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Impacts of Laws and Regulations on CV and AV Technology Introduction in Transit Operations

Douglas Gettman
Kimley-Horn
Phoenix, AZ

J. Sam Lott and Gwen Goodwin
Texas Southern University
Houston, TX

Tom Harrington
AICP—Cambridge Systematics
Cambridge, MA

Contractor's Final Technical Memorandum for NCHRP Project 20-102(02)
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Preface

This memorandum uses the following terminology and focus of its content in a manner consistent with all the associated working papers of the NCHRP 20-102(02) project.

Definition of Automated Vehicle (AV) Transit – The “system” comprising AV Transit includes:

1. Driving automation system(s) and technology per SAE J3016[1];
    a. Other vehicle systems and components which provide driver assistance such as lane departure warning when a human driver is performing the dynamic driving task (DDT) from inside the vehicle or from a remote location; and
2. Other monitoring, supervisory control and passenger safety systems, technologies, and facilities necessary for public transit service, such as precision docking, automated door operation, and dispatch functions.

Definition of Transit Vehicle Operator – The typical term used to identify the person operating a transit vehicle is the “vehicle operator”. However, under SAE J3016 definitions and terminology, a human “driver” is the person who manually exercises in-vehicle braking, accelerating, steering, and transmission gear selection input devices to operate a vehicle. Considering the SAE standard’s intent to define terms for driving automation systems only, the term vehicle driver is specified. In the working papers, the terms vehicle driver and vehicle operator may be used interchangeably, depending on the context, and point of emphasis. Likewise, the terms “remote driver” (per SAE J3016) and “remote operator” will likewise be used interchangeably.

Definition of Transit Operating Agency — Transit operating agencies can be any type of public, governmental, or non-profit entity, such as transit authorities created with certain governmental responsibilities; municipal, county, and state government public transportation departments; medical/educational institutions; and local management authorities/districts. A transit operating agency can also be “for profit”. Most operators who provide purchased transportation under contract are for-profit companies.

1 SAE J3016 is the Society of Automotive Engineers Standard titled – Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles; the standard was revised September 30, 2016.

Introduction

Public transit agencies will face changes in the way they approach operating policy with the introduction of automated roadway vehicle (AV) technology over the next few decades. The impacts could require a rethinking of many aspects of the agency operations, with the results of the decisions affecting employees, agency management structure, and transit patrons. In the six working papers of this project we investigated the following topics:

1. AV technology evolution for public transit
2. Safety considerations for AV transit
3. Workforce deployment issues
4. Agency operating policies
5. Laws and regulations
6. Identification of research, development, and policy activities necessary and advantageous to advance adoption of AV technology in public transit

While technology may continue to develop in research and demonstration projects, widespread operations are limited by the sticky issues presented by the regulatory environment of public transit.

The existing framework of laws and regulations will need to be adjusted and adapted over the course of time to address AV transit applications. However, there is an equally important consideration of what must be changed and adapted in transit vehicle designs to satisfy laws and regulations that **will not be changed**.

There are many other relevant laws and regulations that are not being considered in this project which do not focus strictly on transit services, such as driving registration and licensing, product/vehicle liability, roadway infrastructure design standards, and insurance requirements. The roles of local, state, and federal government in establishing these types of laws and regulations are still developing. Other National Cooperative Highway Research Program (NCHRP) 20-102 projects and parallel research efforts at the American Association of Motor Vehicle Administrators (AAMVA), United States Department of Transportation Joint Program Office (USDOT JPO), and National Highway Traffic Safety Administration (NHTSA) are discussing such issues.

SAE J3016 Levels of Automation

- **Level 0** – the human driver does everything.
- **Level 1** – an automated system on the vehicle can *sometimes assist* the human driver conduct *some parts of* the driving task.
- **Level 2** – an automated system on the vehicle can *conduct* some parts of the driving task, while the human continues to monitor the driving environment and performs the rest of the driving task.
- **Level 3** – an automated system can both conduct some parts of the driving task and monitor the driving environment *in some instances*, but the human driver must be ready to take back control when the automated system requests.
- **Level 4** – an automated system can conduct the driving task and monitor the driving environment, and the human need not take back control, but the automated system can operate only in certain environments and under certain conditions.
- **Level 5** – the automated system can perform all driving tasks, under all conditions that a human driver could perform them.

Ultimately, the impacts of AV deployment in public transit services are implied by the answers to these key questions:

1. What changes to the laws and regulations must be addressed?
2. What will the vehicle technology suppliers need to change in their designs to fulfill mandatory laws and regulations?

Overview of the NCHRP 20-102(02) Study

This project identifies a roadmap of activities to be performed by industry groups, legislatures, the federal government, and others that will facilitate automated roadway transit operations. The project is focused on the potential barriers imposed by operating authority policies, agency regulations, and governmental laws relative to the transit environment. Without adjustment, the combination of new technology with old rules could result in undue delays and restrictions to deployment, which reduces the cumulative societal benefits that could have accrued if automated systems technology was implemented earlier.

The project consisted of five tasks:

1. Develop a technology baseline for the current state of the practice in AV transit
2. Identify issues and impacts on transit vehicle driver and associated staff
3. Identify government regulations and laws impacting AV adoption in transit
4. Develop an implementation plan to address the challenges identified in Tasks 1-3
5. Prepare a final report consolidating Tasks 1-4

We have organized the five tasks to produce six working papers and this final report:

- **Working Paper #1 Automated Vehicle Technology Deployment Scenarios for Public Transit** provides an overview of the deployment scenarios for AV technology in transit applications.
- **Working paper #2 Safety Assurance Considerations – Blending Transit and Automotive Safety Analysis Methodologies** provides a foundation of technical information concerning safety from which subsequent considerations of operating agency policy and governmental safety regulations can be addressed.
- **Working Paper #3 Workforce Deployment – Changes and Provisions of Future Policy and Contracts** and **Working Paper #4 Operating Agency Policy – Potential Issues and Changes Required** address the implications of automating roadway transit vehicles with respect to local operating agency issues, including labor relations and training, broad operating planning and policy, and response to governmental laws and regulations.
- **Working Paper #5 Government Laws and Regulations – Issues and Changes to be Considered** addresses issues in the federal and state governmental laws and regulations over public transit, as well as issues and possible changes that may be required in vehicle designs to effectively comply with regulations.

- **Working Paper #6 Timelines for Industry and Government Preparation in Advance of AV Transit Implementation** addresses the preliminary timeline for deployment of progressive transit automation in overall consideration of technology, policy and regulatory changes that will be required.

This final report consolidates the findings of working papers #1-#6 and presents the research findings as a comprehensive list of additional activities that will be helpful in advancing AV transit in the United States.

TECHNOLOGY

State of AV Technology Development

Advances in research and development of AV technology are being announced almost daily, and industry perception is continually changing for even the most knowledgeable people in the field. New announcements or developments could substantially change these contents as time progresses, particularly regarding the technology availability timeline.

There are parallel research and development processes occurring between AV, which hold the promise of driverless operations, and connected vehicle (CV) communication technologies that enable safer and more efficient driving for both human- and computer-driven vehicles through warnings and detailed information sharing.

Automated Vehicles – More than 20 years ago, AV technology advanced in the U.S. via the USDOT (United States Department of Transportation) Intelligent Vehicle Highway System (IVHS) Automated Highway System (AHS) program (although many research initiatives preceded this technology demonstration dating back to the 1950s)[2]. In the early 2000s, development was reinvigorated by the DARPA Grand and Urban Challenges, which brought universities and private sector teams together[3]. AV technology today is generally advancing under private sector initiatives of the automobile industry original equipment manufacturers (OEMS), Tier 1 suppliers, software companies such as Google, robotics-oriented start-up companies, and combinations thereof.

Major recent strides in accuracy, affordability, and capability of sensors, software, computing, and geo-location technology are enabling AVs. A few OEMs are actively developing marketable automated vehicle models for the industry shown in **Figure 1**, and almost all major automobile manufacturers are racing to bring these new product offers to the market place as soon as possible.

[2] http://onlinepubs.trb.org/onlinepubs/sr/sr253.html

[3] https://en.wikipedia.org/wiki/DARPA_Grand_Challenge

Source: Mercedes

Source: Audi

Source: Nissan

Figure 1. Automated Roadway Vehicles Will Be on the Market by 2020s

Connected Vehicles – Over the last 20+ years, CV technology was primarily driven by USDOT initiatives. Some of the CV program evolution was in direct response to the numerous challenges of the grand vision of the AHS. CV technologies use wireless communications between vehicles, the infrastructure, and mobile devices to improve safety and mobility and reduce environmental impacts of human-operated vehicles[4]. NHTSA released an advanced notice of proposed rulemaking in August 2014 requiring dedicated short-range communications (DSRC) 5.9 GHz communications capability as a standard for light vehicle manufacturers and is expected to do the same for heavy-duty trucks and buses in the year following[5]. As of 2016, these mandates have not been made, but are still considered imminent.

CV communications can also use 3G and Fourth-Generation Long-Term Evolution (4G/5G LTE) technology for non-safety-critical applications. Vehicle-to-vehicle (V2V) and vehicle-to-other road users (V2X) technologies can improve safety by warning bus drivers of obstacles and imminent crash threats. Vehicle-to-infrastructure (V2I) applications can improve both transit vehicle travel efficiency and passenger service. CV technologies have been used for over 20 years now in hundreds of locales around the U.S. and the world for providing priority green time at traffic signals, known as transit signal priority (TSP).

Effectively implementing connectivity through V2V and V2I communications requires USDOT, state departments of transportation (DOTs), and local agency coordination, communication standards, OEM cooperation, and potentially international governmental coordination within the global automobile, transit, and commercial vehicle markets. Technology readiness was demonstrated in Ann Arbor, MI by University of Michigan transportation research institute (UMTRI) in the USDOT Safety Pilot program[6]. Large-scale field tests of CV applications in the U.S. are scheduled for 2018 in Tampa, FL; New York, NY; and the State of Wyoming, some of which include transit applications. These efforts are all ongoing and will not be addressed in this document[7].

Automated Transit Vehicles – The prospects for AV transit applications in general mixed traffic operation now appears realistic in the foreseeable future. Automated steering, throttle/propulsion and braking, and precision docking controls for buses have already been demonstrated to improve safety and efficiencies of buses augmenting the skills of human drivers[8]. Automated transit systems on fixed guideway facilities have been in use for over 40 years[9]. These transit systems have sophisticated supervisory control functions (connected technologies) necessary for safe and efficient management of even just a single transit line with a small number of individual vehicles. We foresee the marriage of the CV and AV worlds to enable truly driverless transit vehicles in the long term, with corresponding enabling developments in transit station and fixed facility design. In addition, we believe AV transit

[4] http://www.its.dot.gov/landing/cv.htm

[5] http://www.nhtsa.gov/Research/Crash+Avoidance/Vehicle-to-Vehicle+Communications+for+Safety

[6] http://www.its.dot.gov/safety_pilot/

[7] http://www.its.dot.gov/pilots/

[8] http://www.path.berkeley.edu/sites/default/files/documents/IM_15-1_low%20%282%29.pdf

[9] https://en.wikipedia.org/wiki/Automated_guideway_transit

applications will provide operational flexibility resulting in a whole paradigm shift that must now begin to be included in planning studies as shown in **Figure 2**.

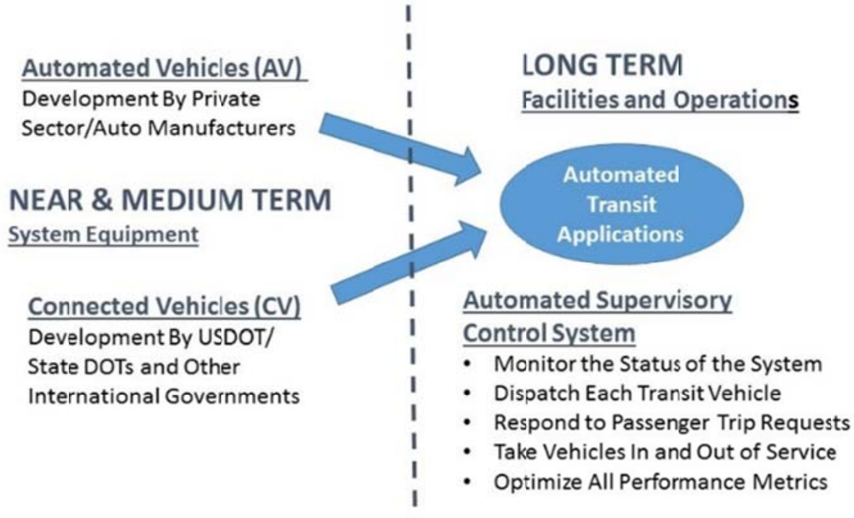

Figure 2. Parallel AV/CV Development Paths Potentially Coming Together for AV Transit Operations

Definitions of Business Models and Service Types

Much discussion is underway in the transportation industry about the place for the "private business model" of automated car services (e.g., automated Uber or Lyft), and the differences of services through a "public transit business model." Current terminology being used to address this private business model is a transportation network company (TNC), and some have referred to this as a "private transit" service. There are several hybrid combinations of these basic business models. A public transit entity could contract with a private vehicle operator for services and establish a formal public/private partnership(s) where the public entity provides a franchise to a private operator to use public assets (i.e. land/right-of-way) in providing the transit service.

Although fixed-route public transit service will certainly continue into perpetuity along very high-demand corridors as the basic backbone of public transit service, a new type of "first-mile/last-mile" service will likely develop, which is being described by Federal Transit Administration (FTA) as a "mobility on-demand" type of transit[10].

AV Fixed-Route Transit Service – Common transit service within urban areas providing traditional customer service with a fixed set of origin/destinations visited by the transit vehicle regardless of demand, but without a human driver. This fixed-route service would operate on set schedules/headways and vehicles on some routes could potentially only make stops when passengers indicate their intent to board or alight the vehicle.

AV On-Demand Transit Service – Common transit service within urban areas that provides automated dispatching and management of transit vehicles for a user-selected origin/destination combination. Rides are shared among any member of the public. Although solo rides are

[10] https://www.transit.dot.gov/funding/applying/notices-funding/mobility-demand-mod-sandbox-program

possible if the demand is very low for a given origin/destination pair and for a given time of day, this will not be guaranteed. The service operates much like a horizontal elevator. New passengers may enter or exit at any point on a route. This public transit service would have specified pick-up/drop-off locations designed for passenger convenience, which may number many more locations than existing fixed-route transit service. This service may provide specialized (i.e. minimized delay) routing of a given vehicle through the network of routes given the origins and destinations of the riders.

AV Paratransit or Rural On-Demand Transit Service – Working from the concept of paratransit as it is provided today, each registered user will be able to pre-define their personal pick-up and drop-off locations and time of day they will be taking their trip. Trip details are customizable to that specific user's personal needs, and changes are possible in real time as necessary. Advance reservations will be required only shortly (i.e. an intentionally vague time frame that could range from minutes to hours) before the trip actually occurs (depending on vehicle availability and trip location). When the trip reservation includes service involving a disability that requires special attention with human oversight of the boarding and alighting process (e.g., conditions where special equipment or visual/audio attention is required to assist the passenger), this may be accomplished via remote viewing/control of the vehicle and its special equipment by transit system personnel located in the operations control center or an onboard "customer service agent."

AV "Automated Taxi" On-Demand Service – An on-demand vehicle service provides customized rides which may or may not include ride sharing (as determined by pricing and user preferences). Passenger pick-up and drop-off would be determined by the user – e.g., my home driveway, my airline terminal curbfront by "door #3," my specific destination street address at the curb, and so on. These vehicle services operate like taxi services operate today.

Historical Context of Automated Transit Systems

Automated transit systems on *fixed guideways* have been in operation for more than 40 years.

Automated Guideway Transit/Automated People Mover Systems – The USDOT federally funded pilot project of the first fully automated guideway transit system began passenger service in 1964 at Pittsburgh's South Park (see **Figure 3**). Following this prototype system's demonstration of automation viability came the airport systems at Tampa Airport and Seattle/Tacoma Airports. These initial systems became known as automated guideway transit (AGT) systems, but the more whimsical automated people mover (APM) moniker soon became commonly used. Throughout the 1970s and 1980 the successful deployment of fully automated train systems began to allow fundamentally different configurations of airport terminal facilities to be created, such as the massive Atlanta airport with its spine APM system connecting numerous airside concourses. The Atlanta system has now been expanded to carry secure air passengers between destinations spread over more than a mile across the airfield. Many more airport APM systems have been built by numerous system suppliers in the following years.

A USDOT federally funded demonstration of the first **urban** APM application was the initial "loop" system in downtown Miami that began service in the mid-1980s. This "Metromover" was extended in the 1990s to connect several adjacent business districts with the Central Business District (CBD) and provide access points at over 20 station locations. Other urban systems were soon in service throughout the world, beginning with the fully automated urban system in Lille, France, which began service in 1983 and was followed by systems throughout Europe and Asia. One of the first **regional-scale** automated systems was the Vancouver Sky Train, which began fully automated passenger service in the mid-1980s and expanded several times to include multiple lines. Many fully automated **metro** systems are now in service throughout the world, such as the Singapore Metro subway system that runs without an operator or even attendant transit personnel onboard[11]. In general, the term APM is commonly applied to ***airport and special-use systems***, and the term AGT is commonly applied to **larger urban systems that reach a full regional/metropolitan scale** of service.

The last 50 years of AGT/APM system development has also provided a strong platform from which AV transit applications can extend. Fully automated, driverless trains have been safely operated over many millions of vehicle-miles with no service-related passenger fatalities. This is a testament to the rigorous and highly standardized testing process and safety regulations and procedures for AGT/APM systems (ASCE 21-13; International Electrotechnical Commission [IEC] 62267)[12]. The AGT/APM industry prepared this important foundation upon which the future mass transit applications of AV driverless roadway technology can build.

The functional elements of conventional ***automated train control systems*** will be important reference points as new robotic vehicles are deployed in transit service. These aspects of transit operations are defined below from the American Society of Civil Engineers (ASCE) 21-13 APM

[11] Observatory of Automated Metros, http://metroautomation.org/.

[12] http://orfe.princeton.edu/~alaink/SmartDrivingCars/Stanford_TRB_Conf_July2013/Transit&SharedMobility/Lott_TRB_Stanford.pdf

Standard and the relevant functionality will be addressed further in subsequent chapters of this working paper.

