision accident in which the first harmful event is the collision of an animal, other than an animal powering another road vehicle, and a road vehicle in-transport.

1.12 Collision involving fixed object: A collision involving fixed object is a collision accident in which the first harmful event is the striking of a fixed object by a road vehicle in-transport. Fixed objects include such objects as guardrails, bridge railings or abutments, construction barricades, impact attenuators, trees, embedded rocks, utility poles, ditches, steep earth or rock slopes, culverts, fences and buildings.

1.13 Collision involving other object: A collision involving other object is any collision accident other than a (1) collision involving pedestrian, (2) collision involving motor vehicle in-transport, (3) collision involving other road vehicle in-transport, (4) collision involving parked motor vehicle, (5) collision involving railway vehicle, (6) collision involving pedalcycle, (7) collision involving animal, or (8) collision involving fixed object.

4.3 Appendix 3: Regulatory Framework Comparison Tables

Currently, federal regulations are largely silent on AVs. While some states have regulated AVs, the regulatory landscape remains a loose patchwork of varying degrees of requirements. System Safety Program Plans (SSPP) and Security and Emergency Preparedness Plans (SEPP), currently developed and maintained by rail transit agencies around the United States, are useful resources for developing a coherent and consistent set of safety and security requirements. A new but similar framework, Safety Management Systems (SMS) and Transit Agency Safety Plans (TASPs), will be replacing the existing plans, putting forth a more advanced interpretation and implementation of transportation safety management.

The following tables analyze the SSPP, SEPP, and SMS/TASP requirements in an "a-la carte" manner. Reviewing each component as a standalone requirement creates the potential to combine them in a modified framework. Please note that while AV implications for the insurance industry are not the focus of this research, insurance carriers are included on this list to the extent that they function as regulators. They can dictate the terms of their policies for manufacturers, fleet operators, and private owners. As such, many of these elements and requirements can offer a great deal of value to ensuring the safety and security of AV operations for insurance purposes.

4.3.1 SSPP Elements

Table 3 – SSPP Element Comparison

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
1. Policy Statement and SSPP Authority - 659.19(a)	No	Yes. Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers (possibly), Insurance Carriers.	This type of requirement could translate into a similar requirement where chief executives approve an overarching safety plan and are held accountable for that plan.
2. Goals and Objectives - 659.19 (b)	Partial – FL legislation has a statement re: goals of legislation.	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers (possibly), Insurance Carriers.	This type of requirement could be useful in that it provides thematic direction for legislation, rules, and policy.
3. Overview of Management Structure - 659.19(c)	No – but potentially may exist in manufacturer's internal practices.	Federal Government, State Governments, Local Governments, Fleet Operators,	This type of requirement could apply to divisions or branches of a manufacturer or fleet operators in

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
		Manufacturers, Insurance Carriers.	order to provide assurances on clear leadership and safety accountability in their AV processes.
4. SSPP Control and Update Procedure - 659.19(d)	No	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Insurance Carriers.	This type of requirement could apply to manufacturers or fleet operators in order to ensure safety plans are reviewed and changes are documented.
5. SSPP implementation Activities and Responsibilities - 659.19(e)	No	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Insurance Carriers.	This type of requirement could apply to manufacturers or fleet operators in order to ensure accountability for the execution of safety plans are reviewed.
6. Hazard Management Process - 659.31	No	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Insurance Carriers.	This type of requirement could apply to manufacturers, fleet operators, and governments in order to ensure that hazards associated with manufacture, operations, and interactions between AV and infrastructure are continuously being identified, analyzed and addressed.
7. System Modification - 659.19(q)	No	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Insurance Carriers.	This type of requirement could apply to manufacturers, fleet operators, and governments in order to ensure that modifications to manufacturing processes, fleet operations, or infrastructure take safety concerns into account.
8. Safety Certification - 659.19(h)	No	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Insurance Carriers.	This type of requirement could apply to manufacturers, fleet operators, and governments in order to ensure that new operations, infrastructures, or processes address safety concerns or hazards prior to operations.
9. Safety Data Collection and Analysis - 659.19(i)	No	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers,	This type of requirement could apply to manufacturers, fleet operators, and governments in order to ensure that safety data associated with

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
		Insurance Carriers.	manufacture, operations, and interactions between AV and infrastructure are continuously being identified, analyzed and addressed.
10. Accident Incident Investigations - 659.35; 659.19(j); 695.33; 695.35	No	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Insurance Carriers.	This type of requirement could apply to manufacturers, fleet operators, and governments in order to ensure that accident data is reported as soon as possible, is stored for analysis, and corrective actions are formulated as needed.
11. Emergency Management Program - 659.19(k)	No	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Insurance Carriers.	This type of requirement could apply to manufacturers, fleet operators, and governments in order to ensure that AV operations are coordinated during emergencies and emergency response.
12. Internal Safety Audits/Reviews - 659.19(l) 659.27	No	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Insurance Carriers.	This type of requirement could apply to manufacturers, fleet operators, in order to ensure that safety is continuously being reviewed and compliance with associated regulations.
13. Rules Compliance - 659.19(m)	No	Federal Government, State Governments, Local Governments [particularly relevant to Law Enforcement], Fleet Operators, Manufacturers, Insurance Carriers.	This type of requirement could apply to manufacturers, fleet operators, to ensure that maintenance procedures are complied with, and a review process to ensure that AV software is consistently performing as designed.
14. Facilities and Equipment Inspections - 659.19(n)	No	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Insurance Carriers.	This type of requirement could apply to manufacturers, fleet operators, in order to ensure facilities and maintenance equipment are continuously inspected. Furthermore, this type of requirement could be expanded to include ensuring equipment, facilities, etc. are up-to-

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
			date and appropriate for maintenance and repairs on the latest technology.
15. Maintenance Audits and Inspections - 659.19(o)	No	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Insurance Carriers.	Same as above.
16. Training and Certification Program for Employees and Contractors -659.19(p)	Partial – States such as NV require AV manufacturers to train operators in the operation of AVs.	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Retailers, Insurance Carriers.	This type of requirement could apply to manufacturers, fleet operators, retailers, and governments in order to ensure that AV "operators" are adequately trained in the operation of particular vehicles. In terms of application to retailers, this type of requirement could be used to ensure that retailers provide some level of training to individual consumers so that they understand the capabilities of their AV.
17. Configuration Management and Control - 659.19(q)	No - but potentially may exist in manufacturer's internal practices.	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Insurance Carriers.	Similar to number 7 above, this type of requirement could apply to manufacturers, fleet operators, and governments in order to ensure that changes to manufacturing processes, fleet operations, or infrastructure are documented and accounted for.
18. Local, State & Federal Requirements - 659.19(r)	Partial	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Insurance Carriers.	While in context of SSPPs this requirement applies to employees and contractors working on the transit system, in the AV universe each State which has regulations on AV has varying degrees of requirements for operators, including licensing.
19. Hazardous Materials Program - 659.19(s)	No – but may apply under other analogous legislation (EPA, DEP etc.)	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers,	This type of requirement could apply to manufacturers and fleet operators if not already covered by analogous legislation.

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
		Insurance Carriers.	
20. Drug and Alcohol Program - 659.19(t)	No	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Insurance Carriers.	This type of requirement may be applicable to fleet operators or those who perform maintenance on AVs to ensure that those individuals performing maintenance work are fit for duty.
21. Procurement -659.19(u)	No	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Insurance Carriers.	This type of requirement may be applicable to fleet operators or those who perform maintenance on AVs have safety concerns accounted for in their logistical processes.