- **Automatic Train Control (ATC)** – The system for automatically controlling train movement, enforcing train safety, and directing train operations. ATC includes subsystems for automatic train operation (ATO), automatic train protection (ATP) and automatic train supervision (ATS).
- **ATO** – That subsystem within the ATC system which performs any or all the functions of speed regulation, programmed stopping, door and dwell time control, and other functions otherwise assigned to the train operator.
- **ATP** – That subsystem within the ATC system which provides the primary protection for passengers, personnel, and equipment against the hazards of operations[13] conducted under automatic control.
- **ATS** – That subsystem within the ATC system which monitors and manages the overall operation of the APM system and provides the interface between the system and the central control operator.

[13] Safety analyses of AGT/APM systems identify hazards which describe a condition that could result in an accident, without identifying an accident or potential causes. Distinguishing the hazard from the accident and its causes facilitates hazard analysis and selection of the mitigations designed to eliminate or reduce risk. Examples of hazards are train-to-train collision, train-to-structure collision, train collision with other object, and person struck by a train.

South Park Demonstration Project – Pittsburgh began service in 1964

Source: Official Skybus Webpage, http://www.brooklineconnection.com/history/Facts/Skybus.html

Miami Metromover began service in 1986; Source: Kimley-Horn

Singapore Land Transport Authority Northeast Line began passenger service in 2003, followed by the Circle Line (2011) and Downtown Line (2013)

Source: Kimley-Horn

Figure 3. 50-Year History of Fully Automated Guideway Transit Systems

Robotic Vehicles in Automated Transit Network Systems – At the time APM/AGT technology began to develop in the 1960s and 1970s, an extension of that concept began to develop for automated guideway systems that would provide a “network” configuration of guideways and stations along which small individual vehicles would operate. The concept included off-line stations such that AVs could bypass on the main line. This birthed the concept of providing “personalized” service directly between a passenger’s origin station to his/her destination station without stopping at any other stations along the route. Originally known as **personal rapid transit** (PRT) and **group rapid transit** (GRT), the concept was aggressively pursued through major planning projects and system technology development beginning in the 1970s. One of the first Urban Mass Transit Administration (UMTA) people mover system demonstration projects was the West Virginia University APM system in Morgantown, West Virginia. This system is currently being rehabilitated and remains the only network guideway system in the U.S. with trains dispatched by trip requests of passenger in the stations – a demand-response dispatching concept integral to the PRT/GRT concept[14].

Over the past 25 years there have been several examples of PRT/GRT systems in small, specialized public transit systems, which deployed robotic vehicles operating along dedicated transitways. These prototype systems (i.e., one of a kind systems) have been operating completely unmanned and steering themselves without physical guidance mechanisms. For purposes of this discussion, each are treated as “guideway” systems in that the vehicles follow a fixed route within a prescribed “transitway” like systems that are physically guided along their path. These robotic systems generally fall into the class of AGT called PRT, GRT, or in more common terminology used in recent years – “automated transit network” (ATN).

Three such systems are currently in public transit service using robotic vehicles steering themselves along a fixed-route transitway without physical guidance, although all **either calibrate their position from magnetic markers along the guideway** or **sense the guideway sidewalls using laser technology**. Two different size robotic vehicle systems built by a system supplier from the Netherlands are shown in their deployment locations in **Figure 4.** The larger vehicles in the figure have been operating in a business district since 2005, and the smaller vehicles have been carrying passengers within the office complex since 2010. The other operating system is located at Heathrow airport in London England and began passenger service in 2011.

[14] https://en.wikipedia.org/wiki/Automated_guideway_transit

Figure 4. Robotic Vehicle ATN Systems Currently Operating in the Netherlands (photos above) and in Masdar City, Abu Dhabi UAE (photos below)

Source: 2getthere

An important distinction of these example unmanned robotic (self-driving) APM transit systems is their operational dispatching “on-demand” when passengers request a trip. If a vehicle is not already at the origin point when the passenger arrives, one is dispatched to this station either with passengers that want to go that destination, or completely empty, much like how a bank of elevators works in an office building or hotel with many floors. Demand-response services that operate in ATNs demonstrate that small vehicles can make direct origin-to-destination trips with the same or better level of service as single fixed-route lines utilizing larger vehicles/trains that make mandatory stops at each station. The cost-benefit of such automated transit systems is critically linked to the fact that they do not have an employee dedicated to operating each vehicle. This on-demand travel feature is discussed further in Chapter 5 dealing with applying functional and operational capabilities of AV technology to public transit service.

Connected Vehicle and Automated Bus Systems – Several test-bed locations for prototype CV technology evaluations have been deployed in Ohio, Michigan, and Arizona. The USDOT Safety Pilot in Ann Arbor, MI included CV equipment (here-I-am and driver assistance warnings) on a small group of transit vehicles during the year-long evaluation of the technology. CV technologies on transit vehicles are envisioned to have a significant near-term safety impact, with bus crashes having significant severity, typically with many injuries and major traffic congestion after effects.

Some applications, such as platooning or cooperative-adaptive cruise control, require both automated and connected components. Bus platooning as shown in **Figure 5** was first demonstrated by California's Partners for Advanced Transportation Technology (Caltrans PATH) in 2003 using the magnetic nail technology developed for the automated highway system in the mid-1990s. The project was known as the Vehicle Assist and Automation (VAA) research program, and the deployment reached full demonstration in 2009.

Toyota also demonstrated this capability of running bus platoons combined with automated steering during the 2005 Expo in Aichi, Japan (see **Figure 6**). Toyota presented this important achievement to the international transit community as the Intelligent Multimodal Transit System (IMTS) at the 2005 ASCE International APM/ATS Conference (Aoki, Hayashida).

Demonstration project in 2003 Source: Caltrans	Demonstration project in 2009 Source: Caltrans PATH

Figure 5. VAA Demonstration Project Source: Caltrans

Source: Wikimedia, and: http://www.expo2005.or.jp/en/technology/imts.html)

Figure 6. Toyota IMTS Automated Buses

From these early demonstrations of unmanned robotic vehicles steering themselves and from past demonstrations of automated vehicles connected with other vehicles for platooning purposes (typically with a bus operator still sitting in the driver's seat), technology has advanced over the past decade to where vehicles will soon operate in a truly driverless mode – steering themselves, tracking their location with precise geo-coordinates, and knowing the specific path they must follow to any specific destination using high-definition digital maps. A new age of AV transit may be emerging although there are significant challenges ahead.

Lessons Learned from 50 Years of Automated Transit Systems

Half a century of experience with fully automated transit systems provides several lessons, and opportunities for AV transit technology applications in the next half century.

1. Enthusiasm can outpace the maturation of automated systems' capabilities. There are often many enthusiasts who see the great potential of automation in the field of transportation, and they push the dialogue to extreme promises of what can be accomplished.
2. Research and development of new technology requires major capital investments. Cutting edge research and development of automation technology is very expensive, typically involving:
    a. Conceptual design development of components, subsystems, and integrating technologies
    b. Prototyping major elements and proof-of-concept testing
    c. Development of test facilities by public and public-private partnerships and conducting numerous trials to vet the system concepts, determine actual performance capabilities, and thereby find and resolve weaknesses in the original design
    d. Commercial product/system design with appropriate analyses and further testing

   e. Producing a complete pilot/demonstration project with safe operations carrying passengers in service conditions suitably representative of the promised deployment operating conditions
   f. Adapting the design to satisfy transit-grade specifications for system deployment can induce or reveal design flaws that are difficult and expensive to resolve when going beyond the initial proof-of-concept deployments
3. Partnerships are required to deliver a complete operating system. Most transit systems involve integrating many different types of technology and construction, usually including the original technology developer (i.e., the vehicle system supplier), civil and architectural design firms, control and communication system integrators, construction firms, and often financial firms to address interim financing, bonding, and insurance requirements.

Hurdles to Deployment – Bringing advanced technology to the market place can face hurdles not apparent when the pursuit began. Several aspects of slowing deployment have been seen in the historical context of advanced transit system technology, such as:

1. **Funding regulations constrain sources of Automated Transit supply** – Transit system procurements within the U.S. which are made with grants from the FTA require a significant percentage of the system supply, including the transit vehicles, come from U.S. sources of supply. There are a variety of ways to satisfy the specifics of the "Buy America Act" requirements, but tracking and documenting all supply sources for system equipment and fixed facilities is a major hurdle that must be cleared for any federally funded transit project.
2. **Labor agreements may constrain fully automated operations** – Even when full automation is accomplished and there is no longer a need for operators or attendants onboard, there have been circumstances where labor collective bargaining agreements required a human operator be retained at the front of each train or onboard as an attendant.
3. **Owner/operator transit agencies want someone to backstop their risk** – Any new technology applied early in its development cycle requires a sharing of risk – both with respect to operating costs and liability.
4. **Acceptance by industry professionals and system operators will take time** – The acceptance of fully automated transit in the U.S. has been slow to take root. For most of the past 50 years, fully automated systems have only been deployed within or connecting to major airports, but have been rejected as a technology of choice for more conventional transit lines.
5. **Public acceptance of automated systems takes time** – The uneasiness that a passenger can feel when riding in a vehicle with no human operator can be a factor in the public acceptance of the fully automated transit system. And major publicity over any crash or collision involving an AV vehicle of any type will add to this discomfort.
6. **Challenges of "Safe" system design require extensive analysis and testing** – The transit industry's venture into full automation has historically been based on rigorous safety analyses that have been derived from the aerospace/military industry.
7. **Americans with Disabilities Act (ADA) mandates for Transit Systems are particularly difficult for fully automated systems** – Of major importance with respect

to fully automated transit systems is the U.S. government's enforcement of the Americans with Disabilities Act[15]. This set of governmental regulations has specific requirements for many aspects of a disabled transit patron's ability to access public transit.

Implications of Technology Readiness for Transit

Caltrans PATH work dating back to 2003 demonstrated several automated transit functions including automated platooning and automated steering on transit vehicles[16]. These prototype AV technology features were demonstrated in revenue service in Lane County, Oregon in a pilot deployment. The approach uses magnetic nails/markers embedded in the pavement along the bus rapid transit (BRT) route (and did so as well in the freeway tests in 2003).

Sensors – Passenger vehicle technologies, spurred by the Defense Advanced Research Projects Agency (DARPA) challenges in 2005-2009 have outpaced developments specifically targeted for general purpose transit operations. The integration of enabling technologies (sensors) for automated operation is just beginning to find its way into buses. As sensor technologies continue to advance, transit specific versions will need to address bus-specific form factors for equipment installation, but also sensitivities, placement, field of view, and other parameters different for modern transit vehicles than for passenger vehicles.

Artificial Intelligence – Artificial intelligence algorithms also need further development specifically for transit applications. Buses do not respond the same as passenger vehicles to basic throttle and steering commands and have more challenging requirements for algorithms that merge a bus into a stream of vehicles, weave across several lanes of traffic, or execute left-turns in intersections, for example. It is not enough to just drop in an algorithm(s) designed for passenger vehicles (or trucks, for that matter) and automate transit vehicle operation. Significant work is necessary to modify the operating parameters of these methods for transit operation in general mixed traffic environments.

The low-speed shuttle mode operating at Level 4, however, has shown significant developments over the last five years with several systems in revenue service and a host of new pilot deployments coming online across the world. These vehicles work with existing guidance and control technologies by substantially simplifying the operating environment (and thus the complexity of their control algorithms) and lowering the speed to minimize the severity of failures. The significant opportunity for automation in transit is likely scaling up the technologies developed for low-speed shuttle operation to use on common bus form factors

Communications – All shuttle operations require significant bandwidth and continuous communication links for remote monitoring and piloting in the event of vehicle system failures. Existing communications methods should be adequate for such operations and not impede any development of automation in transit services. There is no debate that CV technologies which link vehicles to continuous data streams the roadway infrastructure and from other vehicles about the operating environment can substantially enhance automated operations. There is

[15] https://www.access-board.gov/guidelines-and-standards/transportation/facilities/ada-standards-for-transportation-facilities

[16] http://www.path.berkeley.edu/sites/default/files/publications/PRR-2009-12.pdf

nothing inherently precluding computers from ingesting data from existing CV concepts and acting on it automatically, except that in many cases some information transmitted is expected to be consumed by a human driver (particularly the general category of "traveler information").

Mapping – High-resolution maps of the roadway network and street infrastructure are critical for enabling generalized Level 3 and Level 4 operation of AVs including transit vehicles. HERE has notably identified this as a market need and is beginning to offer this as a service[17]. Road centerline maps enabling route guidance for human-driven vehicles simply cannot be used by AVs for tactical negotiation of the roadway environment. Onboard storage of such a sub-lane-level precise (and hopefully accurate) dataset is formidable and requires more than what can be easily stored on a $99 navigation device. The data regarding traffic control elements such as speed limits, stop signs, traffic signals, turn restrictions, and so on is a similar need for Level 3 and 4 operation and specific data relative to transit operations will be needed for general operation of AV Transit. Since these data are typically managed by a myriad of state, county, and local government entities today, a standardized database of the infrastructure assets will almost assuredly need to be managed by a third party(s) or the federal government. This is a formidable challenge to generalize operation of AVs at Level 3 and Level 4 across the U.S. and the world.

AV Enabling Technologies and Transit Applications

Service applications of automation technology within transit vehicles are an important first definition of AV introduction to public transit. Subsequent chapters will address the associated **facilities** and **operational considerations** of AV introduction into transit systems. **Table 1** illustrates the correlation of human/machine interface functionality, and transit vehicle capabilities with progressively higher levels of automation on the NHTSA/Society of Automotive Engineers (SAE) scale.

Table 2 is organized as follows:

1. **NHTSA/SAE Automation Level** provides a first level correlation to the AV enabling technologies matrix presented in Table 2.
2. **HMI Operational Classification Level** provides a basic description of the human/machine interface (HMI) in each transit vehicle as the AV functions move from Level to Level. This indicates the level of responsibility, skill, and attention a human must maintain as the transit vehicle operates within its given operating environment.
3. **Example Automated Machine Functions** indicates a correlation to the AV enabling technology matrix of Table 2. Note that these are examples, since a comprehensive description is beyond the intent of this summary.
4. **Transit System Applications** provides a representative explanation of transit system application, without attempting to provide a comprehensive discussion.
5. **Potential Deployment Timeline.** Although timelines for deployment are difficult to forecast, the times indicated are a first attempt at assessing when a mature functionality for general transit use will be possible.

[17] https://company.here.com/automotive/intelligent-car/here-hd-live-map/

Note that the timeline for technical feasibility does not consider the separate timelines for institutional changes to operating policy, governmental agency regulations, and associated laws. These aspects will be addressed in subsequent working papers.

Table 1. Human/Machine Interface Functionality

NHTSA/SAE Automation Level	HMI Operational Classification Level	Example Automated Machine Functions	Transit System Applications	Potential Deployment Time Line
0. No Automation	Human driving	None	Conventional roadway transit vehicles, no automation	Today
	Human driving with warnings	Forward Collision Warning (FCW), Blind Spot Warning (BSW), Lane Departure Warning (LDW)	Conventional roadway transit vehicles with necessary sensors that provide warnings now and may enable automation later	Today - 2020
1. Function Specific Automation	Human driving with machine assistance	Adaptive cruise control, lane following, emergency braking (separately)	Safety-enhanced conventional roadway transit vehicle	
			a.) Enhanced technology buses	2015-2020
			b.) Enhanced technology automobiles (e.g., ride-share vans)	2015-2020
2. Combined Function Automation	Machine-driving in special environments for enhanced safety	Adaptive cruise control, automated braking, and lane following (together)	Advanced technology roadway vehicles with platooning with an operator on each vehicle monitoring the automated driving functions	
			a.) Special environment: buses in High occupancy vehicle (HOV)/managed lanes	2020-2025
			b.) Special environment: BRT in exclusive transitways with controlled at-grade crossings of city streets and pedestrianways	2015-2025

NHTSA/SAE Automation Level	HMI Operational Classification Level	Example Automated Machine Functions	Transit System Applications	Potential Deployment Time Line
3 **Limited Self-Driving Automation**	Machine-driving with human oversight	Automated driving over portions of a route with substantive travel distances, but with human operator available to take control if required	Automated operations between stations; onboard attendant (present for failure management and emergency incident management)	
			a.) Special environment: buses in HOV/managed lanes	2020-2030
			b.) Special environment: BRT in exclusive transitways with controlled at-grade crossings of city streets and pedestrianways	2020-2030
			c.) Mixed traffic environment: local bus routes and demand-response dispatch service on local city streets and arterials	2025-2035
		Automated driving with high-precision maneuvering at low speeds	Automated operations during high-precision maneuvers; onboard attendant (present for failure management and emergency incident management)	
			a.) Station approach and docking maneuvers at platform berth	2015-2020
			b.) Precision maneuvering in storage areas or within maintenance depot	2015-2025

NHTSA/SAE Automation Level	HMI Operational Classification Level	Example Automated Machine Functions	Transit System Applications	Potential Deployment Time Line
4. Full Self-Driving Automation	Machine-driving without human presence required; provisions for human-driving operations by roving “recovery” personnel or by remote control from a centralized or nearby location	Automated driving, path determination and station berthing without a driver onboard at any time from origin to destination,	Automated transit route or demand-responsive dispatch operations; empty vehicle repositioning/storage	
			a.) Special environment: protected (e.g., campus) environment on dedicated transitways at low operating speeds	2015-2020
			b.) Special environment: automated HOV/managed lanes with operator boarding at HOV/managed lane facility exit station stop	2025-2035
			c.) Special environment: BRT in exclusive transitways with controlled at-grade crossings of city streets and pedestrianways	2025-2035
			d.) Mixed traffic operations (i.e. interacting with other non-automated vehicles) at low speeds on city streets	2025-2035
			e.) Mixed traffic operations (i.e., interacting with other non-automated vehicles) at all speeds and in any roadway operating environment	2030-2050

Potential Evolution of New Transit Paradigms

The conventional transit bus coach has evolved to the 40' bus size typically used today because it provides a good balance of cost-benefit when the bus is full (driver compensation, fuel, and other operating costs offset by transit fares). Similarly, the use of 50' to 80' rail cars has provided the backbone of transit service in high-demand travel corridors over the past century. But inefficiencies of many current transit systems result simply because the buses and trains are not full of riders on the route throughout the day. From the passenger's perspective, in many communities it simply takes too long to get from an origin to a destination as the transit vehicle/train makes many stops along the route, and transfers between one route and another add additional waiting time.

Further detrimental impacts to transit ridership are created when transit agencies invest in expensive line-haul systems on major routes with the objective of raising the benefit-cost ratio for transit, while creating the last-mile/first-mile connection problem in doing so. If transit vehicles can be made smaller and be deployed to operate in more of a point-to-point type service on roadways using demand-responsive automation like an ATN, we believe that trip times of individual patrons will likely become closer to private autos or taxis, bringing more transit users to the system.

By removing the overhead cost of having an operator on every vehicle or train from the cost of fleet operations through automation, we believe the benefit-cost ratio of such an AV-based system could become an attractive option for transit agency investment, with the added stipulation that the regulatory and operational issues are addressed.

Near- and Medium-Term Operations

We posit that the earliest applications of AV technology to transit will involve the operation of buses as they travel along dedicated transitways such as exclusive BRT corridors, within HOV roadway facilities, or on existing bus on shoulder routes. In the near term, these facilities can be upgraded to allow AV technology to autonomously steer the vehicles, perform propulsion and braking control, operate in multi-bus platoons, and provide collision avoidance protection.

AV technology will allow the BRT vehicles to be platooned (or "virtually coupled") to create more train-like operation without the need for the track of light rail transit (LRT), and likely at reduced cost with similar line-haul capacity. This concept of dynamically reconfiguring a train of AVs is also being pursued for commercial trucks in the U.S. and Europe with serious emphasis on near-term operation due to cost savings due to fuel efficiency [18]. Anti-platooning and close-following laws in several states are critical regulations that need to be addressed (not only for trucks, but for buses in BRT lines) and a new research project addressing these legal constraints is needed.

Another development expected in the near term is the blending of the previously developed and demonstrated guidance technology using magnetic markers with rapidly advancing high accuracy global positioning system (GPS) technology, Inertial Measurement Units (IMUs) and high-definition maps. The combination of these technologies allows the vehicles to operate in a

[18] https://www.eutruckplatooning.com/About/default.aspx

free-ranging mode along some of the route, but then using the magnetic marker technology in the immediate vicinity of station stops using to provide extremely accurate and reliable docking and route alignment.

Figure 7. Toyota IMTS Automated Buses Source: Wikimedia

We believe the second context for early transit deployment of L4 AV transit will be in campus-like settings where there is a semi-controlled environment in which vehicles can operate at relatively slow speeds. This environment is commonly found in college and university campuses, large medical complexes, and master-planned communities where a transit vehicle operating at reasonably low speeds can interact with other traffic, pedestrians, and cyclists at low risk of injury or crashes. This scale of deployment has already been accomplished in the CitiMobil2 project conducted by the European Union, including limited operations on roads with mixed traffic and basic traffic signals as well, at very low speeds[19].

As collision avoidance, object/person detection technology, and automation control algorithms continue to evolve and become more accurate and capable of handling more complex situations, speeds can be increased and a wider range of roadway facilities can be navigated. These evolutionary steps will probably take more than 10 years to be safely implemented.

Long-Term Operations

Operating concepts may pass through a complete paradigm shift during the long-term development of AV transit applications. In fact, the flexibility of future transit systems that respond dynamically to changing demand patterns will likely gradually begin to replace many, if not most fixed-route transit operations.

As an example of this paradigm shift is the conceptual conversion of fixed guideway LRT systems to multiple physically or virtually entrained AV rubber-tire roadway transit vehicles as a BRT line. Conceptually, the future world of AV transit technology could allow the same vehicles

[19] http://www.citymobil2.eu/en/

to operate on some combination of dedicated transitways and/or conventional roadways while operating along their assigned travel path. In this potential future, a fleet of smaller automated transit vehicles could also be dynamically repositioned through strategic distribution anywhere in the transit network to serve changing demand patterns.

It is likely that the typical transit services during busy times of the day will include multiple riders bound for the same destination from the same origin or with a limited number of stops for pick-up or drop-off on a common route. We believe the difference from typical fixed-route, line-haul transit operations today will be the more direct origin-to-destination station service with fewer stops along the travel path of every transit patron. Transit users will have a travel time that closely matches the personal automobile.

Empty Vehicle Management is especially important since during significant periods of time (e.g., at night) there will typically be many fewer trip requests than during the peak periods. During those off-peak times the automated supervisory control system will send empty vehicles into storage locations placed throughout the transit network, typically near the portions of the transit network where high demands will arise during the next peak activity period. Then as trip requests are received, the supervisory system will dispatch a nearby and available empty vehicle to pick up the transit patron(s). It is this functionality that optimizes the use of energy and vehicle-miles by automatically removing vehicles from service as ridership demand drops.

Potential Near- and Medium-Term Changes to Fixed Facilities

The changes to transit facilities in the near term necessary to accommodate the new operational concepts for Levels 3 and 4 automated vehicles will begin to impact both conventional roadway and guideway transit facilities. The challenges of full automation and facilities that comply with safety and ADA requirements will be particularly challenging, particularly for locations that are planned to be built in the next 10 years.

Transit Stop Locations – In general, as transit operations begin to employ on-demand features that allow the transit users to create more customized trips, the number of locations where transit service can be accessed could increase. This also brings consideration of an increase to the number of weather-protected shelters at new transit stops.

With the origin/destination options increasing from what is provided today with conventional on-demand public transit service, the realities may include the need to provide enlarged zones for public transit vehicles to stop adjacent to or within high-demand trip generators like urban districts, university campuses, high-capacity rail stations and airports. Adequate provisions for protected boarding and alighting need to be provided for the number of large and small transit vehicles that may arrive during high activity periods.

Transition Zones at Protected AV Operating Environments – Early applications of Level 3 automated driving within protected environments like HOV/managed lanes of shoulder lanes will necessarily require the transit vehicles to transition back to primarily manual control as the vehicles leave the protected areas and enter mixed traffic operations still with perhaps Level 1 or Level 2 features available to the driver. These transition zones may eventually be possible while the vehicle is moving at high speeds, but for the near term the provision of a transition zone where the vehicle can be brought to a stop or substantially reduce the operating speed is likely to be necessary while the transition occurs.

Multi-Berth and Off-Line Stations – Transit station facilities in the near term will begin to change from fixed guideway station configurations. Starting in the near term, the functional ability to platoon AVs will immediately require BRT stations to accommodate multiple vehicles simultaneously stopping in each station along the line. This is the most eminent functional capability that will impact the conventional configurations of existing bus rapid transit facilities.

In the intermediate term, conventional online stations, at which all vehicles/trains passing along the main line transitway must stop at every station to allow any passengers to board or alight each vehicle/train, will likely gradually be replaced by off-line stations. Many vehicles (or virtual trains of vehicles) will bypass many stations without stopping since the transit supervisory system (e.g., the fare collection and vehicle dispatch system) will know if any passengers need to board or alight at each stop.

Maintenance and Storage Facilities – Maintenance facilities for AV automated transit systems will be configured much like conventional bus maintenance facilities, whereas the storage facilities can be located anywhere that is accessible to the route. Storage areas placed in locations away from the maintenance facility will be dynamically utilized throughout the day. Each storage facility's strategic placement and capacity will be designed to hold a portion of the operating fleet in a "hot standby" mode, until such time each vehicle is dispatched back into passenger service.

There will still need to be storage in or near the maintenance facility, since each vehicle will need a pre-service checkout and test, as automated guideway transit systems go through today. However, remote diagnostic checkout of all functions of vehicles will likely be possible due to existing wireless communications and software technology (e.g., Tesla vehicles and many other OEM vehicles get software updates over the air in 2016[20]), thus eliminating the need to size the maintenance facility storage areas to hold the whole operating fleet.

Findings on AV Technology Deployment in Transit Service

AV technology will impact the public transit industry in a dramatic way during the next two to three decades. Transit service types (fixed-route, demand-response, etc.) will be the key determinant of the business models by which transit services will be delivered. AGT/APM maturation over the last 50 years has shown that design of transit systems with automated functions must be applied in an integrated fashion across multiple subsystems (e.g., vehicle driving, vehicle location determination and guidance, vehicle/station berth interface, V2V and V2I communications, etc.).

Enabling AV transit technology is by its nature a complex system but is maturing rapidly. Technology is not expected to be the limiting factor for transit applications, unless the safety requirements are made so stringent that systems are too costly or too complicated to deploy.

[20] http://arstechnica.com/cars/2016/01/finally-over-the-air-software-updates-for-your-car-are-becoming-a-reality/

Specific designs for large transit vehicles combined with progressive demonstration in test environments will likely be the path toward improving safety and mobility of transit operations through automation.

Timelines expected for AV transit technology readiness are:

- Near term (5-10 years) will see applications of AV transit technology to BRT transitways and HOV lanes, in addition to more advanced technology applications for L4 vehicle location determination, guidance and pathing in controlled environments such as campuses.
- Medium-term (10-15 years) will reach L4 driverless vehicle operations in HOV, BRT, and low-speed mixed traffic environments.
- Long-term (15-30+ years) will have AV transit vehicles operating in all environments and will be integrated into fully automated transit systems.

Subsequent working papers explore in more detail the issues and barriers to adoption of AV transit technology by transit operating agencies. These considerations will frame the roadmap of activities needed to overcome these barriers and improve safety and mobility for transit patrons through automation.

Research Projects on AV Technology Deployment in Transit Service – The timeline for initial deployment of AV technology in transit service starts now, and the early years of partial automation will be as important as the later years of full automation. The key research projects for undertaking based on the considerations and findings of this working paper are as follows:

1. **AV Transit Liability, Insurance and Risk Acceptance** – Research would be helpful on the liability aspects and insurance coverage that will be distributed between the vehicle manufacturer, the operating agency and the human operator, particularly for times when transitions from automated vehicle control to human operator control is a frequent occurrence. The area of focus would be from legal and contractual (collective bargaining) considerations. The related aspects of employee and passenger "acceptance of risk" when onboard public transit vehicle where the human operator is no longer responsible for all functions required to operate the vehicle is a related area also needs further legal research, which could be addressed under this project.
2. **Legal Constraints to Platooning and Virtual Coupling** – The concept of dynamically reconfiguring a train (platoon) of AV vehicles has relevant application both in the near term and increasingly in the medium and long term. Anti-platooning and close-following laws in several states are critical regulations for this research project to determine their legal application to buses in BRT transitways or HOV lanes for the near term. And for the long term the legal implications of such laws on lower-speed arterial street as well as high-speed freeway operating conditions would be beneficial if considered.
3. **Features and Configurations of Transit Fixed Facilities** – Beginning with an assessment of the practical and technical implications for providing more direct service without intermediate stops using off-line stations, a beneficial research project would evaluate the implications for operations in line-haul high-capacity. The work would evaluate how this new concept could potentially allow almost all stations to be designed for fewer number of vehicle berths. Near- to medium-term changes to transit fixed facilities research activities would include exploring features and right-of-way requirements for station/stop locations, transition zones from the main operating lanes

into off-line stations, and the configuration of multi-berth boarding positions. In addition, precision docking can enable all stops to offer level boarding for the physically challenged.

4. **Virtual Entrainment of AV Transit Vehicles** – Additional research would focus on the long-term implications of dynamic entrainment with virtual coupling/uncoupling to allow longer “trains” moving through the transitway/roadway system then separating into individual vehicles when berthing at stations.

SAFETY

USDOT Automated Vehicle Safety Initiatives

NHTSA Federal Policy Guidelines for Automated Vehicles

In September of 2016 the National Highway Traffic Safety Administration of the U.S. Department of Transportation released a major policy document titled Federal Automated Vehicles Policy – Accelerating the Next Revolution in Roadway Safety.[21]

Safe Design of Highly Automated Vehicles (HAVs) – NHTSA has made the following statement in the September 2016 policy document (p. 11, ref. footnote 1. above) concerning the self-certification of safety by HAV developers/manufacturers. It should be noted that with respect to the safe design of AV technology for any type of public roadway testing and deployment, NHTSA retains the requirements for compliance with the FMVSS.

> *Under current law, manufacturers bear the responsibility to self-certify that all of the vehicles they manufacture for use on public roadways comply with all applicable Federal Motor Vehicle Safety Standards (FMVSS). Therefore, if a vehicle is compliant within the existing FMVSS regulatory framework and maintains a conventional vehicle design, there is currently no specific federal legal barrier to an HAV being offered for sale.*
>
> *However, manufacturers and other entities designing new automated vehicle systems are subject to NHTSA's defects, recall and enforcement authority. DOT anticipates that manufacturers and other entities planning to test and deploy HAVs will use this Guidance, industry standards and best practices to ensure that their systems will be reasonably safe under real-world conditions.*

In establishing a framework within which each vehicle developer/manufacturer is to design for safe HAV operations, the September 2016 policy document identifies these three realms of guidance for design performance (**Figure 8**):

- **NHTSA Guidance** – Scope and process
- **Automation Functional Key Areas** – Specific to each HAV system
- **Cross-Cutting Areas** – Applicable across all automated equipment/subsystems

The *operational design domain* (ODD) defines a particularly relevant set of criteria which is discussed further in Chapter 5 with respect to considerations for HAV applications in public transit service. Also important is the definition NHTSA gives to the "*fall back minimum risk condition*":

> *The fall back minimal risk condition portion of the framework is also specific to each HAV system. Defining, testing, and validating a fall back minimal risk condition ensures that the vehicle can be put in a minimal risk condition in cases of HAV system failure or a failure in a human driver's response when transitioning from automated to manual control.*

[21] http://www.nhtsa.gov/nhtsa/av/

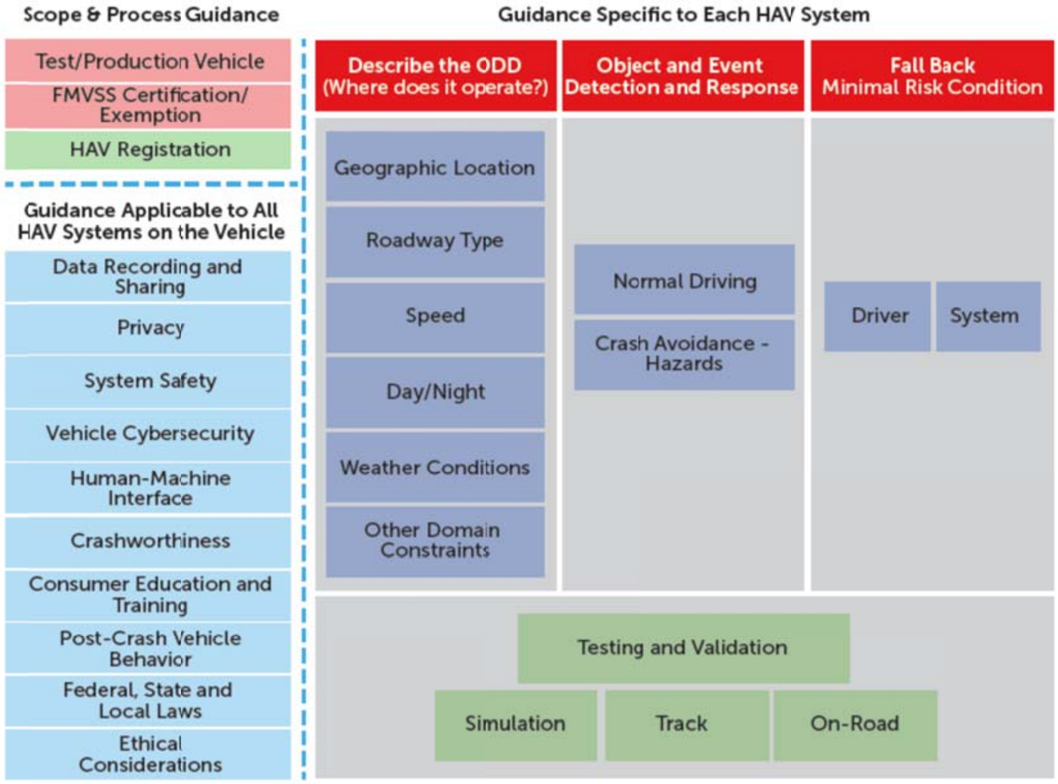

Figure 8. NHTSA Framework for Guidance of and Safe HAV Design Performance

Several important articles and reports have been referenced in the NHTSA policy document, including published articles by automobile manufacturers active in the CAMP Consortium[22]. Also, particularly noteworthy are several NHTSA reports that are specifically addressing **electronic control systems** for vehicle automation.

- USDOT/NHTSA Report to Congress: "Electronic Systems Performance in Passenger Motor Vehicles" http://www.nhtsa.gov/Laws-&-Regulations/NHTSA-Reports-Sent-To-Congress
- Assessment of Safety Standards for Automotive Electronic Control Systems http://www.nhtsa.gov/DOT/NHTSA/NVS/Crash%20Avoidance/Technical%20Publications/2016/812285_ElectronicsReliabilityReport.pdf

These technical documents provide valuable information on safety methodologies and processes that provide a benchmark for continuing decisions by NHTSA as it moves toward rulemaking changes and additions to its safety regulations for HAV roadway vehicles.

[22] CAMP – Crash Avoidance Metrics Partnership (CAMP) Automated Vehicle Research (AVR) Consortium http://www-esv.nhtsa.dot.gov/Proceedings/24/files/24ESV-000451.PDF

Federal Motor Vehicle Safety Standards and Regulations

Since the 1970s the National Highway Traffic Safety Administration has been establishing and maintaining safety standards known as the Federal Motor Vehicle Safety Standards and Regulations for the automobile industry in the United States[23]. Other countries around the world have followed suit with their own very similar safety requirements. As summarized in the referenced article, the three series of automobile safety requirements that are best known are as follows:

1. Crash avoidance (100-series)
2. Crashworthiness (200-series)
3. Post-crash survivability (300-series)

NHTSA also has defined a battery of tests and test acceptance criteria to monitor compliance with the FMVSS. NHTSA performs tests and rates the demonstration of compliance of every vehicle model sold in the United States though a five-star rating system. These traditional safety requirements will likely be gradually expanded to include HAV technology safety tests.

Currently, a process is underway to assess the applicability of FMVSS standards to AV technology[24]. Through this ongoing review process, NHTSA is identifying which standards may need to be changed to properly address highly automated roadway vehicles, as well as identifying what new FMVSS standards will need to be added to test and confirm the adequate safe design of both light and heavy vehicle AV products and other automation conversions (such as aftermarket AV "kits") that will likely be brought to the US marketplace.

FTA National Public Transportation Safety Program

The USDOT Federal Transit Administration has been preparing for a new Public Transportation Safety Program since 2013 when FTA introduced the transit industry to fundamental changes to the federal transit safety program authorized by MAP–21. The final rulemaking was published as 49 CFR Part 670 in the August 11, 2016 Federal Register and established the new Safety Program – now in effect as of September 12, 2016[25].

Overall, the new rules establish new requirements for Safety Plans and Safety Plan Documentation and Record Keeping, as well as providing more specific guidance for hazard analysis, management and the related risk assessments through a **Safety Management System**.