4.3.2 SEPP Elements

Table 4 – SEPP Element Comparison

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
Policy and Goals Statement - §659.23(a)	No	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Insurance Carriers.	This type of requirement could translate into a similar requirement where chief executives approve an overarching security plan, including specific security goals, and are held accountable for that plan.
Threat and Vulnerability Management - §659.23(b)	No	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Insurance Carriers.	This type of requirement could be useful for ensuring processes are in place that account for managing threats to AV passengers, operations, and facilities. This would most likely apply to fleet operators.
Passenger and Employee Security Controls - §659.23(c)	No	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers,	While this may not have the same applicability to employees as 659's coverage of transit employees, it is nonetheless worthwhile. Similar to

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
		Insurance Carriers.	the above provision, this would be useful in that it would require documenting measures taken protect AV passengers. This could apply to physical and cyber security. In July 2015, hackers were able to exploit vulnerabilities in a Jeep Grand Cherokee equipped with Chrysler's Uconnect system. This type of requirement could account for securing system vulnerabilities and being able to effectively respond to situations where these systems are compromised.
Internal Security Review Process - §659.23(d)	No	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Insurance Carriers.	This type of requirement could be useful in that it provides quality controls to ensure that security plans in place are being followed.
Security Plan Availability to SSO - §659.23(e)	No	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Insurance Carriers.	Absent a safety oversight type agency responsible for AV operations, this provision would ensure that other bodies responsible for overseeing safety and security of AV operations are provided details of relevant plans.

4.3.3 SMS/TASP Elements

Table 5 – SMS/TASP Element Comparison

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
		Safety Plans	
General Requirements - §673.11	No	See SSPP table, lines 1-3.	Same as SSPP table lines 1-3

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
Certificate of Compliance - §673.13	No	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Insurance Carriers.	This type of requirement could be useful to governments and insurance carriers, by requiring fleet operators and manufacturers to develop and certify a safety plan.
Coordination with metropolitan, statewide, and non-metropolitan planning processes -§673.15	Partial	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers.	While not officially mandated, this type of requirement exists in practice in some states that have strong public-private working relationships. Making this a formal requirement could encourage more of these working relationships and ensure that pertinent safety data is being shared among relevant stakeholders.
Safety Management Systems			
General Requirements - §673.21	No	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Insurance Carriers.	This type of requirement could be useful in that it would list the necessary elements of an SMS or comparable system.
Safety Management Policy - §673.23	No	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Insurance Carriers.	This type of requirement could be useful in that it provides thematic direction for legislation, rules, policy, and enumerates accountability for safety across organizational levels.
Safety Risk Management - §673.25	No	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Insurance Carriers.	This type of requirement could apply to manufacturers, fleet operators, and governments in order to ensure that hazards and safety risk associated with manufacture, operations, and interactions between AV and infrastructure are continuously being identified, analyzed, and addressed.
Safety Assurance - §673.27	No	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Insurance Carriers.	This type of requirement could apply to manufacturers, fleet operators, and governments in order to ensure that safety data associated with manufacture, operations, and

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
			interactions between AV and infrastructure are continuously being identified, analyzed and addressed; that changes to manufacturing processes, fleet operations, or infrastructure are documented and accounted for and do not present new unacceptable safety risks; that procedures and standards are complied with; and any hazards or safety risks not captured under the Safety Risk Management process are identified and evaluated accordingly.
Safety Promotion - §673.29	No	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Insurance Carriers.	This type of requirement could apply to manufacturers, fleet operators, and governments in order to ensure that employees and contractors are adequately trained a have clear and open lines of communication for conveying safety data throughout the organization. This communication could also extend to private consumers. By analyzing incident data captured by AVs event recorders, manufacturers and retailers can tailor their training to customers in response to commonalities identified in this data.
Safety Plan Documentation and Recordkeeping			
Safety Plan Documentation - §673.31	No	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Insurance Carriers.	This type of requirement could be useful in that it requires specific documentation, and maintenance of that documentation, for safety activities. This could apply to manufacturers and fleet operators to ensure their safety activities are sufficiently documented.

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
Safety Plan Records - §673.33	No	Federal Government, State Governments, Local Governments, Fleet Operators, Manufacturers, Insurance Carriers.	Same as above.

4.3.4 FMCSA Regulations

Federal Motor Carrier Safety Administration regulations, outlined in 49 CFR Parts 300-399, subject commercial motor carriers in the United States to a variety of safety requirements. Because they pertain to motor vehicles, many parallels can be drawn between FMCSA regulations and the eventual landscape of regulations that will govern autonomous vehicle operation; however, the strength of these parallels will depend on a number of factors, including ownership, leasing, and maintenance schemes for vehicles possessed by individuals in private use. These regulations demonstrate how government entities, manufacturers, researchers, and fleet operators must communicate and coordinate to ensure the safety of passenger and freight motor transport.

Table 6 – FMCSA Element Comparison

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
COMMERCIAL MOTOR CARRIER SAFETY ASSISTANCE PROGRAM - 49 CFR Part 350	Partial	Federal Government, State Governments, Researchers, Manufacturers	The US government currently offers certain forms of grant-based funding to research and enhance autonomous vehicle safety. However, it is unclear if an overarching program with clear safety objectives and performance-based targets for AVs exists on a scale similar to the FMCSA program.
COMPATIBILITY OF STATE LAWS AND REGULATIONS AFFECTING INTERSTATE MOTOR CARRIER OPERATIONS - 49 CFR Part 355	No	Federal Government, State Governments	To date, no significant effort has been made to ensure that state AV regulations are compatible with overarching Federal standards.

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
MOTOR CARRIER ROUTING REGULATIONS - 49 CFR Part 356	No	Federal Government, State Governments, Local Governments, Fleet Operators	This section deals with route restrictions and designations for commercial motor carriers. No corresponding Federal legislation defining parameters for limiting AV use along certain routes exists.
FEES FOR MOTOR CARRIER REGISTRATION AND INSURANCE - 49 CFR Part 360	Partial	Federal Government, State Governments, Local Governments, Fleet Operators	AV manufacturers are currently subject to certain registration fees and associated costs in individual states. There is no overarching Federal program for AV fleet vehicle registration and insurance.
RULES GOVERNING APPLICATIONS FOR OPERATING AUTHORITY - 49 CFR Part 365	Partial	Federal Government, State Government, Fleet Operators	No overarching Federal legislation exists which requires AV operators to apply or file for operating authority. However, individual states do require AV manufacturers and operators to apply for the right to test vehicles on public roads.
DESIGNATION OF PROCESS AGENT - 49 CFR Part 366	No	Federal Government, State Government	In the future, the Federal government may mandate that AV operators designate persons upon whom court process may be served.
STANDARDS FOR REGISTRATION WITH STATES - 49 CFR Part 367	No	No – This section defines a fee schedule for motor carrier registration.	
APPLICATION FOR A CERTIFICATE OF REGISTRATION TO OPERATE IN MUNICIPALITIES IN THE UNITED STATES ON THE UNITED STATES-MEXICO INTERNATIONAL BORDER OR WITHIN THE COMMERCIAL ZONES OF SUCH MUNICIPALITIES.- 49 CFR Part 368	No	Federal Government, Fleet Operators	AV fleet operators domiciled in Mexico, Canada, or other countries may eventually be required to register as carriers with the US government, as this FMCSA regulation requires of trucking companies.