Safety Management System – One of the central elements of the FTA Safety Program is the new Safety Management System (SMS) framework[26], which has been introduced in 2016 through FTA outreach. SMS is now being publicized and explained by FTA on multiple fronts,

[23] James Martin, et al; University of North Carolina, Certification for Autonomous Vehicles https://www.cs.unc.edu/~anderson/teach/comp790a/certification.pdf

[24] http://ntl.bts.gov/lib/57000/57000/57076/Review_FMVSS_AV_Scan.pdf

[25] https://www.gpo.gov/fdsys/pkg/FR-2016-08-11/pdf/2016-18920.pdf

[26] https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/FTA_SMS_Framework.pdf

beginning with the most safety-critical operations of rail/fixed guideway public transit systems. Applicability to bus operations is also being discussed by FTA with even smaller transit industry bus operators, as noted above. Eventually the SMS framework will be advocated to any size transit operator for application to their entire public transportation service.

State Safety and Security Oversight – One of the key tenets of FTA's safety regulations was established 25 years ago, when the individual states were given responsibility for safety oversight of fixed guideway and rail systems. In the 1991 Intermodal Surface Transportation Efficiency Act (''ISTEA''), Congress determined that the States, *not FTA*, should be the principal oversight authorities for rail transit within their jurisdictions, given that public transportation is an inherently local activity which, with few exceptions, does not cross state boundaries.

Known as State Safety and Security Oversight (SSO) program, a new Rule 49 CFR Part 674 was finalized in March 2016 that provides the latest update to the requirements[27]. Under this regulation, each state is required to identify a state safety oversight agency (SSOA), examples of which are the Public Utility Commission in California and the Department of Transportation in Florida.

Vehicle-Focused Safety Standards and Methodologies

NHTSA has been comparing and assessing the attributes of several safety standards, methodologies and guidelines as they progress toward becoming the regulator of the various levels of AV technology. Their specific focus has been on the electronic and computer systems that assume the decision-making process for driving the AV along its path:[28]

MIL STD-882E: Department of Defense Standard Practice, System Safety – This system safety standard practice identifies the Department of Defense systems engineering approach to eliminating hazards, where possible, and minimizing risks where those hazards cannot be eliminated. MIL STD-882E is a required practice as part of military systems automation design.

DO-178C: Software Considerations in Airborne Systems and Equipment Certification – This is an industry-accepted guidance for software in airborne systems and equipment used in the Aviation industry. With the earlier advancement of flight control automation and the important lessons learned within avionics, this standard for automation control software is an important reference for NHTSA.

ISO 26262: Road Vehicles, Functional Safety – This **voluntary** industry standard is the first comprehensive and voluntary automotive safety standard that addresses the functional

[27] https://www.gpo.gov/fdsys/pkg/FR-2016-03-16/pdf/2016-05489.pdf

A history of the related federal regulations is covered first in the Federal Register record, followed by commentary on comments received to the proposed rulemaking. The actual new Part 674 begins on page 28 of the pdf document.

[28] Text combined from the descriptions found to NHTSA reports, with web links provided in Section 1 above – see page 2 in NHTSA Assessment of Safety Standards for Automotive Electronic Control Systems, and pp. 7-9 in NHTSA Report to Congress: "Electronic Systems Performance in Passenger Motor Vehicles".

safety of electrical and/or electronic (E/E) and software-intensive features in road vehicles. ISO26262 has been developed from the original IEC 61508 machine automation safety standards and from other machine automation safety standards for different manufacturing industries. ISO26262 is a key element of SAE automotive safety standards.

FTA New Bus Testing Process – As part of 49 CFR Part 665, all new bus models must undergo testing at FTA's Altoona Bus Testing Facility. These procedures include tests for performance at maximum gross vehicle weight (speeds on grades, parking brake operations), maintainability testing, noise, fuel economy, emissions, and safety tests. Safety tests include basic braking distance tests on a variety of surfaces, structural integrity of the vehicle chassis when stressed in different manners. New tests for AV sensors and actions would likely need to be developed and it would be likely that other test criteria may need to be applied for smaller AV transit vehicles that are not the same size as a standard coach.

Machine Automation Functional Safety Standards

In the *automated guideway* transit industry, there has been a growing interest in the application of a **functional approach** to defining and analyzing safety of the equipment and subsystems. IEC 61508 – Functional System Safety defines functional safety in terms of the requirements and analysis methodologies for electrical/electronic/ programmable electronic (E/E/PE) safety-related systems. This is a product design standard that has had major impact on the automotive industry, and by extension the future safety standards for AV Transit.

Safety Integrity Levels (SIL) – One of the most important contributions of the IEC 61508 functional safety standard was the concept of **safety integrity levels** (SILs). This use of SIL criteria to define functional safety is specifically oriented toward manufactured products that have specific product design requirements that must be met. Within the 61508 framework, the assessment of safe design must be **certifiable** for specific components, assemblies/subsystems and entire electronic/programmable control systems. SIL ratings are used to specify the target level of safety integrity.

A benefit is that the approach using quantifiable SIL criteria makes failure rate probability calculations easier for third party verification and validation. Through commercial use of the IEC 61508 standards-based analysis methodology, off-the-shelf supply of pre-certified components can be established.

ISO 26262 Road Vehicles – Functional Safety

The automotive industry has also applied the SIL methodology in a comprehensive manner using specific Automotive Safety Integrity Levels (ASIL) criteria in ISO 26262. Note again that ISO 26262 is one of the key safety standards that NHTSA has been evaluating as part of the Model Policy and regulatory role.

This automotive safety standard is specifically defined from the overall framework of functional safety methodologies defined in IEC 61508. Automotive Industry applications of ISO 26262 are being used internationally and adopted by the SAE. These vehicle-focused safety methodologies are highly relevant to connected and automated vehicle technology development and manufacturing, including the supply of public transit vehicles.

Standards Program of the Society of Automotive Engineers

A series of new standards under the auspices of the SAE have been in development for several years which are intended for application to AV technology. Some of these standards deal with communications links for inter-vehicle communications and for vehicle-to-roadway infrastructure and internet "cloud-based" functionality.

The standards are divided into two topical groups. The Part 1 topical group comprises 16 standards covering Terms & Definitions; Interoperability; and Vehicle & System Performance Requirements. Within this Part 1 group, standards are being developed on topics such as (selected examples):

- Automatic Emergency Braking Test Methods and Performance Assessment (SAE J3097)
- Automated Driving Reference Architecture (SAE J3131)
- AV Definitions: Key Terms Related to Human Interaction with Automated Driving Systems (SAE J3088)

Part 2 topical group deals specifically with safety, and has sub-groupings of Functional Safety; Safety & Reliability; Active Safety; Safety & Human Factors; and Other Safety. Selected examples from Part 2 are:

- Design FMEA (Potential Failure Mode & Effect Analysis) and Process FMEA (SAE J1739)
- Adaptive Cruise Control Operating Characteristics & User Interface (SAE J2399)
- DSRC Requirements for V2V Safety Awareness (SAE J2945/2)
- Recommended Practices for Signal Preemption Message Development (SAE J2945/10)

Product Orientation of Vehicle-Focused Safety Methodology

NHTSA has embraced the SAE standards program as a key element of the USDOT policy for highly automated vehicles. Therefore, it is anticipated that the vehicle manufacturers will be using these standards as the primary source of the vehicle-focused safety methodology from this point-in-time forward, within the functional safety framework based on ISO 26262.

By utilizing this set of standards for functional safety that allow a more precise and "transferable" calculation of the SIL level for components, assemblies and subsystems, manufacturers of AVs can supply products that are certifiable with respect to their safe design.

With this expectation of product certification, it is important to consider that the safety integrity levels and the associated methodologies are **product oriented**, and as such have "safety" criteria defined by design objectives and product failure norms. Per the NHTSA report referenced above[29], the definitions of safety in ISO 26262 are the "absence of unreasonable

[29] Table 1 Definition of Safety and Hazard, p. 11; NHTSA Assessment of Safety Standards for Automotive Electronic Control Systems; DOT HS 812 285, June 2016

risk." The definition of hazards is based on operating conditions for the manufactured components, assemblies and control systems – conditions in which failures are characterized by control system response that has "unintended behavior of an item with respect to its design intent."

Transit System-Focused Safety Standards and Methodologies

The new initiatives by FTA to emphasize SMS are timely in that they begin to create a safety culture within each transit operating agency and authority. However, the details of the FTA requirements within the SMS framework are mostly in the form of guidelines which generally have intended application to fixed guideway/rail systems. The applicability of SMS methodologies to bus operating agencies is also highly relevant – especially with respect to safety risks of transit vehicle interactions with pedestrians and other traffic.

To put the topic of system-level safety analysis in perspective, it is helpful to understand that the systems engineering practices and the related safety engineering methodologies generally referenced in the fixed guideway transit industry have been drawn from the standards guiding the automation of military and avionics systems over the past 50 years. The transit industry was simultaneously advancing the applications of automated systems when the first fully automated transit systems were deployed in the 1960s.

Safety engineering in these parallel fields began with a principal focus on the hazardous implications of failure modes which could result in "catastrophic" accidents. Safety was viewed in this context to assess and mitigate the risks of serious equipment damage, personal injury or fatalities resulting from such hazardous conditions.

MIL Standard 882

The approach to safety defined by MIL Std. 882 starts with a **Hazard Analysis** process that can begin in an early conceptual stage. Hazard Analysis combines the severity of the accident and the probability of occurrence of the hazard to create the risk index for the system. The most recent versions of MIL Std. 882 add considerable information about the safety analyses of *software* from its importance in the control of the system – defined as a "software control category."

The FTA began to adapt the processes and methodologies of the military programs as the safety analysis of transit systems began to match the complexities of aerospace systems. During the 1980s and 1990s MIL Std. 882B and its successor 882C (i.e., version "C") became a specific document that transit agencies and system designers/suppliers called for in technical specifications and project requirements.

The "system-level" approach to a safety analysis from MIL Std. 882C System Safety Program Requirements proved very effective for guiding the increasingly more automated train control technologies that were being applied in the fixed guideway transit industry during the 1970s, 80s and 90s.

System-Focused Risk Assessment and Hazard Resolution Process – The Automated People Mover Standards Committee of the ASCE determined in the review process for the 2005 update to ASCE 21 there was a need to codify the processes of MIL Std. 882C as it had been applied to transit systems in a manner that disconnected the text from the continually evolving Military Standards process. Because of this initiative, the essential content of MIL Std. 882C was adapted to a specific application for purposes of the APM Standard, and included in the ASCE-21 as Annex A: System Safety Program Requirements.

The System Safety Program (Annex A) of the APM Standards now covers the essential requirements for:

- System Safety Program Plan
- Preliminary Hazard Analysis
- Subsystem Hazard Analysis
- System Hazard Analysis
- Operating and Support Hazard Analysis

A distinguishing characteristic of the system-focused approach to the safety analysis is that the *whole operating system* is addressed, including vehicles, guideways, stations, surrounding right-of-way and all places and ways that people interact with the system.

This process includes full documentation of the hazard resolution activities through a **Hazard Tracking System**. This Hazard Tracking System is used to manage and record identified hazards, associated mishaps, risk assessments, identified risk mitigation measures, selected mitigation measures, hazard status, verification of risk reductions, and risk acceptance. This is a document that is maintained from the early design phase of the system notionally updated throughout the lifecycle.

Safety Standards for Software-Controlled Functions – Highly relevant to modern automation technology is the use of computers to control many functions of machines, including where software performs vital, safety-critical functions. In the case of the ASCE 21 APM Standard, several means of using software-based computer controls are identified.

More recently multiple new standards have been advanced to specifically address safety of software-controlled systems, including the latest version of MIL Std. 882E which has a specific section addressing software control functions for military systems. Also, the avionics industry has produced an important software standard – *DO-178C: Software Considerations in Airborne Systems and Equipment Certification.* Both software standards have been evaluated by NHTSA in the referenced NHTSA report from June 2016 and a useful comparison of the basic tenets of each of these standards for electronic and computer processor software controls has been made with ISO 62626 and other software safety standards.

FTA Rules, Methods, and Guidelines Drawn from MIL Standard 882

FTA Safety Program Requirements provide a general process that applies to all **rail** transit systems. Drawing from MIL Std. 882, FTA requires that an organized process be undertaken to perform a suitable safety analysis for any transit “system” project as a condition of receiving federal funding.

Rule 49 CFR Part 673 *Public Transportation Agency Safety Plan* establishes the requirements for Safety Plans, Safety Management Systems, and Safety Plan Documentation and Recordkeeping. As part of these updated program requirements, a further structuring of this process has been established under the new SMS requirements (see Chapter 2) in which the conducting of a hazards analysis process is central to the requirements.

Although FTA does not specifically address automated train control or other signaling, communications, electronic subsystems, or software, there are typically other such standards that are identified, such as:

- American Railway Engineering and Maintenance of Right-of-way Association (AREMA) Communications and Signals Manual of Recommended Practices
- IEEE 1483 for safety verification
- IEEE 1012 for software Verification & Validation

This process of referring to other standards for complex control system requirements establishes a potential model for the incorporation of AV technology to public transit applications under the FTA guidelines and program requirements.

Automated Guideway Transit System Safety Standards

In the United States, a complete functional and operational standard that includes specific safety requirements has been developed under the auspices of the ASCE (See **Figure 9**). The ASCE 21 Automated People Mover Standard (as discussed above) has had multiple updates of the past 20 years, and continues to be actively improved by representatives from APM technology system suppliers, owner/operator entities, and academia from around the world.

In 2009 the International Electrotechnical Commission published a new safety standard for Automated Urban Guided Transport (AUGT) which is structured slightly differently from the ASCE standard (See **Figure 9**). IEC 62267 is specifically directed toward full regional unmanned metro systems.

Figure 9. Two International Standards for Fully Automated Guideway Transit Systems

Added to these two international standards are the comprehensive railway system standards prepared and maintained under the European Union's Cenelec EN program. A noted set of related safety guidelines for EN standards are called MOD Safe – Modular Urban Transport Safety and Security Analysis. These guidelines are intended for hazard assessments and safety analyses throughout the life cycle of a transit system.

ASCE 21 Automated People Mover Standard[30] – The committee that continues to enhance its content and make editorial improvements of the ASCE-21 APM Standard has worked continuously since the first version was published by ASCE in 1996. The work of the committee follows the ASCE standards committee criteria that ensure a balanced consensus process. The standard addresses minimum functional design requirements, safety requirements, acceptance testing requirements and operating requirements for fully automated guideway transit systems. The document has been developed to span as many guideway-based technologies as possible, while still maintaining acceptable requirements for both small and large fully automated systems.

Figure 10 illustrates this ASCE 21 maximum unsafe failure rate for the ATC system in comparison to the IEC 61508 SIL criteria for functional safety in machine automation – criteria also used in the ISO 26262 safety standard for automobiles. The threshold between SIL 3 and SIL 4 is shown to be the equivalent level of probability of dangerous failure condition that is deemed to be Unacceptable in the transit system-focused methodology prescribed in the ASCE-21 Automated People Mover Standard[31].

Safety integrity level (SIL)	Average frequency of a dangerous failure of the safety function $[h^{-1}]$ (PFH)
4	$\geq 10^{-9}$ to $< 10^{-8}$
3	$\geq 10^{-8}$ to $< 10^{-7}$
2	$\geq 10^{-7}$ to $< 10^{-6}$
1	$\geq 10^{-6}$ to $< 10^{-5}$

ASCE 21 Automatic Train Control MTBHE requirement of one failure in (1×10^8) hours, or one failure in 11,415 years

Figure 10. Safety Integrity Levels Defined in IEC 61508 with Comparison to the Mean Time Between Hazardous Events for Automated Train Control Systems in ASCE 21

IEC 62267 Automated Urban Guided Transport Safety Requirements – This standard was first published in 2009. As the name indicates, this standard for "automated urban guided transport" is intended to address safety requirements for large, urban metro systems and not small scale "people movers". This IEC standard is specifically targeted toward:

"… the safety requirements needed to compensate for the absence of a driver or attendant staff who would otherwise be responsible for some or all of train operation functions."

[30] http://ascelibrary.org/doi/book/10.1061/9780784412985

[31] In Figure 10, PFH = "probable failures per hour" and MTBHE = "mean time between hazardous events"

This limitation of the intended “scope” of the IEC 62267 AUGT safety requirements to only those functions that are assumed by the automation in replacement of a “driver” makes it not directly comparable to standards that encompass all aspects of an operating transit line – such as ASCE 21. Further, the organization of the IEC standard content is by driver/attendant functions which are assumed by the automated system.

An important supplemental safety document to IEC 62267 was published as a separate technical report following the publishing of the standard. This work involved an international working group that developed a consensus statement of a “generic system-level hazard analysis”. Published under the same IEC number, the special study document carry’s the designation as a “Part 2” technical report – IEC 62267-2.

European Standards for Railway Applications – European railway standards called **Cenelec EN standards** address Reliability, Availability, Maintainability and Safety (RAMS) in an integrated and cohesive manner, and have strong correspondence to many of the IEC standards. Relevant EN standards for fully automated fixed guideway transit systems include:

- CENELEC EN 50126 – Railway Applications – The specification and demonstration of Reliability, Availability, Maintainability and Safety
- CENELEC EN 50128 – Railway Applications – Communications, signaling and processing systems – Software for railway control & protection systems
- CENELEC EN 50129 – Railway Applications – Communications, signaling and processing systems – Electronic systems for signaling

European standards, as well as the IEC standard 62267, are designed specifically to assist operating agencies that have manually or semi-automated railways in the orderly process of migrating them to full automation of the transit line. Another key difference of the EN safety program in the railway standards when compared to ASCE 21 is that **safety risk is assessed based on functions rather than components** – with similarity to the principles of functional safety. The safety criticality of a **function** determines the Tolerable Hazard Rate (THR) for that function, and the corresponding SIL that needs to be achieved. This determines the acceptable failure rates and development processes for the hardware and software that support each function.

There is also an EN compatible set of safety assessment and analysis guidelines developed under the auspices of the European Union known as **MOD Safe**, or Modular Urban Transport Safety and Security Analysis. The work evaluated where there were deficiencies of standardization for technical safety functions when applying the safety process over the complete project life cycle and multiple guideline documents have been prepared for progressive use.

Process Orientation of System-Focused Safety Methodology

NHTSA's assessment of electronic control system safety standards concludes that MIL Std. 882 is "not a safety *certification* standard." Rather MIL Std. 882 is a process of safety analysis and documentation that can support appropriate oversight through reviews and audits, while still allowing flexibility to the project program manager and contractors to determine the details of the safety design[32]. It remains a system-focused safety analysis process that is structured to protect human life and property.

In addition, the NHTSA report from June 2016 that assessed multiple different safety analysis methodologies described the difference between MIL Std. 882 and other methodologies in the following way.