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
REPORTS OF MOTOR CARRIERS - 49 CFR Part 369	No	Federal Government, Fleet Operators	This regulation covers annual reporting requirements for motor carriers of a certain Class, and associated rules for classification of carriers. The Federal government may eventually define fleet vehicle "classes" and associated annual reporting requirements for AV operators.
PRINCIPLES AND PRACTICES FOR THE INVESTIGATION AND VOLUNTARY DISPOSITION OF LOSS AND DAMAGE CLAIMS AND PROCESSING SALVAGE - 49 CFR Part 370	No	Federal Government, State Governments, Manufacturers, Fleet Operators	No regulations currently define specific parameters for filing of claims in instances of loss, damage, or injury as a result of AV use. Federal and State governments may someday define how claims are filed, acknowledged, and investigated.
BROKERS OF PROPERTY - 49 CFR Part 371	No	Federal Government, State Governments, Fleet Operators	This section applies to brokers who arrange transportation of property by motor carriers. Brokers may someday serve as intermediaries in a coordinating role for movement of goods via AV, and must be subjected to recordkeeping requirements and additional regulations.
EXEMPTIONS, COMMERCIAL ZONES, AND TERMINAL AREAS - 49 CFR Part 372	No	Federal Government, State Government, Local Governments, Fleet Operators	AVs which operate in defined commercial zones, are used for transportation to and from schools, or are operated by cooperative associations may be exempt from particular rules and subject to other supplementary rules, as are the motor carriers covered in this section.
RECEIPTS AND BILLS - 49 CFR Part 373	No	Federal Government, Fleet Operators	AV operators may someday be required to maintain specific information regarding cargo or passenger transported for billing and recordkeeping purposes.

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
PASSENGER CARRIER REGULATIONS - 49 CFR Part 374	No	Federal Government, State Governments, Fleet Operators	This section defines anti-discrimination measures for passenger carriers, along with other rules regarding ticketing, baggage, schedules, and station facilities. AV operators may be subject to similar regulations which control certain aspects of the customer experience.
TRANSPORTATION OF HOUSEHOLD GOODS IN INTERSTATE COMMERCE; CONSUMER PROTECTION REGULATIONS - 49 CFR Part 375	No	Federal Government, Fleet Operators	This section regulates commercial carriers moving household goods across state lines. In the future, the Federal government may require commercial AV operators moving household goods to manage pickup, shipping, and delivery of goods in a particular manner.
LEASE AND INTERCHANGE OF VEHICLES - 49 CFR Part 376	No	Fleet Operators, Federal Government, State Governments	Government authorities may someday elect to define the parameters by which an AV owner may lease vehicles to another operator for provision of shipping or passenger transportation services.
PAYMENT OF TRANSPORTATION CHARGES - 49 CFR Part 377	No	Federal Government, State Governments, Fleet Operators	This section defines conditions for extension of credit to shippers by motor carriers. Widespread AV technology adoption may contribute to unique new payment schemes between vehicle owners, operators, passengers, and others which must be defined and regulated.
PROCEDURES GOVERNING THE PROCESSING, INVESTIGATION, AND DISPOSITION OF OVERCHARGE, DUPLICATE PAYMENT, OR OVERCOLLECTION CLAIMS -49 CFR Part 378	No	Federal Government, State Governments, Fleet Operators	This section includes regulations on duplicate payments and overcharges in commercial shipping. As with the section above, novel payment models and technologies may require new regulations and controls.

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
PRESERVATION OF RECORDS - 49 CFR Part 379	No	Federal Government, State Governments, Fleet Operators, Manufacturers	This section regulates retention, storage, and preservation of motor carrier records. AV operators may eventually be required to archive particular documents related to operations, billing, and other topics.
SPECIAL TRAINING REQUIREMENTS - 49 CFR Part 380	Partial	Federal Government, State Governments, Fleet Operators, Researchers, Manufacturers	Efforts are underway to define the scope of unique training requirements for operators of AVs. The Federal government and states may define specific training requirements, driver responsibilities, and proof of training requirements. These requirements may be developed following consultation with researchers and vehicle operators and manufacturers.
WAIVERS, EXEMPTIONS, AND PILOT PROGRAMS - 49 CFR Part 381	No	Federal Government, State Governments, Fleet Operators, Manufacturers	As AV regulations are developed and adopted, individual manufacturers, operators, and others may need to file for exemption via waiver from particular regulations for special purposes. As defined here in FMCSA regulations, AV regulations must outline the conditions by which exemptions are possible and the application and approval process for exemption from particular rules in emergency situations.
CONTROLLED SUBSTANCES AND ALCOHOL USE AND TESTING - 49 CFR Part 382	Partial	Federal Government, State Governments, Fleet Operators	This section outlines programs and policies in place to protect safety by preventing misuse of controlled substances and alcohol by vehicle operators. Many existing regulations govern drug and alcohol use and abuse by motor vehicle operators; it is likely that AV operators will be subject to similar controls. The

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
			unique capabilities of fully-autonomous vehicles may prompt regulatory bodies to revisit aspects of these regulations.
COMMERCIAL DRIVER'S LICENSE STANDARDS; REQUIREMENTS AND PENALTIES - 49 CFR Part 383	No	Federal Government, State Governments, Fleet Operators	Commercial licenses may someday be required for operators of autonomous commercial vehicles. Federal and state authorities may elect to regulate the conditions by which drivers can obtain a license via testing.
STATE COMPLIANCE WITH COMMERCIAL DRIVER'S LICENSE PROGRAM - 49 CFR Part 384	No	Federal Government, State Governments, Fleet Operators	The Federal government, in establishing unique licensing requirements for AV operation, would likely require that all states remain in compliance with Federal licensing laws, as this section requires regarding commercial carrier operations. Funding for infrastructure projects may be linked with compliance, and the Federal government may conduct regular tests and reviews to evaluate levels of compliance.
SAFETY FITNESS PROCEDURES - 49 CFR Part 385	No	Federal Government, State Governments, Fleet Operators, Manufacturers	This section defines a process by which the FMCSA assigns safety ratings to motor carriers, issues required remedial actions, assures safety for new motor carriers, and prohibits unsafe carriers from operating. Federal or state authorities may someday design and implement a safety rating system for AV manufacturers or fleet operators, requiring them to meet minimum safety thresholds and complete specific remedial actions or risk losing certification. Government

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
			authorities may deploy auditors and investigators to assess compliance, and conduct reviews according to a regular schedule.
RULES OF PRACTICE FOR MOTOR CARRIER, INTERMODAL EQUIPMENT PROVIDER, BROKER, FREIGHT FORWARDER, AND HAZARDOUS MATERIALS PROCEEDINGS - 49 CFR Part 386	No	Federal Government, State Governments, Fleet Operators, Manufacturers	This section governs proceedings by which the Chief Safety Officer of FMCSA determines whether or not safety violations have taken place, levies fines and civil penalties, and compels compliance with regulations. Federal regulators may someday be granted powers to conduct similar proceedings involving AV manufacturers and fleet operators.
MINIMUM LEVELS OF FINANCIAL RESPONSIBILITY FOR MOTOR CARRIERS - 49 CFR Part 387	No	Federal Government, State Governments, Fleet Operators, Manufacturers	AV manufacturers and fleet operators may eventually be subjected to minimum financial responsibility requirements by Federal regulators. These regulations provide incentives for safe development, maintenance, and operation of vehicles in passenger and freight contexts.
COOPERATIVE AGREEMENTS WITH STATES - 49 CFR Part 388	No	Federal Government, State Governments, Fleet Operators, Manufacturers	Some states may elect to form cooperative agreements with Federal regulators to enforce AV safety rules and share responsibility for inspection and enforcement activities.
RULEMAKING PROCEDURES - 49 CFR Part 389	Partial	Federal Government, State Governments, Fleet Operators, Manufacturers, Researchers	Federal and state regulators must define procedures by which interested parties can participate in review and development of new AV legislation. Similar rules govern the process of rulemaking in other industries, including commercial trucking. While these parties participate in current legislative

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
			development, practices specific to AVs may need to be formally codified.
FEDERAL MOTOR CARRIER SAFETY REGULATIONS; GENERAL - 49 CFR Part 390	No	Federal Government, State Governments, Fleet Operators, Manufacturers, Researchers	This section defines terminology and applicability of FMCSA regulations to different individuals. AV regulations must similarly define terms and identify individuals and organizations subject to AV regulations.
QUALIFICATIONS OF DRIVERS AND LONGER COMBINATION VEHICLE (LCV) DRIVER INSTRUCTORS - 49 CFR Part 391	No	Federal Government, State Governments, Fleet Operators	This section defines minimum qualifications for commercial drivers and minimum duties of motor carriers to ensure their drivers are qualified. AV fleet operators and individuals may eventually be required to meet certain criteria which extend beyond the requirements of licensing. Driver requirements may include age limits, physical exams, background checks, and other controls.
DRIVING OF COMMERCIAL MOTOR VEHICLES - 49 CFR Part 392	No	Federal Government, State Governments, Fleet Operators, Manufacturers, Researchers	AV regulations will likely define specific operating rules for normal and hazardous operating conditions, outline specific vehicle requirements such as lighting, and set restrictions on dangerous practices. These regulations will govern daily AV operation in a high level of detail, and development of such regulations will need to engage all major players in AV development, operation, manufacturing, and research.
PARTS AND ACCESSORIES NECESSARY FOR SAFE OPERATION - 49 CFR Part 393	No	Federal Government, State Governments, Fleet Operators, Manufacturers, Researchers	This section discusses and defines specific vehicle parts, requires that vehicles be equipped with certain parts, and mandates that vehicle

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
			operators maintain a familiarity with the parts and accessories discussed. Given the large volume of new technologies integrated into AVs, regulations will likely need to define the capabilities of individual parts and mandate a minimum level of functionality for all vehicles.
HOURS OF SERVICE OF DRIVERS - 49 CFR Part 395	Partial	Federal Government, State Governments, Fleet Operators, Researchers	AV fleet operators and individual drivers who operate sub-Level 4 autonomous vehicles may be subjected to some form of hours of service requirements and associated recordkeeping requirements. AV technology adoption is likely to have a significant impact on existing hours of service regulations for commercial purposes; researchers, fleet operators, and legislative authorities will likely need to collaborate in revisiting these regulations.
INSPECTION, REPAIR, AND MAINTENANCE - 49 CFR Part 396	No	Federal Government, State Governments, Fleet Operators	AV operators and fleet owners will need to periodically inspect and maintain equipment, functions which become increasingly important in complex systems. Federal and state regulators will likely define inspection and maintenance requirements for AV-specific components and require operators to maintain and track information on repairs and maintenance performed.
TRANSPORTATION OF HAZARDOUS MATERIALS; DRIVING AND PARKING RULES - 49 CFR Part 397	No	Federal Government, State Governments, Fleet Operators	Commercial AVs, like current motor carriers, will likely be involved in transportation of hazardous materials. Regulators may revisit these requirements, though regulations governing transportation of

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
			hazardous materials via AV may largely resemble existing commercial trucking regulations.
TRANSPORTATION OF MIGRANT WORKERS - 49 CFR Part 398	No	Federal Government, State Governments, Fleet Operators	AV regulations may govern specific transportation uses, including movement of migrant workers. Associated regulations may outline specific safety requirements, required equipment, and recordkeeping practices.
EMPLOYEE SAFETY AND HEALTH STANDARDS - 49 CFR Part 399	No	Federal Government, State Governments, Fleet Operators, Manufacturers	Future regulations for AVs may mandate specific health and safety requirements covering equipment dimensions and required features. Manufacturers will need to work with regulatory bodies to ensure that vehicle designs are in conformance with all relevant standards.

4.3.5 FRA Regulations

40 CFR Parts 200-299 define specific Federal Railroad Administration regulations pertaining to freight and passenger railroads in the Unites States. These regulations establish safety rules and requirements, enforcement techniques, reporting relationships, and engineering standards for rail vehicles and structures. In an AV context, these regulations are useful in revealing how complex transportation systems involving major private companies and public entities can be managed and monitored to improve coordination and reduce safety risks nationwide. As with FMCSA regulations, the applicability of these regulations to AV safety is dependent on factors including ownership schemes; individuals who possess AVs for independent use are unlikely to be subjected to rigorous and complex regulatory requirements as would fleet owners and operators.

Table 7 – FRA Element Comparison

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
INFORMAL RULES OF PRACTICE FOR PASSENGER SERVICE - 49 CFR Part 200	No	Federal Government, State Governments, Fleet Operators, Infrastructure Providers	This section regulates an application process which is required before track owners downgrade rail shared with Amtrak. In the future, owners and operators of AV infrastructure may be required to coordinate upgrades and downgrades to equipment with federal or state regulators, vehicle developers, and others, to ensure that safe and efficient AV operation remains possible.
RAILROAD POLICE OFFICERS - 49 CFR Part 207	No	Federal Government, State Governments, Fleet Operators	It is possible that states may deploy police officers specifically for the purpose of monitoring safety violations related to AV operation.
RAILROAD SAFETY ENFORCEMENT PROCEDURES - 49 CFR Part 209	No	Federal Government, State Governments, Fleet Operators, Infrastructure Providers	It is highly likely that Federal and State governments will establish detailed safety rule enforcement processes and fee schedules for rule violations. Fines and compliance orders may be issued to individuals in a position of responsibility for system safety.
RAILROAD NOISE EMISSION COMPLIANCE REGULATIONS - 49 CFR Part 210	No	Federal Government, State Governments, Fleet Operators, Infrastructure Providers	With new business models and technologies for vehicle service delivery, ambient noise from vehicles idling at dispatch points may become a concern. It is possible that state and local regulations will attempt to control environmental and health impacts of excess noise.
RULES OF PRACTICE - 49 CFR Part 211	No	Federal Government, State Governments, Fleet Operators, Infrastructure Providers, Manufacturers	This section defines specific rules and procedures to manage safety inquiry processes. When regulators or others identify safety concerns within an AV fleet or infrastructure

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
			system, they will likely be required to follow formal procedures to conduct a review of the issue.
STATE SAFETY PARTICIPATION REGULATIONS - 49 CFR Part 212	No	Federal Government, State Governments, Fleet Operators, Infrastructure Providers, Manufacturers	This section defines rules for State participation in surveillance and investigation activities surrounding Federal railroad regulations. AV regulations will likely contain similar jurisdictional overlap which must be managed through defined procedures, allowing states to conduct joint or parallel investigations into safety issues.
TRACK SAFETY STANDARDS - 49 CFR Part 213	No	Federal Government, State Governments, Infrastructure Providers	Much as this requirement defines minimum safety standards for railroad track, the Federal government may develop and enforce minimum safety standards for roadways with AV-connected communications infrastructure and other AV-specific design features. Given the broad range of AV technologies currently available, it is unclear how these standards might take shape; performance-based standards may be more feasible than standards requiring use of specific technologies.
RAILROAD WORKPLACE SAFETY - 49 CFR Part 214	No	Federal Government, State Governments, Fleet Operators, Infrastructure Providers, Manufacturers	Federal and State governments may establish specific safety rules governing inspection, maintenance, and construction activities for vehicles and infrastructure. Enhanced capabilities of AVs will allow for additional layers of safety protection during construction and road work, but will require