> *ISO 26262 and DO-178C both make safety engineering an integral part of the product development process. On the other hand, MIL STD-882E specifies a system safety engineering process separate from but parallel to the product development process.*[33]

It is reasonable, therefore, to use a different characterization of the system-focused process of safety analyses and assessments for transit applications of automation technology, when compared with methodologies that focus on the functional safety of machines and manufactured products leading to "safety certification."

Considerations of AV Transit Safety Assurance

For consideration of the safety analysis process suitable for AV roadway vehicle technology deployment in public transit service, the focus of the methodology should be placed on the whole operating system throughout the project life cycle. However, this system focus does not obviate the need for operating vehicles that have been safely designed as products intended for use in public transit service. This process of comprehensive safety assurance methodology means that all aspects of the specific site deployment must be addressed with each project.

Further, there is an important complication to the safety assurance process for AV transit with the reality that there will be a progressive application of different levels of automation, particularly for bus operations. This will inherently create different and important new dimensions of hazards and risks that analysis processes must address.

The best approach appears to be a blending of automotive and transit system safety methodologies discussed in the previous chapters. The discussion that follows provides considerations of how these and other factors may play into a comprehensive safety assurance process for AV transit systems.

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[32] P. 23, Section 3.11 Review, Audit, and Certification; NHTSA Assessment of Safety Standards for Automotive Electronic Control Systems; DOT HS 812 285, June 2016

[33] P. 9, Section 3.1.1 Process Prescription, Ibid

Nature of Hazards and Risks in the AV Transit Operating Environment

Each project and local site application of automated roadway vehicles will necessitate specific attention to the operating environment and inherent hazards that could be faced for that specific transit service. Applying an appropriate system safety assurance process is essential, along with the overall planning and execution of the system safety program in accord with the FTA SMS guidelines.

A definition by NHTSA of design criteria for “highly automated vehicles” would include the ODD (refer to **Figure 8** above) – operational conditions that also have corresponding vehicle-related failures and hazards for which the vehicle design must safely mitigate. From these requirements, the vehicle manufacturers will assess the probability of a hazardous event occurring from which unacceptable failures could occur that are outside the vehicle’s intended design.

This SAE compliant design will be done within an AV manufacturer’s self-certification process and the corresponding safety assessment letter submitted to NHTSA. The “cross-cutting” areas and automation functions that are to be addressed in the letter are summarized in **Table 2**, which is taken from p. 34 of the recently released USDOT/NHTSA policy document.

Table 2. Applicability of Federal Automated Vehicle Policy Guidance Areas to SAE Level 2-5 Automated Vehicle Systems

Levels of Automation	SAE Levels 3, 4, 5 (HAVs)	SAE Level 2
Safety Assessment Letter to NHTSA	***Yes***	***Yes***
C. Cross-Cutting Areas	***Fully***	***Partially***
C.1.Data Recording and Sharing	Yes	Yes
C.2 Privacy	Yes	Yes
C.3 System Safety	Yes	Yes
C.4 Vehicle Cybersecurity	Yes	Yes
C.5 Human Machine Interface	Yes	Yes
C.6 Crashworthiness	Yes	Yes
C.7 Consumer Education and Training	Yes	Yes
C.8 Registration and Certification	Yes	Yes
C.9 Post-Crash System Behavior	Yes	Yes
C.10 Federal, State and Local Laws	Yes	Clarify to driver
C.11 Ethical Considerations	Yes	Yes
F. Automation Function	***Fully***	***Partially***
F.1 Operational Design Domain	Yes	No
F.2 Object and Event Detection and Response	Yes	No
F.3 Fall Back (Minimal Risk Condition)	Yes	No
F.4 Validation Methods	Yes	Yes
G. Guidance for Lower Levels of Automated Vehicle Systems	***No***	***Yes***

Based on this premise of vehicle-focused safety certification inherently addressed by the vehicle product design, the AV transit system operator and the authority having jurisdiction will conduct the overall safety assurance program that would include the vehicle's design safety certification along with other systems (such as transit signal priority or preemption, roadway lane markings, off-line stations, fences, etc.) to assess hazards and risks for the entire transit operation. This safety assurance program would begin with the initial planning of the system, and continue throughout the design, implementation and ongoing operations of the AV transit system. In a sense, the safety assurance process of the operating agency wraps around the safety certification provided by the vehicle manufacturer.

One item to be considered in the application of the NHTSA vehicle self-certification process in public transit applications and the overall safety assurance process is that there is no prescription of analytical methodology for the hazard analysis and risk assessment in ISO

26262. Various methodologies such as a Hazard and Operability Analysis (HAZOP), Failure Modes and Effects Analysis (FMEA), and System Theoretic Process Analysis (STPA)[34] are allowed regarding the vehicle's electronic control system at the discretion of the vehicle manufacturer.

Driving Tasks in Transit Vehicle Operation – In considering the criteria defining the ODD of public transit vehicles, it important to recognize that automated operation of transit vehicles within a fully automated system imposes more than automation of just the driving functions within the responsibilities of the "machine-operator." Note that the automated transit operations tasks that should be included in the automation based on IEC automated train operations include the following items not addressed by the CAMP automated driving tasks:

- Supervising passenger transfer (i.e., the boarding and alighting process),
- Operating a train to and from storage locations or the maintenance depot, and
- Detection/management of emergency situations.

These are tasks that are complex and impose different kinds of hazardous situations from those tasks of driving the vehicle. New vehicle subsystems not typically provided with regular automotive applications of AV technology may be required, such as systems to monitor the doorways of the vehicle to ensure that passengers have passed safely through the doorways. Such requirements may dictate a different set of operational design domains for public transit applications of Level 4 automation when the vehicle is certified by the vehicle manufacturer to operate in an unmanned mode.

Although multiple formal variations in the NHTSA ODD definitions given to the AV manufacturers for purposes of self-certification are not necessarily proposed, a range of operational design domains for public transit applications may be appropriate to define.

Complexities of AV Transit Hazards and Risk Assessments – The breadth of the AV transit vehicle and system safety assurance process must encompass failures and hazardous conditions overall that include:

- Roadway infrastructure design and maintenance
    - Lane markings, signage, lane geometry
    - Signal systems and V2I
    - Communications system backbones
- Environmental conditions and variations
- Pedestrian, bicycle and non-automated vehicle interactions
- Vehicle Hardware system failures
- Vehicle Electronic control systems & detection/sensing system failures
    - Multi-signal sensor/detector interpretation & harmonization
- Vehicle Programmable software-based control & monitoring systems failures
    - Failures and programming anomalies, obsolescence

[34] https://www.nhtsa.gov/DOT/NHTSA/NVS/Public%20Meetings/SAE/2015/2015SAE-Hommes-SafetyAnalysisApproaches.pdf

- Vehicle Human-Machine interfaces and interactions/response conditions
    - Alertness, understanding, knowledge, ability to act (SAE Level 2-4)
    - ADA passenger boarding/alighting provisions, visual and audio announcements, wheelchair restraint systems, etc.
- Malicious, capricious security breaches and manipulations

It is also important to recognize that automated roadway vehicle systems in transit service is considerably more complex than any such train control systems applied to automation in fixed guideway transit. This is particularly true within the automated roadway vehicle's control system which employs multiple sensor systems, electronic and software driven control systems, and (perhaps) artificial intelligence. While ISO 26262 provides a clear process for functional safety, automated driving sensors provide inputs that are now effectively infinite as the range of environments that a given AV can navigate is uncontrollable. Machine learning and pattern recognition systems that process the inputs can produce non-deterministic and un-provable responses to a given set of inputs, resulting in a system that can't reasonably be verified to do "action X" in response to "input set Y". These conditions are more complex than anything that has been attempted in the safety assurance processes developed in the automated fixed guideway transit field.

Operating Authority's Involvement in Risk Assessment – The various standards and FTA SMS safety program approach generally follows the safety assurance process derived from the MIL Std. 882 methodology. This process of assessing risks through the system safety assurance process, with the Authority Having Jurisdiction directly involved, will reasonably include:

- Local safety-culture considerations
- Risk comparisons to human-operated transit
- Cost considerations of implementing the possible hazard mitigations
- Adjusting the ODD or system deployment approach to eliminate the hazard

These scenarios for system failure, and the potential for hazardous conditions becoming more probable due to human intervention to override safety functions, requires implementation of strong procedures and protocols that must first be defined and vetted through the hazards and risk assessment process while the system is in the conceptual design phase.

AV transit operating plans and associated protocol for actions by onboard backup operators or roving operations "recovery" personnel must be an integral part of the SMS hazard analysis and resolution process. Both of the following must be part of the safety assurance plan for the specific transit system deployment:

- the vehicle response to a failure or hazardous condition that reverts to what NHTSA calls a "fallback" action, and
- the operations personnel failure response rules and protocols.

Comprehensive Approach to AV Transit Safety Assurance

A comprehensive approach to developing the US transit industry's approach to safety assurance can help speed this disruptive technology revolution. A cooperative effort between the USDOT/State government sector, the automotive/transit vehicle manufacturers and AV technology development sector, and the public transit industry sector will yield the best result. Taking a proactive approach in the consensus process will have substantial benefits over delaying until one or the other sectors takes the next step or simply reacting to the direction the technology is heading.

Functional Safety is provided through self-certification by the manufacturers/vehicle supplier using the approach in the SAE/ISO 62626 standards. The Safety Assurance Process building from the FTA SMS principles then would wrap around the vehicle technology and add other physical elements and subsystem equipment such as the right-of-way, roadway infrastructure wayside V2I communications equipment, supervisory dispatch control systems, and the fixed facilities and associated station equipment.

Benefits of Industry Consensus Standards for AV Transit – Taking a comprehensive approach to developing an industry norm for AV transit systems will not only involve the methodologies described, and not only the expansive system elements mentioned, but also creating a suitable consensus standard(s) that addresses the whole transit system's safety requirements.

Such an industry definition of methodology and a generic framework of hazard definitions will not remove the need for the safety assurance process to be applied to every new project to address unique hazards that are present in each site-specific location. If properly developed, the industry norms will facilitate each local authority's application of the methodologies for their local projects.

In developing a transit industry consensus standard, a key issue would be to addresses the system failure response that "falls back" to a "minimum acceptable risk condition". Safety criteria suitable for the transit industry would have to be defined with respect to a product manufacturer's minimum design requirements, particularly with how exactly an AV responds to defined hazards to provide an "absence of unreasonable risk" in accord with a manufacturer's "design intent."

Although the suggestion of a consensus standard is possibly a disruptive idea in the current free market of AV development, such an endeavor would need the full involvement of SAE, both federal and state government agencies, and the transit industry through entities like American Public Transportation Association (APTA) in North America and possibly the International Association of Public Transport (UITP) in Europe.

Safety Assurance Process Roles and Responsibilities

There are many parties that typically would have a role to play in the deployment and operation of an AV public transit system, including the governmental bodies, local transit authority or bus operator, as well as the employee unions and insurance companies. But not all have a direct responsibility for the implementation of a comprehensive safety assurance program. Roles and responsibilities with respect to safety assurance, contractual obligations/liability, system planning/design/implementation, as well as vehicle/system testing and acceptance will need to be defined.

All of the following entities should have responsibilities resulting from an AV transit safety assurance program:

- Local Authority Having Jurisdiction for Safety Assurance
    - Legal responsibility
- System Equipment/Facilities Manufacturers, Suppliers and Constructors
    - AV Manufacturer/Supplier
        - Vehicle safety
    - System Integration Contractor
        - Cybersecurity of ITS systems, V2V/V2I communications systems, vehicle dispatch and operations command and control (supervisory control system)
        - Safety of station systems and equipment
    - General Contractor(s)
        - Safety of physical transit stations, Maintenance/Operations Facilities, and Transitways/Roadways
- Local and State Government Agency
    - Safety of roadway design/maintenance and traffic signal system
- Local Government(s) responsible for multimodal transportation infrastructure
    - street parking, street lighting, street furniture, signage and lane markings
    - building codes and land use ordinances, roadway system right-of-way planning and complete street/pedestrian/bicycle facilities design provisions
- State Safety Oversight Agency (e.g., State Department of Transportation)
    - Implementation of safety management system
- NHTSA
    - FMVSS
    - ODD certification (potential)
- FTA
- Industry Groups Providing Consensus Standards
    - SAE
    - APTA
    - Others as they become involved

A comprehensive approach to AV transit system safety assurance starting at the project level through the involvement of the local and state parties, combined with a comprehensive approach to developing regulations and standards at the national and international levels, offers the best promise for a fast and effective deployment of AV technology. For much more detail on this important element of the future of AV transit, refer to Working Paper #2 of this project.

Findings on AV Transit System Safety

NHTSA Policy – The Federal AV Policy established an initial process whereby automobile manufacturers and AV developers can submit a written assertion of their safe design, using SAE standards as their primary basis of certification – a standard regiment that is supported by the ISO 62626 Road Vehicle Functional Safety standard. Within that safety standard a process of certification documentation is established, although the precise calculation details in hazard analysis and risk assessment are allowed through several different methodologies (such as Failure Modes and Effects Analysis or System Theoretic Process Analysis).

FTA Policy – Transit system safety has been addressed by the FTA through the timely establishment of a new Safety Management System rulemaking. The SMS is very like a process also adopted by FAA, and is well suited to serve as a foundation for future safety assurance processes that will be necessary for complex AV deployments in transit service.

Vehicle-Focused Methodologies – Safety methodologies that use an approached based on “functional safety” are derived from an original machine automation IEC 61508 standard which defined a process of assessing “functional safety”, from which numerous industry sector specific application standards have been prepared. In the automotive industry, the resulting functional safety standard is the ISO 62626 standard that has become the principal safety methodology written into the SAE standards for automated vehicles.

System-Focused Methodologies – Originally applied as MIL Std. 882, the basic methodology of following a set program of safety methods, beginning with the performance of a hazards analysis and risk assessment. The methodology then continues with the conducting of a systematic program to identify, mitigate and manage the risk of any unacceptable accidents which could result in a hazardous event that is unacceptable – i.e. resulting in fatalities, injury and/or significant equipment damage.

In addition, several safety standards written specifically for automated guideway transit systems also follow in this line of methodology, including ASCE 21 Automated People Mover Standard, IEC 62267 Safety Requirements for Automated Urban Guided Transport, and the set of Cenelec EN standards for railways applicable to fully automated railways.

AV Transit Safety Assurance Considerations – The operation of an automated transit system requires a comprehensive safety assurance approach, with assessment of safety impacts of hazards beginning in the conceptual design phase, and continuing throughout the life cycle of the project. Hazardous conditions that are possible and which must be assessed for risk and then through design (or other means of risk mitigation) the hazard must be reasonably mitigated. This process must extend from the AV technology to the transitway on which the vehicles would operate, the V2I communications equipment, the stations and facilities of the system and the whole range of possible operating conditions.

Guidance of AV Transit Deployments – Many stakeholders have a role in the process of safely planning, designing and deploying an AV Public Transit system. Multiple federal government agencies, state government agencies, and local government agencies affect the preparation and execution of a safety assurance program by the local public transit operator. The most important consideration that these agencies address is the fact that safety analyses which focus only on the driving automation systems and the other vehicle safety features are not sufficient. **Only a blended approach of the vehicle-focused and system-focused methodologies can comprehensively provide operational safety of automated transit systems.** The role of a conventional transit vehicle’s human operator goes well beyond just “driving the bus.” The management of passengers and the situations that they can bring into the operating system cannot be addressed by vehicle automation technology alone. Human oversight and associated supervisory systems also perform key functions in safety and security of public transit.

Research Projects on AV Transit Safety – There are significant matters to be addressed in the near to medium term regarding the safety analyses required for AV transit deployment in passenger service, especially when automation levels reach L4 full automation. The following key research projects, which are based on the discussions and findings of this working paper, would be beneficial:

1. **Definition of Complete Transit Functions to be Automated** – Research that would assemble a comprehensive definition of tasks/functions typically performed by a human operator or attendant in a conventional transit vehicle/train would be beneficial. The study could also perform a detailed evaluation of automation prospects for those tasks/functions not included in the SAE J3016 defined dynamic driving task (DDT) and ODD.
2. **Categories of Hazards and Risks** – Assessment of categories for hazards and risks as defined by MIL Std. 882 and its derivatives (e.g., ASCE-21, per **Table 2** above) would be beneficial in a technical study, while considering the necessary criteria and operating environments to assess whether scenarios with any fatality or injury are always Unacceptable for any AV transit application. Further, the study could assess whether there are scenarios where one or more fatalities could be categorized as Undesirable or Acceptable for some AV transit applications or circumstances. Subsequently, the study could provide a definition of associated operating environment, level of automation, conditions of other vehicle access control, etc. for the scenarios as defined.
3. **Generic Hazards Analysis** – Preparation of a Generic Hazard Analysis for each type of operating environment and level of automation is a recommended study, beginning with IEC 62267, Part 2 as an initial template of methodology and types of hazards and then expanding the analysis to represent conditions of AV transit deployment.
4. **New Consensus Standard for AV Transit Systems** – Research that would perform an adaptation of an existing automated guideway transit safety standard, or alternatively creation of a totally new standard, with full involvement of the transit industry (operating agencies and system equipment suppliers), governmental authorities, and AV technology researchers/developers would be informative.
5. **Transit Operational Design Domain** – Development of the parameters, criteria, and characteristics of the AV transit specific operational design domain is needed in a form compatible with the ODD defined by the SAE for non-transit applications.

WORKFORCE

Transit Industry Readiness for AV Technology

During the project, several workshops were held with transit operators to discuss issues, including workforce challenges. Several themes emerged during the workshop discussion, with topics of high interest including:

- **Unions and Labor** – Will workers (primarily bus operators) be eliminated with AV transit systems? As AV transit technology advances, unions are indicating their concern regarding the timing of the implementation, the displacement of workers, and the need to be actively involved at the earliest stages when AV transit technology is first being considered.
- **Human drivers/operators** versus trusting in AV technology –Will the public feel comfortable riding in unmanned AV transit vehicles?
- **Operational benefits** of AV Transit applications – Can automated transit systems be more reliable than human-driven systems? Non-automated, manually driven vehicles sometimes experience problems staying on schedule, due to variance in bus driver performance. Automation may improve scheduled operations through tighter coordination with traffic signal systems and supervisory systems that may be continually optimizing operations over the entire line.

A clear theme from the discussions was the requirement to involve representatives of the labor force in the early considerations of AV transit deployment. This could involve focus groups, workshops, employee meetings, and direct participation in AV transit demonstration projects and evaluations of technology benefits. Each agency should integrate this employee involvement in their policy-driven planning and it should involve front-line employees directly in the process.

Another clear theme from the discussions was that management and organization structures will probably need modification as AV transit technology is deployed over time. The labor force may shift away from being dominated by operators and mechanics and toward remote monitors, recovery operators, and maintenance personnel with higher levels of technology skill. Organizational models may need new divisions such as a technology operations division. Since this is not the first industry to be affected by robotics and automation, lessons learned from aviation, railroads, and manufacturing may be relevant to transit[35][36][37].

Employee Roles in Compliance with Federal Regulations

During the workshops, the participants discussed regulatory aspects of safety and ADA compliance in the context of AV transit. Passenger access to platforms, assistance with boarding vehicles and docking/securing patrons in wheelchairs are all significant challenges of AV transit. When no driver is onboard a public transit vehicle, how will these things be

[35] https://economics.mit.edu/files/11563

[36] https://www.aerotek.com/insights/working-in-america-the-onset-and-impact-of-automation

[37] http://reason.com/archives/2015/03/07/automation-may-be-labor-union-death-knel

accomplished? Depending upon the disability, additional technology solutions (auto-energized ramps, auto-securing tie-downs, etc.) may be required to perform these functions without human assistance. It may be challenging to envision these additional functions with today's technology, but perhaps by the time that "all" buses are capable of driverless operations such features will be proven as well. In the interim, however, it is difficult to imagine a driverless BRT line without such functions. While the self-driving technology may enable a BRT operation on dedicated transitways today, attendants will still be needed for ADA compliance for the foreseeable future.

Employee Transition and Training

AV transit implementation could mean significant changes to the way transit employees function. These changes range from revising roles/duties, normalizing work schedules and perhaps decreasing total staff over time. Existing employees will likely require education and training to modify their roles. Additional issues discussed in the workshop include:

- **Human vs machine** – Which will be responsible for the vehicle during progression from higher levels of automation back to manual control? A gradual and well-timed transition from machine control to human control is critical for success. While the opposite scenario is also important (driver handing over control to the machine), the release of the vehicle from automated operation back to the driver is a critical safety event. Union issues will likely arise when collisions occur. Was the driver assistance system or L3/L4 automation responsible? Was the driver responsible?
- **Role of current drivers** – About 40% of the operator's time is spent on passenger related issues (e.g., fares, loading and unloading) and 60% spent driving. How will passenger issues be addressed when the operator is completely removed from the transit vehicle?
- **Driver hours and salary changes** – Most operators work 10-12 hours daily. Currently the work hours occasionally increase to 16 hours a day when the transit agency experiences staffing shortages (so the same drivers may work at both the AM and PM peak periods). Some industry representatives believe that AV transit implementation will normalize operators' work day and potentially shrink their schedules to 8 hours daily and 40 hours weekly. If these factors do in fact result in total fewer hours than transit vehicle operators currently work, it will translate into less take home pay.

Unions and Collective Bargaining

For decades, unions have represented hundreds of thousands of transit workers and have brokered contract terms, working conditions, wages, and benefits. These negotiations are conducted with the intent to ensure the fair treatment of employees while providing the transit agency with quality employees to meet the agency's service goals.

Traditional Bargaining Items

Typically, unions help determine the working conditions, (hours, days, duration) for transit workers. Issues about wages, rates, and compensation rest at the heart of most agreements. Rules about the frequency of work and overtime situations are also contained in the contract. Unions also intervene, on behalf of the employee, when disputes with the agency occur. Unions frequently serve as a "checks and balances" system when agencies make workforce decisions, e.g., promotions and layoffs. Unions also assist in protecting workers from safety risks and unsafe working conditions.

During the Transit Industry Stakeholder Meeting #2, participants noted that the most significant concern of unions is the displacement of workers due to AV transit deployment. This concern may also be expressed by agency advisory boards and elected officials. Currently, few collective bargaining agreements mention the impact of technology on workers' jobs. However, as the transit industry incorporates AV transit, unions may decide to include language in contracts that specifically addresses new changes that workers may face because of AV transit deployment.

In the future, negotiations may expand and include clauses aimed at workforce retraining, reassignment, and guidance on downsizing.

Stakeholder participants also expressed concern regarding lawsuits filed by unions to protect operators' jobs. Many cited the Federal Transit Act 13 C Federal Rule, which provides transit labor protection so that jobs cannot be taken away from public employees[38]. Comprehensive information on 13c can be found in TCRP Legal Research Digest June 1995, #4.

Employee Training and Retraining

Even basic L1 ADAS technology presents the potential to reduce collisions, fatalities, injuries, and insurance claims of conventional fixed-route transit. As new technology works its way into public transit over the next few decades, employees, unions, and transit agencies must begin the process of identifying the new positions that emerge and how to incorporate current workers into these positions. In some instances, employees will need retraining and/or additional education to understand how to operate (or maintain/repair, as appropriate) the technology and systems. The early periods of transition from L0 to L3 automation will be especially important as the operators will require special training for the transition of control from manual to automated and more importantly from automated driving back to manual control. Some have argued that the risks induced by L3 driving systems may be too significant to allow on transit vehicles, particularly in mixed traffic environments. Regardless, training and retraining will be a significant component of introducing AV technology into transit operations as the man/machine interface becomes integrally involved in the driving tasks.

The most obvious positions impacted by AV transit implementation at L4 levels are those of vehicle operators. Finding new roles for vehicle operators means examining their current roles and duties. Typically, operators are responsible for driving, for ensuring safety (in and around the bus and patron safety), and for addressing passenger issues. With AV transit, former drivers, dispatchers, and street supervisors will probably convert to operational roles as staff in the Operations Control Center (OCC) or as roving "operations response" personnel. A key element of the new roles will be direct interaction one-on-one with patrons, via remote video phone and/or intercom systems. In addition, the eventual deployment of L4 automation will likely also involve a significant number of vehicle operators who remotely take control of vehicles from the OCC when necessary. Such situations may include driving the vehicles to operational

[38] http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_lrd_04.pdf

recovery or maintenance and repair locations, maneuvering the vehicle around an unexpected obstacle or extracting the vehicle from unusual circumstances such as a software failure.

Imagining and preparing for the type of jobs needed over the long term because of AV transit implementation is not just the role of the transit agency, but also should also be undertaken by the unions and drivers themselves. Cooperation between all parties would ensure a better understanding of who will be directly impacted by the technology and to what extent. Such cooperation will lead to new work opportunities, e.g., cross training and promotions as well as additional training/education for employees.

Resizing the Workforce

Little to no research on cost-benefit evaluation of the introduction of AV to transit systems has been done to date. Given that the current cost of transit operations is dominated by the cost of the driver (25%-40% of the cost), automated driving systems can provide lower-cost services – based on the premise that AV transit technology can be shown to be as safe as human driving and able to navigate the wide range of operational scenarios that humans can currently handle when the drivers are removed. The amount of reduction in workforce cannot be accurately identified without a detailed identification of the operating paradigm (such as how many vehicles a remote operator can monitor reliably).

Changes resulting from the implementation of AV transit will likely mean considering changes to the job descriptions, titles, skills and number of employees. As discussed above, transit operating agencies must give the utmost concern and sensitivity as to how these changes will occur. Initially, full time equivalent (FTE) positions could be eliminated via attrition. As workers retire, transit agencies may make decisions not to fill these positions because the work can be spread across fewer employees in their new roles. This approach allows for a natural and progressive shrinkage of the number of employees.

Section 13c of the Federal Transit Act

Equally important are the potential changes to federal law that may be required to be made. This major issue for public transit authorities concerns 13 C Federal Rule, which specifically states that jobs cannot be taken away from public transit employees. Refer to 49 U.S.C. 5333(b), also known as "Section 13(c)" of the Federal Transit Act[39].

The statute reads in part:

> *As a condition of financial assistance … the interests of employees affected by the assistance shall be protected under arrangements the Secretary of Labor concludes are fair and equitable.*
>
> *Arrangements under this subsection shall include provisions that may be necessary for –*
>
> a. *the preservation of rights, privileges, and benefits (including continuation of pension rights and benefits) under existing collective bargaining agreements or otherwise;*
> b. *the continuation of collective bargaining rights;*

[39] https://www.dol.gov/olms/regs/compliance/statute-sect5333b.htm

c. the protection of individual employees against a worsening of their positions related to employment;
d. assurances of employment to employees of acquired public transportation systems;
e. assurances of priority of reemployment of employees whose employment is ended or who are laid off; and
f. paid training or retraining programs.

The reality that automation will eventually reduce the total size of the public transit system work force may be one of the most significant policy considerations that will need to be addressed within each local transit operating agency over the coming years. This matter alone may pace the rate at which AV transit technology can be implemented in many locales, resulting in a significantly longer timeframe for AV transit deployment as labor force reduction and redeployment will only be able to occur gradually without revision to Section 13c of the Federal Transit Act.

Findings on Workforce Deployment

Research Projects on AV Transit Workforce Deployment – There are significant matters to be addressed in the near to medium term regarding the redeployment of the transit operating agency's workforce as AV transit is progressively brought into passenger service and as levels of automation are progressively increased. The following key research projects should be considered for undertaking based on the considerations and findings of this working paper:

1. **AV Transit Employee Roles and Responsibilities** – A study to develop preliminary job descriptions for future employee roles and responsibilities as progressively higher levels of transit automation are deployed by a "typical" small, medium, and large transit operating agency, and as different types of transit service are implemented (e.g., first-mile/last-mile circulator/connector service, line-haul BRT service, arterial street corridor service, and regional long-distance commuter bus service).
2. **Employee Involvement Guidelines** – The transit industry would greatly benefit from the preparation of a planning template of steps which frames a generic process involving employee representatives in AV transit technology investigations/demonstrations and subsequent phasing of deployment. These steps would serve to define for each phase of AV transit technology implementation the progressive redeployment of the existing workforce to new roles and responsibilities.
3. **Union Contract Guidelines** – A policy study that leads to the preparation of draft language for future union contracts would be very beneficial, which specifically provide for a progressive implementation of AV transit technology and the associated transition of employee roles and responsibilities.
4. **Automation of Employee Actions in Compliance with ADA** – A technical research project that first performs an evaluation of current employee actions and responsibilities in assisting and protecting passengers with disabilities when accessing transit vehicles and the corresponding securement of wheelchairs once onboard could then produce technical guidelines for automation of these functions in design of AV transit vehicles. This research would investigate the means and methods to accomplish these actions as higher levels of vehicle automation are achieved. Equipment functional capabilities/features, employee involvement/monitoring, and employee location (i.e., at

the vehicle or remote) should be defined for each automation level and type of transit service.

OPERATING POLICIES

Planning Policy Considerations

Automation of buses and vehicles providing public transit service will begin to affect many local transit operating agencies within the next 5 to 10 years. **Table 1 identifies** estimated time-frames for the common introduction of AV technology by transit operating authorities. Over the next 30 years, all agencies will likely begin operating with AV transit technology in some services and many transit services could be operating with AV technology in all their services by that time. In the 30-year time frame, it is likely that the dispatching and operational fleet management for some agencies will also be fully automated.

Policy makers in all transit operating agencies would benefit from addressing the incorporation of AV technology into agency and regional short-range and long-range transportation plans, even as AV transit technology is still in the developmental phase today. Infrastructure decisions made today could shape what is feasible in the future and agencies will want to make capital investments that can leverage the benefits of new technology. Transit agencies must coordinate closely with partner organizations such as metropolitan planning organizations (MPOs), state and local DOTs/highway agencies, FTA, and local county/city planning departments. Two types of planning decisions could be shaped by AV transit technology:

1. Long-Range Transit Planning, focused on planning decisions within the transit agency, and
2. Regional Planning and Coordination, focused on the coordinated planning needed between transit agencies and other regional planning organizations[40].

Long-Range Transit Planning

AV transit technology should be included as a matter of policy dialogue within the top levels of any transit agency's management during the near term to give direction to agency plans for 10, 20 and 30 years in the future. AV transit technology will likely provide the opportunities for fundamental changes in the way the public transportation is delivered, reducing costs and improving efficiencies. As such, transit agencies will want to begin thinking about how to prepare for these changes by:

1. developing or revising strategic visions to consider potential changes to service delivery (e.g., demand-response networks versus line-haul configurations),
2. identifying opportunities and threats posed by the new technology, and
3. identifying potential strategies for managing the changes.

The transit operating agency's long-range service expansion plans would benefit from considering the potential impacts of AV technologies on passenger service levels, potential capital investments and infrastructure needed to deliver AV transit service, and costs and benefits of these changes. AV technology may be applied to transit in a variety of service roles, which need to be better understood through technical research projects and associated policy studies. Key decisions about the required infrastructure in each of the settings are needed well in advance of the adoption of the vehicle technology, and long-range planning by transit

[40] Note that NCHRP 20-102 (09) *Providing Support to the Introduction of CV/AV impacts into Regional Transportation Planning and Modeling* is currently on-going and anticipated for completion in 2018.

operating agencies will need guidelines for these new AV transit applications as soon as possible.

Types of AV Transit Services – Current thinking within the transit industry has discussion centered on the following types of automated transit services.

High-frequency BRT or express bus routes, operating in semi- or fully- protected environments (e.g., dedicated transitways or managed lanes) – AV transit using L3 automation in transitway applications such as BRT lines is anticipated to be widely available in the 2020 – 2030 time frame. Securing the necessary right-of-way for transit lanes, whether within an existing roadway or for a new facility, is challenging and costly and will need considerable advanced planning. BRT stations must be planned to consider surrounding land uses and key connections to other transit lines and multimodal connections. For BRT or express bus routes that will operate on dedicated or managed lanes, special attention will need to be paid to the access points or for situations where transit vehicles will merge into and out of mixed traffic. Corridor planning studies and alternatives analyses should integrate AV technology into the modal and alignment screening process that leads to the selection of a Locally Preferred Alternative.

First-Mile/ Last-Mile Applications in protected environments (e.g., campuses), in dense urban districts, or suburban/rural settings with low-speed operations (e.g., less than 35 mph) – AV transit is being discussed actively around the world as ideal technology to provide First-Mile/Last-Mile (FM/LM) connections to high-capacity transit lines and commuter rail service. L4 automation in FM/LM circulation service is possible today in campus environments. FM/LM L4 service in mixed traffic at low speeds on city streets within dense urban districts is anticipated to be widely occurring in the medium term (2025 -2035) time frame. In addition, Level 4 AV transit systems could enable expansion of frequency and coverage for what are typically less productive feeder bus routes, and in low density rural areas in the medium to long term.

Conventional fixed-route transit operating in mixed traffic in unprotected environments like arterial streets – These environments could present some of the greatest challenges to full deployment of driverless transit vehicles. The typical city bus encounters numerous conflicts and obstacles including pedestrians and cyclists, illegally parked vehicles, and turning vehicles. These routes also carry heavier passenger loads and typically have frequent stops. In the near term, L2 automated driver assistance system (ADAS) features of AV technology could benefit bus operations by supporting schedule adherence and more effectively utilizing transit signal priority (TSP) to improve travel times and reliability. Long-range plans will need to consider the operating cost savings as well as the vehicle and capital costs of AV technology when setting policy goals for service expansion of AV technology into general bus lines.

Other Long-Range Planning Considerations – As long-range plans begin to define the transit services of the future; additional details will need to be defined to better understand the capital improvement needs and long-term financial impacts. Service changes (i.e. demand-response) enabled by AV transit technology could affect a whole range of capital assets owned and maintained by agencies, including busways, stations and stops, vehicles, communications systems, and maintenance facilities and equipment.

An integral part of service planning is addressing how public transit agencies would pay for AV technology deployments. Considerations must be given to the potential for AV technology having long-term operating cost savings but significantly higher up-front capital infrastructure costs. Examples of capital and operations and maintenance cost implications are for AV transit system dedicated lanes and stations with additional right-of-way, or a diversified vehicle fleet with more small vehicles to maintain along with larger traditional coaches. Some current research indicates that the on-vehicle equipment could perhaps pay for itself by reducing out-of-pocket costs for liability claims due to crashes involving public transit vehicles[41].

Finally, long-range planning of major transportation systems and infrastructure always greatly benefits from public outreach. This key element of the planning process should fully solicit input from customers, stakeholders and the public. These stakeholders must be informed of the benefits and potential impacts of AV technology. The transit agency's planning process should therefore begin to include surveys and focus groups to determine what the transit users think about AV technology and the deployment of self-driving vehicles in public transit service.

Regional Planning and Coordination

AV technology deployment will require significant planning and coordination between transit agencies and other regional transportation agencies. This coordinated planning will most likely need to be done by the MPO. The development of the region's Long-Range Regional Transportation Plan (RTP) will bring together the transit operator(s) with the highway operators and local governments responsible for arterial and urban streets and communities. Interagency discussions at the regional level should identify roles and responsibilities, opportunities for integrated technologies and shared facilities, needed infrastructure improvements, and potential safety impacts. The financial plan element of the region's Constrained Long-Range Plan (CLRP) will require a realistic assessment of the capital and operating costs (and savings) associated with AV technology, expected funding sources, and trade-offs between investments in AV transit systems versus traditional rail and bus services.

Some of the key policy areas where AV technology for transit would benefit from being addressed as part of the regional transportation planning process include:

- Commitment to deployment of intelligent transportation systems infrastructure to enable and V2I communications
- Preservation of right-of-way for dedicated lanes, and/or conversion of existing freeway and/or managed lanes
- Congestion management
- Planning for safe pedestrian and bicycle facilities in proximity to AV transit routes
- Enhanced mobility of seniors and individuals with disabilities through coordinated health and human services plans
- Air quality impacts of AV transit systems
- Planning and design of intermodal hubs
- Potential for land use changes

[41] http://orfe.princeton.edu/mwg-internal/de5fs23hu73ds/progress?id=IIwQlPRptnVw3pMVwC5ypYo9uC-ocLTKfudSflQAdF4,

AV transit lines will impact urban areas as provisions are made to accommodate the new technology. For example, potential changes to land use and development might occur when AV FM/LM transit service within dense urban districts is implemented. Curb lanes, for example, may need to be strategically protected for use by FM/LM circulators to berth in stations (suitably designed for ADA compliance). This will impact future curb parking, pedestrian facilities and building access in the immediate vicinity.

AV transit may have significant impacts in the suburbs. By 2040 (and probably before, given the pace of development investment), it is likely that AV transit technology will be able to provide on-demand public transit service in real time using L4 unmanned vehicles to more cost-effectively serve very low density areas. This could significantly increase the ease and convenience of access to high-capacity commuter rail and BRT lines while reducing the need for large parking facilities at rail stations.