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
			significant coordination and new procedures.
RAILROAD FREIGHT CAR SAFETY STANDARDS - 49 CFR Part 215	No	Federal Government, State Governments, Fleet Operators, Manufacturers	Just as regulatory bodies set minimum safety standards for conventional vehicles, regulators will establish minimum standards for required safety equipment, ensure that all equipment is maintained appropriately, and possibly define performance-based standards for vehicle safety.
SPECIAL NOTICE AND EMERGENCY ORDER PROCEDURES: RAILROAD TRACK, LOCOMOTIVE AND EQUIPMENT - 49 CFR Part 216	No	Federal Government, State Governments, Fleet Operators, Manufacturers, Infrastructure Providers	In certain instances, Federal or State safety inspectors may issue notice that vehicles or roadways may not remain in service until safety violations are resolved. AV regulations, as with rail regulations, may require safety violations to be resolved immediately before a special notice is lifted.
RAILROAD OPERATING RULES - 49 CFR Part 217	No	Federal Government, State Governments, Fleet Operators, Infrastructure Providers	This section defines testing and training requirements, inspection procedures, and recordkeeping requirements to ensure that railroads are operating according to safety standards. Similar requirements may govern AV infrastructure and fleet control centers, individual operators, and fleet vehicle owners.
RAILROAD OPERATING PRACTICES - 49 CFR Part 218	No	Federal Government, State Governments, Fleet Operators, Infrastructure Providers	This section, like the section above, lays out specific operating rules applying to railroad workers on trains, tracks, and in control positions. Workers involved in AV inspection, maintenance, and construction will likely be subject to similar requirements.

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
CONTROL OF ALCOHOL AND DRUG USE - 49 CFR Part 219	Partial	Federal Government, State Governments, Fleet Operators	This section outlines programs and policies in place to protect safety by preventing misuse of controlled substances and alcohol by train operators and employees. Many existing regulations govern drug and alcohol use and abuse by motor vehicle operators; it is likely that AV operators will be subject to similar controls. The unique capabilities of fully-autonomous vehicles may prompt regulatory bodies to revisit aspects of these regulations.
RAILROAD COMMUNICATIONS - 49 CFR Part 220	No	Federal Government, State Governments, Fleet Operators, Infrastructure Providers	This section, establishing minimum wireless communication technology requirements for trains and train operators, pertains directly to AV regulation. The Federal government may define specific technologies that must be installed and communication performance measures that must be met before AVs and infrastructure can be considered safe.
REAR END MARKING DEVICE—PASSENGER, COMMUTER AND FREIGHT TRAINS - 49 CFR Part 221	No	Federal Government, State Governments, Fleet Operators, Manufacturers	AV regulations may define specific markers and signals to be included on the vehicle for visibility and communication purposes.
USE OF LOCOMOTIVE HORNS AT PUBLIC HIGHWAY-RAIL GRADE CROSSINGS - 49 CFR Part 222	No	Federal Government, State Governments, Fleet Operators, Manufacturers	Though vehicles may not be required to sound a horn at intersections or crossings, AV regulations may require visual or auditory warnings of some type to be issued automatically in sensitive situations. In testing, communication between vehicles has proven essential to safe

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
			operation of intersections with higher volumes of AV traffic.
SAFETY GLAZING STANDARDS—LOCOMOTIVES, PASSENGER CARS AND CABOOSES - 49 CFR Part 223	No	Federal Government, State Governments, Fleet Operators, Manufacturers	Vehicle manufacturers and parties who maintain vehicles may be required to install parts that fulfill certain standards, such as shatterproof and glazed windows required of rail vehicle manufacturers.
REFLECTORIZATION OF RAIL FREIGHT ROLLING STOCK - 49 CFR Part 224	No	Federal Government, State Governments, Fleet Operators, Manufacturers	As above, regulations may require manufacturers and fleet operators to install and maintain particular visual warning devices and other technologies to ensure that AVs may be easily identified by other vehicles, pedestrians, and cyclists, as well as remote infrastructure sensors.
RAILROAD ACCIDENTS/INCIDENTS: REPORTS CLASSIFICATION, AND INVESTIGATIONS - 49 CFR Part 225	Partial – Some states currently require incident reporting from manufacturers / operators	Federal Government, State Governments, Fleet Operators, Manufacturers, Researchers, Infrastructure Providers	Federal and state regulatory authorities must develop reporting and feedback mechanisms by which accidents can be classified, investigated, and mitigated appropriately. While AV-specific incident reporting practices exist in some states, no national framework for such a process exists. Risk reduction depends on implementation of an effective system.
OCCUPATIONAL NOISE EXPOSURE - 49 CFR Part 227	No	No – Operator noise exposure is not anticipated to be a significant issue as AV technology develops.	
HOURS OF SERVICE OF RAILROAD EMPLOYEES; RECORDKEEPING AND REPORTING; SLEEPING QUARTERS - 49 CFR Part 228	No	Federal Government, State Governments, Fleet Operators, Researchers	AV fleet operators and individual drivers who operate sub-Level 4 AVs may be subjected to some form of hours of service requirements and associated

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
			recordkeeping requirements. AV technology adoption is likely to have a significant impact on existing hours of service regulations for commercial purposes; researchers, fleet operators, and legislative authorities will likely need to collaborate in revisiting these regulations.
RAILROAD LOCOMOTIVE SAFETY STANDARDS - 49 CFR Part 229	No	Federal Government, State Governments, Fleet Operators, Manufacturers	As stated earlier, AVs will likely be subject to minimum safety design requirements. Unlike rail, where locomotives and cars are regulated separately, AVs will be regulated as single passenger vehicle or freight vehicle units.
STEAM LOCOMOTIVE INSPECTION AND MAINTENANCE STANDARDS - 49 CFR Part 230	No	Federal Government, State Governments, Fleet Operators, Manufacturers	Given the complexity of AVs, regulators may establish more rigorous inspection and maintenance requirements. Fleet operators and individual owners may become responsible for implementing these programs, keeping records, and tracking progress toward milestones.
RAILROAD SAFETY APPLIANCE STANDARDS - 49 CFR Part 231	No	Federal Government, State Governments, Fleet Operators, Manufacturers	This section defines specific technical and engineering requirements of rail vehicle safety appliances. AVs may eventually be subject to similar requirements, though the variability of AV technology may make specific requirements more difficult to define.
BRAKE SYSTEM SAFETY STANDARDS FOR FREIGHT AND OTHER NON-PASSENGER TRAINS	No	Federal Government, State Governments, Fleet Operators, Manufacturers	As above, this section describes specific brake performance requirements and technical

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
AND EQUIPMENT; END-OF-TRAIN DEVICES - 49 CFR Part 232			specifications. Similar requirements may be established for AV sensors, communications technologies, and operator interfaces.
SIGNAL SYSTEMS REPORTING REQUIREMENTS - 49 CFR Part 233	No	Federal Government, State Governments, Infrastructure Providers	This section requires rail operators to report incidents involving signal failure. AV operation will also be dependent upon proper operation of signal-like infrastructure at intersections and along roads, making some type of incident tracking and reporting necessary.
GRADE CROSSING SAFETY - 49 CFR Part 234	No	Federal Government, State Governments, Infrastructure Providers	The interface points between different roadways, and between AV roadways and other modes, will be sensitive areas of AV road systems. Federal and state regulators may define specific safety requirements, performance standards, and required technologies in these areas.
INSTRUCTIONS GOVERNING APPLICATIONS FOR APPROVAL OF A DISCONTINUANCE OR MATERIAL MODIFICATION OF A SIGNAL SYSTEM OR RELIEF FROM THE REQUIREMENTS OF PART 236 - 49 CFR Part 235	No	Federal Government, State Governments, Infrastructure Providers, Fleet Operators	As with rail, AV infrastructure providers may be required to report significant modifications to fixed AV signaling systems or other communications technology.
RULES, STANDARDS, AND INSTRUCTIONS GOVERNING THE INSTALLATION, INSPECTION, MAINTENANCE, AND REPAIR OF SIGNAL AND TRAIN CONTROL SYSTEMS, DEVICES, AND APPLIANCES - 49 CFR Part 236	No	Federal Government, State Governments, Infrastructure Providers, Fleet Operators	Governmental bodies have strong incentives to regulate safety aspects of wayside signaling and communications systems for AVs. As with rail, regulations may set standards for maintenance, inspection, installation, and repair of certain technologies, given their