It is currently quite a challenge to assess how AV technology will impact travel behavior, roadway capacity and traffic congestion in regional planning models since no reasonable scale real-world systems are deployed. Some predictions indicate that in the long term, AV adoption in privately-owned vehicles (or major adoption of shared-ride aTaxi services) may double the current carrying capacity of freeway facilities. Even without substantial gains in maximum capacity, the reduction in crashes will increase throughput and reliability of traffic facilities. Some researchers believe that such a future may (further) reduce the attractiveness of public transportation modes, particularly for suburban commuters. Others have expressed that expected increases in “no occupant vehicles” (NOV) moving through the system will prove counter-productive to decreasing congestion as vehicle trips escalate faster than person trips[42]. At the current time, the amount of uncertainty regarding the future transportation system “look and feel” is, at least in the opinion of the authors, at an “all-time high”; at least in the modern era since the completion of the interstate highway system.

As prediction models are developed and refined based on case studies of real-world deployments, planners will better understand how particular AV transit supply services will affect mode choice and support the long-term mobility goals of a region. It seems reasonable that the availability of automated FM/LM transit services would help to make public transit a more attractive choice, but without success stories that document the actual mode-shift, the perceived benefits are still in the realm of conjecture (i.e. some handful of agencies are going to have to “go first”). Policy decisions of the local transit operating agency concerning AV technology deployment must be considered in the context of this uncertainty, and points toward the increased importance of coordinated planning across a region.

All local and regional decision-making parties, including elected officials, will need to support AV technology introduction to put appropriate projects in the transportation improvement program (TIP), and then achieve successful deployments. This support must also exist within the board of directors for the transit agency itself for agency policy to be created. Many authorities have boards appointed by elected officials who have keen interest in union support, which may generate a reluctance to fund automation systems too quickly.

[42] http://www.theatlantic.com/politics/archive/2016/01/will-driverless-cars-become-a-dystopian-nightmare/459222/

Operating Policy Considerations

Transit agency operations policies include the following:

- Where and when services will be offered
- What safety practices will be followed by employees and patrons
- What activities of patrons are allowed or disallowed
- How ADA and Title VI (civil rights) requirements are addressed
- How union arrangements are handled
- Employee rules, regulations, and duties
- Emergency protocols
- Technical operational agreements with local agencies such as signal priority

Automation technology will affect all areas of operational policy. Operating agency management and boards will need to continuously assess how these areas are affected as AV technology development progresses. As safety and reliability issues are resolved by AV transit technology developers over time, it will become clearer how specific policies will need revision. Some example areas of operations policy are discussed in the following sections.

Level of Automation Limits and Boundaries of Deployment

NHTSA/SAE is anticipating that automated roadway vehicles will initially be offered for specific levels of automation by the manufacturers, but only within certain geographic areas (i.e. geo-fenced) and on certain classifications of roadways. The same will apply to transit services. If these AV buses from that manufacturer are to travel on other roadways not located inside the defined geo-fence network, then the vehicles will only be able to operate with a human driver onboard in L2 or L3 levels of automation.

Policy decisions concerning staffing levels may be required to allow even these limited deployments in the example cited above, since human operators may still need to be present to assume the driving tasks over portions of the vehicle's travel. This transition from automated driving to human driving requires provisions such as expanded roadway right-of-way, removal of curb parking and/or installation of additional lighting for safety and security of passengers. Policy decisions of the public transit operating agency would need to consider these aspects, along with coordination of the changes affecting urban districts/developments, local governments and regional transportation agencies.

It is likely that AV transit policies will evolve in a regional manner, similar to how legislative rules and regulations on AV driving are evolving on a State-by-State basis in the U.S. Right-of-way, infrastructure and workforce deployment aspects will require policy decisions on capital investments, staging of operational personnel and interagency coordination that is significantly different than necessary with manual public transit vehicle operations.

Policy Implications of Multi-Sourced System Components

Automated vehicle technologies and connected vehicle technologies are being developed in parallel paths. The result of these parallel development paths will be procurements that could purchase different subsystems from different source-suppliers, and thereby impose some board policy aspects of decision concerning the risks of subsystem integration – particularly in the near to medium term for agencies that decide to become "early adopters" of the advanced technology systems. Management or board decisions at the local transit operating agency level could be involved in determining what kind of subsystem technologies should (or can) be purchased, since complete AV roadway transit systems may not be offered from a single source in either the near term (or possibly even long term). As market forces apply over the next 10 years, suppliers will be purchased by other suppliers, go out of business, change service and equipment models, upgrade to new technologies, terminate support for old technologies, and so on. Not unlike purchase of technology for any other purpose, policies will need to be established to deal with the realities of an emerging niche market.

Operating-Fleet Management Plan

The benefits of AV technology deployment provide good prospects for meeting customer service objectives while also meeting sustainability goals. With the flexibility that AV technology will provide over the long term, it will ultimately be possible to operate a diverse fleet with different vehicle platforms (size, weight, propulsion systems, and capacity) sized to meet the demand patterns of the service area. Over the long term, this will allow a high level of optimization in fleet operations when inefficiencies can be dynamically addressed throughout the day by dispatching smaller vehicles into service to replace larger vehicles. Operating-fleet management plans are typically based on ridership forecasts into the foreseeable future, but the paradigm shift that AV transit technology will bring also raises the importance of other policy-related factors such as:

- Environmental and sustainability benefits can potentially provide a key policy rationale for the deployment of progressive levels of automation in roadway vehicle transit operations under a local transit operating agency's policy goals and objectives.
- The complexity of vehicle automation technology and diverse fleet mix scenarios that allow the type of optimization of operations currently envisioned will change capital costs as well as operating and maintenance costs in ways not be fully understood when early adopters deploy AV technology in the near to medium term.
- Trends toward combining transitions to AV roadway vehicle technology with transitions to electrical propulsion systems will require new types of infrastructure for electrical power distribution. This will be combined with the need for new vehicle storage facilities and battery recharging requirements within the fleet operating plan.

These and many other similar issues will become common considerations in fleet management planning. Policy makers will need to begin understanding and addressing the related new technical challenges as AV implementation progresses in the years to come.

Safety Policy Considerations

Implementing a safety program with a level of complexity which could equal those of the most complicated of rail systems is a major issue of AV public transit deployment. The complexity of AV technology will likely require the establishment of a rigorous Safety Management System[43] under the FTA requirements. Of course, as with most FTA regulations, compliance will be a major factor in receiving federal funds for transit vehicles and infrastructure funding.

Transit properties that only operate buses typically do not maintain a rigorous safety assurance program on the level of those properties that currently operate rail systems. In the future, all transit operating agencies operating AV technology will likely be required by FTA to put into place an SMS that is appropriate for operating an automated transit system.

Local Agency Safety Programs Start with Policy

For a comprehensive safety assurance program to be introduced, there needs to be a policy-level decision to commit the resources and to empower the employees who are assigned safety responsibilities to act when warranted. Under U.S. federal law, the local agency is responsible to execute the safety program, and to work under the guidance and regulatory jurisdiction of their state's designated safety oversight agency.

Safety Analysis and Risk Assessment – In part, the local agency's safety program (in particular, the risk assessments of potential unsafe hazards), will likely be compared to that of the safety of vehicles under the control of a human operator. Policy makers should become actively involved in the discussion of safety and risk assessment if their plan is to prepare their agency for early adoption. Although there has not been any official assessment by FTA (or any other federal agency for that matter) of safety comparisons between human-driven roadway vehicles and machine-driven roadway vehicles, there have been some speculative assessments that machine-driven vehicles will likely be held to a much higher bar (e.g., "five times safer"). At this point in time, there has been no attempt to define precisely how safety will be measured and tested, and what minimum levels of safety will be acceptable for public transit applications.

A policy-making entity like a board of directors will certainly have to deal with the public's perception of their personal safety when riding in an AV transit vehicle. When AV transit is first deployed, the transit patrons will most likely only view this risk from their perception of safety and not from the statistical probability analysis. Policy makers should weigh both aspects considering such concerns to reassure the public that the system is safe. There would also have to be policy considerations of demonstration projects, public information programs, and focus groups to ensure that the transit users are prepared to utilize the new technology when it is deployed.

Crash Liability Determinations in AV Operations – The risks and liability concerns for existing manually operated buses are well understood and incorporated into existing policy and contract terms and conditions (including collective bargaining contracts for vehicle operators). AV technology is heavily dependent on software program logic, sensors, and computers. Some of the related questions raised in the industry stakeholder meetings on this topic were:

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[43] Refer to Working Paper #2 Safety Assurance Consideration, Chapter 2 USDOT Safety Initiatives

1. How will crashes that are caused by something within the operating environment but not caused strictly by an AV equipment or system failure be judged regarding operational liability of the transit agency? Was the AV technology not “good enough” to sense and safely respond to the hazard, and therefore the agency bears some responsibility in a way that is different from a human-operated vehicle?
2. If an accident is judged to be a software control logic failure, will that failure be judged differently by the courts if the vehicle is owned and “operated” by a public agency as compared to a vehicle privately-owned and “operated” by an individual? Will the operating agency be liable up to its legal limits, or will the manufacturer that employed the software programmer be fully liable? Can such protections be reasonably put into place to protect the operating agency?
3. How will the individual liability of the vehicle operator be judged when accidents occur under semi-automated levels of driving – either under automated driver assistance mode (L2) or L3 automation in which the AV technology may have given an alert that the onboard operator must retake control, but the operator did not respond?
4. Will definitions of liability for the vehicle manufacturer, the individual operator/attendant, and the public transit operating agency be determined by:
   a. The US legal system (courts)?
   b. Congress through legislative action?
   c. A combination of these two along with investigations of state or federal agencies to assess what caused the accident?

In summary, policy aspects of safety assurance will likely have significant new guidance that comes from the current initiatives of the USDOT concerning “highly automated vehicles”.

Contracted AV Taxis and TNC Services Considerations

There has been considerable discussion within the transit industry about the contracting of ancillary services to TNCs such as Uber and Lyft. These contracts are being explored for FM/LM access services, and some aspects of demand-responsive transit services. There are a growing number of federal grants to transit agencies to test these contracted services under “mobility-on-demand” initiatives of FTA. Policy makers are being challenged to assess how TNCs and automated taxi service (a-taxis) can be integrated into the local public transportation system.

The major issues affecting AV transit deployments that were discussed in recent workshops centered on the impacts of TNCs on public preferences for travel modes and the resulting implications for public transit operations. Other topics discussed included the trends in urban density/land use which may fuel TNC mode choice and the implications for long-range transportation planning and management, especially when the operational impacts of AV technology are considered as commuter person-trip patterns result in empty vehicle deadheading throughout the roadway system.

The following is a sampling of the discussion topics now being considered within the industry:

1. Will TNC firms like Uber that deploy AV technology bring the demise of transit buses? Many feel that TNC firms deploying AV technology are more advanced than transit

agencies in this field, but the need for transit buses and line-haul transit is not likely to go away as there will still be enough patrons with less money and enough time.

2. The use of TNC on-demand services could be a good solution for transit agencies to providing cost-effective access to high-capacity transit corridors with BRT or rail services, especially in low density areas where transit infrastructure is limited. But when will TNCs begin to view transit providers as competition more than as clients for their contracted services?
3. Will regional transportation plans view as undesirable the "rivers" of conventional-sized AV automobiles (i.e., solo or shared-ride services operated by TNCs) flowing into the city's urban core during peak commute hours? Will the higher occupancy AV transit vehicles operating in dedicated transitways be more manageable for traffic congestion purposes? If so, then does the first-mile/last-mile TNC application make the most sense for transit?
4. Empty vehicle movement must be understood for TNC services when used for typical suburban commute trips. For example, typical park-and-ride transit operations have up to 50% deadheading of empty vehicles moving in the opposite direction from the peak commute direction to supply commuter service from the suburban perimeter into the urban core in the morning peak period, and in the opposite direction for the evening peak period. Empty vehicle trips for a-taxis and AV TNC autos will significantly increase vehicle volumes on the regional roadway systems with related congestion as empty vehicles are redeployed to serve the next commuter's peak period directional trips. In contrast, the use of higher capacity AV transit vehicles would serve to reduce rather than increase congestion.

Potential Regulatory Issues – If local transit operators can satisfactorily address these issues and can integrate TNCs into their overall transit services, there could be critically important policy issues concerning to how federal regulations and laws will be incorporated into the related contractual agreements.

There are currently some contractual issues with TNCs for the provision of contracted services to public transit agencies that have been identified in industry discussion groups such as related sessions at the recent APTA conference. For example, it was reported that TNCs are reluctant to comply with FTA requirements such as driver drug testing. There may be little incentive over the long term for TNCs to partner with public transit agencies, particularly when these private companies could be subject to FTA regulations like ADA and Buy America requirements. In addition, the Title VI implications and the typical fares for TNC services could be difficult to satisfactorily align with typical transit fares.

With the multiple demonstration projects now underway by transit agencies contracting to TNCs for local area services, there will be near-term understanding gained of the policy benefits and impacts of transit agency and TNC partnerships. The FTA regulatory aspects will need to be explored carefully as these demonstration projects proceed.

Findings on Operating Agency Policy

Service Planning – Policy decisions of the local transit agency concerning service planning will chart the course for when and how they will venture into AV transit technology deployments. Some may choose to be early adopters of advanced automation, and other agencies may decide to wait until full L4 automation is proven and readily available from multiple vehicle manufacturers. These decisions drive the agency's input into the regional transportation plans and TIP funding commitments.

Key to the policy decisions will be how AV technology is planned for deployment in ways that effectively increase transit mode choice, such as improving accessibility to high-capacity transit corridors through first-mile/last-mile transit services. Such deployments of AV technology by some agencies could be a major departure from their typical transit applications and legacy route configurations. These types of changes will require a policy-level decision to launch the planning process.

AV Technology Applications – NHTSA is expecting AV technology to be offered by the manufacturer as safety certified for designated levels of operation (such as L4 fully automated driving) on designated classifications of roads within defined area boundaries (i.e. inside the geo-fence network). Policy decisions to implement AV transit will need to also address the reality that, when driving of the vehicles outside of the defined geo-fenced area, portions of the operations will necessarily require a human driver.

Policy-level decisions will be required to accept the added complexity and associated risks with AV technology deployments in consideration of the many benefits that will also accrue. The integration of new technology into the transit operations, and the coordination with other governmental entities for placement of system equipment within the built environment, is a complexity many bus operators have never undertaken. Other issues like cybersecurity, large data management and creation of a sophisticated operations center need policy-level decisions to proceed with implementation.

Safety Program – All public transit operating agencies down to the smallest bus operator who deploy AV technology will be required to establish a rigorous safety assurance program. Policy makers will need the necessary resources and give authority to personnel assigned safety responsibilities to execute a SMS acceptable to FTA and to the appropriate state safety oversight agency.

AV Taxis and TNCs – The primary policy issues that may be faced at the local level concern the full compliance with federal law and regulatory requirements for public transit services when providers are using federal funds. The acceptance by the TNCs of the associated terms and conditions in the local transit agency's contract concerning regulatory compliance could be problematic. Other aspects affecting the policy decision to utilize TNC contracted services include the potential competitive relationship between transit and TNC type of ride-sharing car services, if concerns of some in the transit industry prove to be correct.

Research Projects and Policy Studies on AV Transit Operating Agency Policy – Policy decisions made at the local transit operating agency level will become increasingly more complicated due to the uncertainties of when, how and in what way AV transit deployments will affect passengers, employees and overall operations. The following key policy studies would be beneficial for undertaking based on the considerations and findings of this working paper:

1. **Long-Range Planning Benefit/Cost Analysis Guidelines** – Preparation of guidelines for near-, medium- and long-range service plans could be developed by this policy study's resulting framework for decision making in long-range planning studies. The typical decision framework would typically consider the service benefits and operational/cost impacts of AV transit technologies, including the evaluation of operating fleet and infrastructure capital investments at a planning level of detail. The methodology would account for a variety of variables, including vehicle sizes and fleet requirements, types of service (first-mile/last-mile, high-frequency BRT corridor service, arterial street fixed-route service, etc.), and the associated levels of manpower needed to support the operations – refer to supporting work from research project recommendations noted in Working Paper #3. The policy study would address possible scenarios to be addressed, the sensitivity of the variables, and the associated benefit/cost implications through suggested analytical methodologies and assumptions.
2. **AV Transit Service Types and Operational Planning Parameters** – A policy oriented research study would be beneficial to develop definitions of service types that will become possible with progressive implementation of AV Transit technologies, including operational concepts, passenger service characteristics, vehicle fleet alternatives, dispatch complexity and other operational aspects. The preliminary service types described in the Working Papers could serve as the point of research initiation, including first-mile/last-mile (FM/LM) campus circulators; FM/LM urban district circulators connecting to high-capacity transit corridors; FM/LM systems in suburban and rural areas connecting to high-capacity transit corridors; high-frequency bus rapid transit lines; conventional arterial street corridor transit services; and regional express commuter bus lines. The complete spectrum of operational strategies to be addressed could include fixed-route, flex-route and demand-response (with real-time dispatching).
3. **Benefit/Cost Analysis of Conversion from L3 to L4 Transit Operations** – This research project could develop a benefit/cost analysis of L3 operations with an operator onboard in comparison to L4 operations with no onboard operator required. The comparisons should consider the reduction in operating costs of removing the employee from the vehicle, the reductions in insurance premiums, and associated reduction in legal costs and repair costs as crashes are reduced. Transitions and related safety and insurance/legal cost impacts under L3 operations could be researched to properly reflect the man-machine control transition issues as transitions to and from automated driving modes are continually occurring. This research might also leverage findings for moving from L0 to L2 (basic ADAS services) in drawing comparisons of incremental benefits from one tier of operation to another.
4. **Cybersecurity Issues Affecting Transit Operating Agencies** – Research would be beneficial to assess the necessary risks and technically feasible mitigations of securing the vehicle communications systems, the onboard processors supporting the communications with infrastructure, and the supporting software for AV control and localization which must be periodically updated through program downloads. In addition,

research could address the risks and mitigations that are practical cybersecurity protection for the supervisory control systems and the operations control center operational support software.

5. **Big Data Management**– Research which analyzes the “Big Data” implications of video/audio, command and control signaling, vehicle system diagnostic data and “black box” onboard operational data recording for each vehicle in the AV operating fleet is a very important area requiring further study, as well as the assessment of rescaling of an agency’s data processing capabilities for small, medium, and large transit operating agencies.
6. **Operations Control Center Features and Scale** – A conceptual design study would be beneficial to define an operations control center and supporting local operations centers that could support an AV transit system for a hypothetical small, medium and large operating agency. Quantification of OCC personnel, roles and responsibilities, work stations, remote operator positions, communications and passenger support personnel, as well as management personnel could be accomplished for the conceptual OCC facilities. A description of the facility size and functional areas required to maintain AV transit operations for the small, medium, and large agencies would also be beneficial if prepared.