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
			criticality to smooth operation of the AV network.
BRIDGE SAFETY STANDARDS - 49 CFR Part 237	No	Federal Government, State Governments, Infrastructure Providers, Fleet Operators	There is a possibility that government regulations will initiate new engineering requirements for roadways carrying AV traffic, which could extend to support structures such as bridges. Roadway engineering standards may change significantly to maximize the benefits of AV technology, prompting infrastructure providers to reconsider how certain structures are engineered.
PASSENGER EQUIPMENT SAFETY STANDARDS - 49 CFR Part 238	No	Federal Government, State Governments, Manufacturers, Fleet Operators	This section prohibits rail operators from using passenger cars in service which fail to meet minimum safety standards, such as cars that have been damaged in incidents. AV regulators may define similar standards requiring fleet operators to remove certain vehicles from service.
PASSENGER TRAIN EMERGENCY PREPAREDNESS - 49 CFR Part 239	No	Federal Government, State Governments, Manufacturers, Fleet Operators	While full trains typically carry many more passengers than even the largest road vehicles, passenger vehicle operators may improve safety by developing emergency preparedness plans. Planning ahead to respond to specific emergencies can improve outcomes for passengers in the event of a collision.
QUALIFICATION AND CERTIFICATION OF LOCOMOTIVE ENGINEERS - 49 CFR Part 240	No	Federal Government, State Governments, Fleet Operators	AV regulators are likely to establish specific additional requirements for operators of sub-Level-4 vehicles, which could

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
			include additional testing and certification requirements.
UNITED STATES LOCATIONAL REQUIREMENT FOR DISPATCHING OF UNITED STATES RAIL OPERATIONS - 49 CFR Part 241	No	Federal Government, State Governments, Fleet Operators	This section requires that rail dispatching for US railroads be conducted domestically. Similar regulations may eventually be extended to AV control center and dispatch functions to improve safety, as domestic dispatch operations can be monitored for compliance with all Federal regulations more easily. While AV technology enables many remote operation and communication functions, few regulations address the physical proximity or location of remote dispatch and communication facilities.
QUALIFICATION AND CERTIFICATION OF CONDUCTORS - 49 CFR Part 242	No	No – It is unlikely that commercial passenger AVs will carry any individual serving a “conductor” function who would not be classified as an operator.	
TRAINING, QUALIFICATION, AND OVERSIGHT FOR SAFETY-RELATED RAILROAD EMPLOYEES - 49 CFR Part 243	No	Federal Government, State Governments, Infrastructure Providers, Fleet Operators, Manufacturers	As with rail, individuals working in the AV field who manufacture, install, maintain, and plan for development of AV infrastructure and equipment will likely be required to gain familiarity with Federal and state safety rules. Parties will need to coordinate to ensure that staff working on safety-sensitive projects have demonstrated an understanding of safety rules, possibly through some form of testing.
REGULATIONS ON SAFETY INTEGRATION PLANS GOVERNING	No	Federal Government, State Governments, Infrastructure	As AV manufacturers, operators, and infrastructure providers grow,

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
RAILROAD CONSOLIDATIONS, MERGERS, AND ACQUISITIONS OF CONTROL - 49 CFR Part 244		Providers, Fleet Operators, Manufacturers	change, and merge, they will need to integrate disparate technologies, plans, procedures, and equipment. Federal or state regulations may govern the transition process in these instances, and require a well-developed transition plan before mergers may take place.
GUARANTEE OF CERTIFICATES OF TRUSTEES OF RAILROADS IN REORGANIZATION - 49 CFR Part 250	No	No – This section is largely unique to railroads experiencing financial hardship.	
FINANCIAL ASSISTANCE FOR RAILROAD PASSENGER TERMINALS - 49 CFR Part 256	No	Federal Government, State Governments, Infrastructure Providers, Fleet Operators	At some point in the future, governments may provide financial assistance for terminal points. Passenger movement patterns across AV networks may vary significantly from existing commuting and leisure travel patterns.
REGULATIONS GOVERNING LOANS AND LOAN GUARANTEES UNDER THE RAILROAD REHABILITATION AND IMPROVEMENT FINANCING PROGRAM - 49 CFR Part 260	No	Federal Government, State Governments, Local Governments, Infrastructure Providers, Fleet Operators	This section authorizes the Federal government to provide direct loans to state and local governments, railroads, and joint ventures for rail projects. Similar funding mechanisms may be established for AV infrastructure projects, given the significant cost and wide geographic extent of such projects.
CREDIT ASSISTANCE FOR SURFACE TRANSPORTATION PROJECTS - 49 CFR Part 261	No	Federal Government, State Governments, Infrastructure Providers, Fleet Operators	As in the section above, this section discusses specifics of Federal financing for infrastructure projects.
IMPLEMENTATION OF PROGRAM FOR CAPITAL GRANTS FOR RAIL LINE RELOCATION AND IMPROVEMENT PROJECTS - 49 CFR Part 262	No	Federal Government, State Governments, Infrastructure Providers, Fleet Operators	As in the sections above, this section discusses the parameters of a capital grants program for infrastructure improvements. Such programs may someday be established to promote

Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
			development of AV infrastructure on a broad scale.
SURFACE TRANSPORTATION PROJECT DELIVERY PROGRAM APPLICATION REQUIREMENTS AND TERMINATION - 49 CFR Part 264	No	No – This section is not directly relevant to AV technological development, containing information on how States may assume responsibility for compliance with NEPA during transportation projects.	
ASSISTANCE TO STATES FOR LOCAL RAIL SERVICE UNDER SECTION 5 OF THE DEPARTMENT OF TRANSPORTATION ACT - 49 CFR Part 266	No	Federal Government, State Governments, Infrastructure Providers, Fleet Operators	This section outlines a program which allocates Federal money to States for rail planning, service continuation, and other projects. Federal monies may someday be distributed to states specifically for the purpose of planning, implementing, and supporting AV projects, including infrastructure.
MAGNETIC LEVITATION TRANSPORTATION TECHNOLOGY DEPLOYMENT PROGRAM - 49 CFR Part 268	No	Federal Government, State Governments, Infrastructure Providers, Fleet Operators	While Maglev technology is not directly relevant to AV development, the Federal government may eventually partner with outside groups to deliver completed AV projects in some form. As with Maglev projects, any partnerships of this nature would likely include detailed requirements on safety, profitability, and independence of the system.
ALTERNATE PASSENGER RAIL SERVICE PILOT PROGRAM - 49 CFR Part 269	No	Federal Government, State Governments, Infrastructure Providers, Fleet Operators	This section relates to a program allowing private rail operators to provide passenger service on privately-owned railways in lieu of Amtrak. In the future, public-private development partnerships for AV infrastructure and communication technology may become more common, creating a

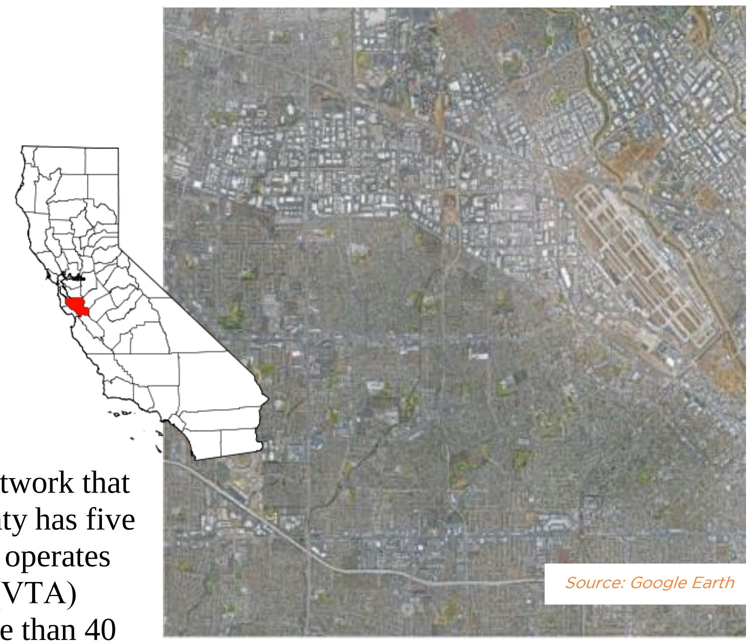
Element / Requirement	Currently exist in AV universe?	Relevant in AV universe? To whom?	How would it look in AV use? Why is it relevant?
			need for parties to negotiate how services will be delivered.
CRITICAL INCIDENT STRESS PLANS - 49 CFR Part 272	No	Federal Government, State Governments, Fleet Operators	This section requires railroads to develop stress management plans for the health and well-being of employees who are involved in major incidents. While AV incidents will likely engage a different set of first-responders, some form of regulation may eventually require AV fleet operators to take post-incident steps to care for employees.

4.4 Appendix 4: Santa Clara County Preliminary Hazard Analysis

This sample Preliminary Hazard Analysis (PHA) presents a framework that could be used to conduct a comprehensive assessment of potential hazards associated with AV implementation. This framework is based on a roughly 5x5 mile study area in Santa Clara County, California. There are currently 13 AV manufacturers in testing phases in California, which make it an attractive area to study. The study area also hosts a variety of high risk associated assets, which is explained in more detail in the *Study Area* section below. The benefit of conducting a PHA in a controlled setting is that results of the analysis on a sample area can be translated to surrounding areas with similar physical and natural characteristics throughout the country. The analysis is provided to help key stakeholders identify hazards and security vulnerabilities, and to begin to develop corrective actions to prevent them from occurring or alleviate their effects.

4.4.1 Study Area

PHA Study Area
Santa Clara County, California



The initial step in the PHA process is to define the physical characteristics of the system to be analyzed. These characteristics are presented in terms of the major elements that make up the system. An understanding of how the individual system elements interface with each other is essential to the hazard identification effort.

Santa Clara County, located in central-western California, has a population just fewer than two million people and encompasses nearly 1,300 square miles. San Jose, the county seat, is the tenth largest city in the United States. Santa Clara County primarily consists of mid to high-dense suburban communities just outside the neighboring San Francisco Bay Area region. For the purposes of this study, a roughly 5x5 mile site was chosen to examine potential hazards and security concerns associated with AV implementation (see Figure 1). The county has an extensive roadway network that includes three major interstates and ten state highways. In addition, the county has five airports, including Norman Y. Mineta San José International Airport, which operates as a “downtown” airport. The Santa Clara Valley Transportation Authority (VTA) maintains and operates an extensive bus fleet and paratransit, as well as more than 40 miles of light rail service.

4.4.2 Identification of Hazards / Vulnerabilities

After defining the system, the second step in the PHA process involves identifying hazards and security vulnerabilities associated with operating AVs and their causal factors. Information for this hazard identification step should be obtained through accident and incident data, analysis of different hazard and security scenarios, expert investigations, and physical characteristics of the site. For the purpose of this study, a less formal approach was adopted that looked at physical characteristics throughout the 5x5 mile site area. Figure 2 outlines several items that should be taken into consideration when assessing hazardous conditions associated with the implementation of AVs.

The following section identifies and details several specific elements and risks associated with AV implementation as it pertains to hazards identified in Figure 2. This is a small sample of hazards identified within the study area, and is meant to highlight some specific trouble areas that could use additional attention.

1. Variable Speed Limit Zones and Traffic Control

    AVs must be able react to speed limit changes in areas that tolerable vehicle speeds fluctuate depending on time of day or special events. Such areas include school zones, loading zones, airports, and places that attract large numbers of pedestrians such as stadiums and convention centers. A full analysis of these types of areas should be conducted to ensure that signage and pedestrian line striping is well maintained and highly visible. Santa Clara County has over 350 schools, more than 30 of which are located within the 5x5 mile site chosen for this study.

    In addition, Levi's Stadium, located in the northern portion of the county, has the capacity to host more than 70,000 people and is accessible by VTA light rail. This poses challenges as motor vehicles and pedestrians have a greater level of interaction when major events occur and draw large numbers of pedestrians. AVs should recognize fluctuations in speed limits and the risks associated with high levels of pedestrian traffic that do not normally occur on a regular basis.

    Location 1.1 identifies a school zone that could be of potential concern for AVs travelling on the adjacent roadway. A potential hazard associated with this location stems from the ways in which AVs will operate with pedestrians present. For instance, at some crosswalks near schools, vehicles are expected to come to a complete stop and give pedestrians the right of way. Because pedestrians often assume vehicles will accept these traffic laws, they are often more prone to enter the right of way with this expectation in mind. There are two signs that must be recognized in order to avoid a hazard from occurring: the variable speed signage specified during particular time periods, and the "stop for pedestrians" signage. If either of these is not identified, pedestrians are at a greater risk of making contact with a moving vehicle. In addition, AVs are at risk of identifying a pedestrian and stopping abruptly or swerving out of the path of travel. This increases the likelihood of making contact with another vehicle or fixed object.

Location 1.2 in Figure 2 identifies an arrival area at an airport. This is another high traffic area that is mixed with both motor vehicle and pedestrian traffic. These zones often have a constant restricted speed, but provide obstacles with sudden vehicle stops and pedestrians moving with luggage. As people are often concerned about making their flights on time, awareness of surrounding locations is sometimes forgotten, and people are prone to dart out in front of vehicles. Understanding the movement of pedestrians and motor vehicles in these areas is crucial for AVs to avoid stopping too abruptly or colliding with other vehicles.

2. Transit and Conventional Vehicle Interaction

Locations 2.1 and 2.2 in Figure 2 identify some potential hazardous areas in regards to multi-modal road operations. AVs will operate in mixed-flow traffic and potentially share travel lanes with conventional vehicle traffic. Traffic signals and channelization should be designed and constructed in accordance with the city standards to minimize the potential for collisions or accidents involving trains, light rail vehicles (LRVs), buses, conventional vehicles, pedestrians, or bicyclists. Because trains and LRVs take longer to stop than rubber-tire motor vehicles, AVs should be able to identify these vehicles and adjust their driving patterns to reflect those of the vehicle in front or behind them.

Through most signalized intersections, AVs will use the same traffic signal phase as conventional vehicles. Where trains and LRVs use the same phase as automobiles, active warning devices will be safety critical and must be tested to ensure that AVs can identify appropriate procedures, especially at locations that present unique conditions, such as train and LRV grade crossings. Some urban and suburban grade crossings do not have gates, or use specific flashing signals to alert motor vehicles that a train is approaching. This can be problematic if AVs do not recognize the signals, or that a train is approaching at a high speed. Grade crossings that do not have gates must also be free of brush and vegetation that may cover signals. If a signal is covered, AVs may have a difficult time detecting a train travelling around a corner at a high speed, where as a conventional vehicle driver could rely on sound and a farther line of site to determine if the crossing is safe. In some rural areas, grade crossings may not have a signalized system to alert drivers that a train is approaching. These areas should be identified before AV implementation, in order to make appropriate adjustments to the grade crossing infrastructure, or program alerts in the vehicles themselves.

3. Vehicle and Roadway Infrastructure

The current conditions of existing infrastructure must be evaluated in order to determine future needs to sustain AV implementation. A large part of safe operations will be placed on how well the vehicle interacts with the surrounding environment. Painted lines are a critical component of ensuring safe and secure vehicle travel. These are of particular importance at locations that allow on-street parking, as well as near areas of heavy pedestrian traffic. In addition, areas near steep or mountainous terrain will be of critical importance when assessing line recognition.

Elements to consider when assessing infrastructure include the suitability and completeness of:

- Signage
    - For automobiles
    - For pedestrians
- Pavement markings
- Pathway delineation
- Line of sight (between trains and automobiles or pedestrians)
- Pathway delineation/sufficient space for crossing
- Signals placement
- Signal timing and indicators
- Operating rules and restrictions
    - For automobiles
    - For pedestrians
- Regulatory mechanisms
- Safety campaigns
- Enforcement

Locations 3.1 and 3.2 in Figure 2 above identify several locations where undefined street lines and street parked vehicles may pose problems. In Location 3.1, the right turning lane may not be easily identified due to the parked vehicles. This may result in an AV attempting to make a turn from the straight or left turn lane only, and poses a potential threat to other drivers not expecting this action. Location 3.2 identifies a bike lane between a travel lane and a street parking area. In this case, AVs may have a difficult time discerning between the travel and parked lane, and predict that the parked cars may actually be a travel lane. This may cause confusion for other drivers or bicycle riders at this intersection and could result in unexpected accidents.

Beyond the scenarios identified above, natural hazards can also pose difficult threats to AVs. Natural hazards consist of naturally occurring severe and extreme climate events, and include a combination of geological, meteorological, and biological hazards, such as earthquakes, coastal erosion, landslides, blizzards, drought, tornados, floods, wildfires, and disease. These types of hazards develop into natural disasters when they severely impact people's lives and livelihoods. Through the application and analysis of contributing factors to natural hazards, forecasts can be developed help understand potential risks, and prepare against such hazards before they become disasters. In Santa Clara Valley County, the San Andreas Fault runs along the Santa Cruz Mountains in the south of the county, which contributes to earthquake activity throughout the state. Earthquakes can potentially disturb and disrupt infrastructure that makes AV driving possible, and can result in serious damage and/or injury to those inside the vehicles and the general public.

Other natural hazards that could potentially impact the safe operations of AVs in Santa Clara County include wildfires and flooding. If flooding were to occur, it could make visibility for AV infrastructure difficult and hard to read. The same types of hazards could occur during severe downpours and rain storms. Another consideration is the damage to infrastructure that the sun can have. Painted lines and crosswalks could become faded and worn due to exposure high heat and sun.

4.4.3 Hazard Vulnerability / Categorization

The third step in the PHA process is to categorize the identified hazards and security vulnerabilities in terms of severity and the probability of occurrence. The United States Department of Defense document *Standard Practice for System Safety*, MIL-STD-882D, establishes system safety criteria guidelines for determining hazard severity and probability.

Together, the hazard/security vulnerability severity and probability properties measure a hazard and vulnerability magnitude and the priority for applying control measures. Hazards are then examined, qualified, addressed, and resolved based on the severity of a potential outcome and the likelihood that such an outcome will occur, which makes up the Hazard/Security Risk Index (HRI). The resulting risk index is a measure of the acceptability or undesirability of the hazard/security vulnerability and is applied to the Hazard Assessment Matrix as seen in Table 8.

Table 8 - Hazard Assessment Matrix

Frequency of Occurrence	Severity			
	(I) Catastrophic	**(II) Critical**	**(III) Marginal**	**(IV) Negligible**
(A) Frequent	IA	IIA	IIIA	IVA
(B) Probable	IB	IIB	IIIB	IVB
(C) Occasional	IC	IIC	IIIC	IVC
(D) Remote	ID	IID	IIID	IVD
(E) Improbable	IE	IIE	IIIE	IVE

Unacceptable

Undesirable (Management Decision Required)

Acceptable with Review by Management

Acceptable Without Review

The Hazard Assessment Matrix assists the decision-making process in determining whether a hazardous condition or security vulnerability should be eliminated, controlled, or accepted, in terms of severity and probability. Table 9 outlines a small sample of potential AV hazards based on severity and probability. This table is meant to be used as an example for developing a more comprehensive matrix that captures all identified hazards.

Table 9 – Sample Hazard Assessment Matrix

General Description		Hazard Cause		Hazard Risk Index		Corrective Action
ID	**Hazard Description**	**Potential Cause**	**Effect**	**Initial Severity-Probability**	**Residual Severity-Probability**	**Possible Controlling Measures**
001	Vehicle stop system fails to stop AV in allowable stopping distance of intersection/pedestrian walkway	AV operator not following procedures; Mechanical failure; AV speeds too high; Improper signage; Unclear painted lines	Minor to severe injury to AV passengers and/or general public; Damage to AV braking system	II-A	II-D	Establish procedure for dealing with brake failure
002	Pedestrian walks in front or into side of AV mid-block	Distracted pedestrian; Pedestrian fails to cross at crosswalk;	Minor to severe injury	I-B	I-C	Public education campaign

		Improper signage; Unclear painted lines				
003	AV and bicycle collision	Distracted cyclist; Cyclist not crossing street at appropriate location; Cyclist trying to race AV	Minor to severe injury	I-D	I-E	
004	AV collides with streetcar/LRV at intersection	AV ignores traffic signal or stop signs; Streetcar operator disregards traffic signal or stop signs; Traffic lights fail to turn to red at signalized intersection; Improper signage; Unclear painted lines	Minor to severe injury to AV passengers and/or general public; Minor to severe damage to AV	I-A	I-D	Enforce safe streetcar operating rules and procedures; Establish proficiency testing program; Establish agreement regarding maintenance of traffic control devices
005	AV sideswipes vehicle at curb	Parking lanes too narrow; Auto door opened into path of AV; Auto parked away from curb fouls AV travel way	Minor to severe damage to vehicles	II-B	II-C	Public education campaign; Provide demarcation line on pavement to identify fouling point for parked vehicles; Enforcement of parking regulations

006	Conventional auto pulling from curb sideswipes AV	Auto driver fails to clear left side before pulling from curb	Minor to severe damage to vehicles	II-B	II-C	Public education campaign; Enforcement of safe automobile operations and regulations
007	Conventional auto running parallel sideswipes AV	Distracted auto driver; Driver error	Minor to severe injury due to collision; Minor to severe damage vehicles	II-B	III-C	Public education campaign; Enforcement of safe automobile operations and regulations
008	Conventional auto rear-ends AV	AV stops and auto strikes AV in rear	Minor to severe injury due to collision; Minor to severe damage to vehicles	II-B	II-C	Public education campaign; Enforcement of safe automobile operations and regulations
009	Failure of signaling system	Equipment failure	Loss of signaling in affected areas during normal operations	I-A	I-D	Provide redundant equipment; Follow routine maintenance
010	Flooding of Roadway	Excessive rain; Water main break	Damage to AV; Inability to read guiding lines	II-B	II-D	Provide storm drainage for 100 year rainfall