LAWS AND REGULATIONS

Laws Protecting Employees

Section 13c Requirements of the Federal Transit Act

49 U.S.C. 5333(b), also known as "Section 13(c) of the Federal Transit Act," has been maintained by the Office of Labor-Management Standards (OLMS) for many years. The overview of this law on the OLMS website [44] begins with the paragraph shown below (*underline text denotes emphasis* added by the authors of this paper):

> *When federal funds are used to acquire, improve, or operate a mass transit system (public transportation), federal law requires arrangements to protect the interests of mass transit employees. 49 U.S.C. § 5333(b) (formerly Section 13(c) of the Urban Mass Transportation Act). Section 5333(b) specifies that these protective arrangements must provide for the preservation of rights and benefits of employees under existing collective bargaining agreements, the continuation of collective bargaining rights, the protection of individual employees against a worsening of their positions in relation to their employment, assurances of employment to employees of acquired transit systems, priority of reemployment, and paid training or retraining programs. 49 U.S.C. § 5333(b)(2).*

The law states in part that as a **condition of financial assistance** from the federal government to a transit operating agency, the interests of employees shall be protected under arrangements which the Secretary of Labor concludes to be fair and equitable. These arrangements are administered under the Office of Labor-Management Standards and include:

- **Preservation of rights, privileges and benefits** under existing collective bargaining agreements
- Continuation of **collective bargaining rights**
- Assurances of **priority of reemployment** of employees who (…are displaced by changes, notably via automation technology systems in this context)
- **Paid training** or retraining programs

These Section 13(c) stipulations are existing law and may contain some of the most challenging aspects of bringing AV technology into the mainstream of public transit system operations

Based on this possibility, transit operating agencies currently receiving federal funding could risk losing their funding due to labor law compliance impacts when implementing L4 AV technology, if the changes are not first vetted with their employee's labor unions. Notably, new services such as first-mile connections using low(er) speed L4 shuttles may not displace existing employees at all (and in fact may require additional employees).

Possible Options for Operating Agencies – Another possible view that has been expressed in stakeholder discussions is to treat this transition to AV technology application in transit service as an opportunity to wean an agency off federal funding by a potential reduction in operating costs resulting from automation. If there is a possibility to move away from Federal funding in contrast to impacts of 13(c), agencies may still be able to optimize costs through other funding solutions, such as local taxes. This is only speculative and research is likely

[44] https://www.dol.gov/olms/regs/compliance/compltransit.htm

needed to assess the different cost variables of such adjustments. Such a study might consider the hypothetical conversion of a medium sized transit agency (as defined by APTA) to progressive application of AV technology in its operations. A thorough benefit/cost analysis could then assess the overall employee workforce and financial impacts of this transition over the course of time, including impacts such as loss of federal funding due to potential reduction of employee staffing levels. No systematic analysis of employee reorganization has yet been done (that we know of). While the general speculation is that many fewer employees would be needed to "supervise" an AV transit system than drive each vehicle manually, it is not clear yet how significant the reductions in staff would be.

Possible Changes to the Law – Other possible changes to the federal transit employee protection law may be considered based on the following questions:

1. As automation of the driving task and employee presence on each vehicle gradually begins to reduce the size of the workforce, should the federal law be revised to allow for attrition?
2. Does the law need to address how or in what way employees can be retrained and redeployed in public transit agencies?
3. How will these changes to employee roles and responsibilities impact contracted employees, and should federal funds be allowed for contracted services in the workforce if those services are not compliant with these federal rules?

Occupational Safety and Health Administration (OSHA) Regulations

OSHA operates as a division of the Department of Labor, and the OSHA Standards regarding workplace safety are contained within 29 CFR Part 1910 — OCCUPATIONAL SAFETY AND HEALTH STANDARDS. OSHA has published standards regarding the application of machines in industrial settings for many years. Chapter Six – *Robotics in the Workplace from OSHA Publication 3067 – Concepts and Techniques of Machine Safeguarding*[45] is particularly relevant.

This aspect of OSHA regulations is worthy of further studies to determine if specific requirements are necessary for AV transit. This is specifically important for operations facilities (dispatching and storage yards), as well as maintenance facilities where OSHA directives and guidelines may need to address processes and procedures concerning robotic vehicles and the potential for workplace hazards. During discussion of this topic in industry stakeholder workshops, one suggestion was to require that the vehicle must be "aware" of human(s) in the vicinity and communicate desired automated actions through some means (audio, lights, text, etc.). Such vehicle awareness functions are integral to operation in the long term.

Laws Protecting Passengers

Title VI of the Civil Rights Act – FTA Regulations

In 1964 the Civil Rights Act established major tenets of social justice in the United States of America. As guidance for the applicability of Title VI requirements relative to transit system

[45] https://www.osha.gov/Publications/Mach_SafeGuard/chapt6.html

projects, FTA Circular C.4702.1B [46] was last updated in 2012 and it serves to protect people from discrimination in transit programs receiving federal financial assistance. The Federal Transit Administration's Office of Civil Rights monitors FTA grant recipients' Title VI internal programs to ensure their compliance with the federal law. The Justice Department is also involved in the process, if violations are found.

The impacts of AV technology deployment will be assessed under Title VI criteria for the ways in which minority populations are served by each new AV transit service. This seems particularly important with the demographic trends showing the suburbanization of the poor. These demographic shifts can create concentrations of transit dependent populations in locations where transit service cannot effectively serve their needs, when compared to populations in the urban core where the heaviest transit investments have traditionally been made. The ability of AV transit deployment is suburban areas will therefore be an important factor in determining the Title VI impacts or benefits.

Environmental Justice Policy – Issues such as those discussed above must be carefully assessed, since FTA's "environmental justice" (i.e. discriminatory impacts of a new transit service) requirements[47] can be a major factor in receiving approval for a given transit project's Environmental Record of Decision (ROD) and the resulting release of New Start funding from FTA.

Even after enactment of the Title VI of the Civil Rights Act requiring equal access to transportation programs and services, many scholars believed that additional safeguards were needed to project these special populations. As a response, President Clinton issued Executive Order (EO) 12898: *Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations*. The Executive Order requires each federal agency to develop what became known as an environmental justice strategy that identifies and addresses disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations. To facilitate this matter across all Executive Branch agencies, an Interagency Working Group[48] was established whose charge is to ensure the protection of minority and low-income populations.

The most basic of environmental justice implications for the introduction of AV transit technology in public transit service is the requirement that the metropolitan planning organizations and transit operating agencies implement a strategy to ensure greater public participation in the decision-making process. **The federal requirements stipulate that this public involvement must include minority populations and low-income populations** that could be affected by the AV transit deployment and the associated environmental hazards, urban renewal programs, and transportation projects.

[46] https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/FTA_Title_VI_FINAL.pdf

[47] https://www.transit.dot.gov/regulations-and-guidance/fta-circulars/environmental-justice-policy-guidance-federal-transit

[48] https://www.epa.gov/environmentaljustice/federal-interagency-working-group-environmental-justice-ej-iwg

Americans with Disabilities Act – FTA Regulations

The ADA first became law in 1990, and today its public transit application is administered by the Civil Rights Department of FTA[49]. There are multiple components of the federal law defining aspects of ADA requirements for public transit agencies:

- CFA 49 – Transportation, including Part 37 Transportation Services for Individuals with Disabilities, and
- Part 38 Accessibility Specifications for Transportation Vehicles.

Part 38 has *more than 30 pages* of regulatory law specifically dedicated to ADA requirements for public transit systems, vehicle equipment and facilities.

FTA Circular C4710.1 has been published for guidance in the application of the law[50], and this 300+ page document is an important reference for transit operating agencies who manage the day-to-day issues of serving their elderly and disabled passengers.

By the nature of such comprehensive requirements of ADA for both transit systems and associated facilities, there are many exceptions granted in the Circular for equipment and facilities that were placed in service decades before the law was passed. The interpretation of "exceptions" is handled under the auspices of the FTA Civil Rights Office. Eventually changes to the law to specifically address AV transit will likely be addressed through a normal process over the course of time as experience with this new type of vehicle technology is obtained.

General ADA Criteria – In CFR 49, Part 38 ADA Accessibility Specifications for Transportation Vehicles requirements, there are a few general criteria that apply across all vehicle types:

- **Minimum clear space** of 48 inches by 30 inches for wheelchair parking inside vehicles, with wheelchair securement against movement while the vehicle is in motion.
- **Interior vehicle handrails and stanchions** required.
- **Wheelchair Access/Circulation Clearance** internal to the vehicle to allow wheelchair maneuvering that allows a "route at least 32 inches wide".
- **Priority Seating and Signs** designating seating locations for passengers with disabilities.
- **Audio Announcements and Visual Instructions** for the hearing and visually impaired.

For buses, vans and fixed guideway systems, there are specifications of the number of wheelchair securement locations (e.g., 2 wheelchair position for vehicles over 22 feet in length), and the minimum forces that each securement device must be able to withstand (e.g., 2,000 lbs.). There are also provisions for "automatic attachment" as well as operability by a person familiar with the system and mobility aid. The Part 38 requirements contain detailed specifications for wheelchair lift design and lifting capacity.

Wheel Chair Ramps – The most challenging requirements for AV technologies that are written into existing law for conventional rubber-tired transit vehicles are those that address vehicle

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49 https://www.transit.dot.gov/regulations-and-guidance/civil-rights-ada/ada-regulations

50 https://www.transit.dot.gov/regulations-and-guidance/fta-circulars/americans-disabilities-act-guidance-pdf

floor height above the boarding surface where the passengers stand, creating conditions where a step up is typically required to board a vehicle.

Vehicle/Platform Edge Gap – FTA's specific requirements for rail mass transit systems stipulate that level platform boarding with a maximum 3-inch gap be provided between the platform edge and the vehicle door threshold at all stations, including a maximum 5/8-inch vertical height difference. The regulations also require that a low-speed people mover system (operating at a speed no greater than 20 mph) must have a maximum gap of 1 inch and a maximum height differential of 1/2 inch.

Key Issues for ADA Requirements with AV Applications – The benchmarks of ADA regulatory requirements described above are of critical importance as new provisions in the law are created for application to AV transit vehicles. There could be one set of requirements during the early stage of AV transit deployment when L3 automation still requires an operations person in every vehicle who can assist with ADA accommodations in the boarding/alighting process. Then a different set of requirements may apply over the long term when under L4 and L5 automation there will be no operations person present in the vehicle, or at boarding locations.

Other questions that are relevant to discuss, investigate and consider through follow-on studies or research activities include:

1. **Will AV transit vehicles be viable for public service with ramps or lifts that are automatically deployed** to board a passenger in a wheelchair, and, if so, what new safety hazards might be induced?
2. **If AV technology supplier designs for unmanned vehicle operations do not provide equivalent ADA compliance** as do conventional human-operated transit vehicles, can regulatory changes be made to accommodate this through exceptions or otherwise?
3. **Will wheelchair securement be required in AV transit vehicles, and how will that be safely automated** if no operator is onboard?
4. **Should AV technology suppliers be changing their vehicle designs to ensure highly reliable maneuvering capabilities for precise docking at stations** that complies with the existing ADA regulations for level platform boarding?

FTA Transit System Regulations

Buy America Requirements

FTA funding for New Starts transit projects is normally contingent on compliance with Buy America regulations in the procurement of systems, facilities and rolling stock. The stipulations of the regulations generally require that equipment and construction materials be purchased from American manufacturing sources specified as a percentage of total content for the subsystems and component parts. The full law has recently been revised by the Fixing America's Surface Transportation (FAST) Act, and established as law in 49 U.S.C. Section 5323(j) / FAST Section 3011.

As one feature of the FAST Act, the US manufactured content of rolling stock will soon to be raised to 70%. In addition, foreign transit vehicle manufacturers must establish a final assembly plant on U.S. soil, as well as meeting the required percentage of the subsystem equipment from American sources.

The existing Buy America law will clearly have major impact on the way that AV transit technology advances in its development and deployment within the United States, since Buy America requirements seem unlikely to be reconsidered just for AV technology application benefits under the current U.S Administration.

Exceptions in the Near Term are likely to be needed which can be granted for a whole project without an extensive waiver application process to place AV transit systems in revenue service quickly. There have already been processes set in place within FTA to obtain waivers for initial test and demonstration projects to not require compliance with Buy America stipulations. To address the evolution of AV technology and to not constrain innovation, this approach of the federal government granting waivers may be a key path to moving forward in the near term.

Considering the current situation where most AV transit vehicle suppliers are not U.S. owned sources of supply, a reduction of the minimum percentage of U.S. subsystems and components could be established in the FTA Buy America regulations.

- **Should the federal government consider changing the FTA Buy America minimum percentages** of U.S. supply for equipment and rolling stock when funding is provided for AV transit technology?

Whenever FTA funds are being applied to transit equipment purchases there is focused federal oversight given to ensure Buy America requirements are met.

- **Should FTA establish an official oversight support office** for providing guidance to transit operating agencies and managing the Buy America regulatory constraints as new applications of AV transit technology begin to come into common service deployment?

A related question was raised concerning the possible mandate of Buy America requirements for transportation network company contracted services to AV transit operating agencies using FTA funding.

- **Will Buy America stipulations also be applied to TNC contractors**, as well, when funding for these services comes from FTA grants?

FTA New Bus Testing Process

49 CFR Part 665 indicates that all new bus models must undergo testing at FTA's Altoona Bus Testing Facility. These procedures include tests for performance at maximum gross vehicle weight (speeds on grades, parking brake operations), maintainability testing, noise, fuel economy, emissions, and safety tests. Safety tests include basic braking distance tests on a variety of surfaces, structural integrity of the vehicle chassis when stressed in different manners. New tests for AV sensors and actions would likely need to be developed and it would be likely that other test criteria may need to be applied for smaller AV transit vehicles that are not the same size as a standard coach.

Transit System Safety Program – Safety Management Systems

Recent updates to these FTA safety programs have included a Safety Management System component which has drawn extensively from the safety program experience of the Federal

Aviation Administration (FAA). As discussed earlier, noncompliance with these safety rules by a transit operating agency could potentially jeopardize FTA New Start funding or conceivably even incur fines or other penalties imposed by FTA if unsafe practices and/or designs are determined to be deployed. In addition, it is possible that such fines could be levied whether federal funds have been used in the procurement of the system equipment, facilities and rolling stock (i.e., transit vehicles).

FTA's Office of Transit Safety and Oversight administers the federal transit safety regulatory program and includes aspects of program compliance. This role primarily addresses oversight for New Starts projects to advance the provision of safe, reliable, and equitable transit service through adherence with legislative, policy and regulatory requirements as established by FTA. It is noted, however, that the **primary oversight of continuing safety program compliance has been delegated to the states**, which the Office of Transit Safety and Oversight has been charged with "certifying" the state-level oversight program.

Although the SMS program has applicability for any size and type of transit operating agency, with specific resources and guidelines available for even the small bus operators (refer to the SMS website link cited in the footnote), the overall system safety program requirements are **only mandated by FTA for fixed guideway rail systems**.

With the new design and operational complexities of AV transit, the new safety risks of automation will make the importance of implementing a full safety program in compliance with FTA guidelines applicable to even small transit operating agencies. Many operators that do not have fixed guideway transit and have never implemented such a thorough safety program as part of their bus operations will likely face a reorganization of their decision-making process, as well as enacting policies and procedures to develop, implement and maintain a comprehensive system safety program plan.

Remote Operator Involvement – There are a variety of ways that human transit vehicle operators currently ensure the safety of passengers, particularly when passengers have special needs such as elderly passengers with canes or walkers, passengers with seeing or hearing disabilities, and passengers in wheelchairs.

1. Will FTA safety laws/regulations allow operations control center personnel to remotely monitor boarding and alighting of disabled passengers sufficiently to adequately mitigate the risks and thereby ensure safe passenger transfers into and out of the vehicle?
2. How much of the safety assurance risk mitigation under these circumstances of remote monitoring will rely on procedural compliance, and how much will it rely on detection and control functions to be automatically executed (e.g., OCC alarms and operator response, or automatic vehicle propulsion interdiction)?
3. Should regulations allow (or necessarily not preclude) remote operators of AV transit vehicles to enable wheelchair lifts or wheelchair ramps, actuate wheelchair securement features, and/or actively supervise the passenger boarding process through remote video/audio links?

NHTSA Vehicle Safety Regulations

Federal Motor Vehicle Safety Standards

As discussed previously, the National Highway Traffic Safety Administration establishes and maintains safety standards known as the Federal Motor Vehicle Safety Standards and Regulations for the automobile industry in the United States.

NHTSA has not yet announced how and if these traditional safety requirements and tests will be expanded to include safety tests specific to what the 2016 USDOT/NHTSA Policy Statement identified as “highly automated vehicle” (HAV) technology. Currently, a process is underway to assess the FMVSS standards’ applicability to AV technology. Through this ongoing review process, NHTSA is identifying which standards may need to be changed to properly address semi-automated and fully automated roadway vehicles, as well as identifying what new FMVSS standards will need to be added to test and confirm the adequate safe design of both light and heavy vehicle AV products that are brought to the US market place. The Executive Summary of a 2016 FMVSS evaluation report[51] assessing how HAV technology could fit into existing standards begins with these summary points:

> *Current Federal Motor Vehicle Safety Standards (FMVSS) do not explicitly address automated vehicle technology and often assume the presence of a human driver. As a result, existing language may create certification challenges for manufacturers of automated vehicles that choose to pursue certain vehicle concepts.*
>
> *The purpose of this work is to identify instances where the existing FMVSS may pose challenges to the introduction of automated vehicles. It identifies standards requiring further review - both to ensure that existing regulations do not unduly stifle innovation and to help ensure that automated vehicles perform their functions safely.*

Clearly, the decisions of NHTSA concerning the expansion of FMVSS standards to address AV technology in general, and AV transit vehicles will have a major impact on the designs of automated roadway transit vehicles that are available for deployment in transit service.

Regarding the early deployment prospects of L4 automation in non-conventional AV transit vehicle designs which are actively being tested in campus and very low-speed environments, the following summary point has been extracted from the Volpe review of FMVSS standards and their potential impacts on AV technology (refer to footnote 14):

> *Automated vehicles that begin to push the boundaries of conventional design (e.g., alternative cabin layouts, omission of manual controls) would be constrained by the current FMVSS or may conflict with policy objectives of the FMVSS. Many standards, as currently written, are based on assumptions of conventional vehicle designs and thus pose challenges for certain design concepts, particularly for ‘driverless’ concepts where human occupants have no way of driving the vehicle (e.g., §571.101, controls and displays, §571.111, rear visibility, §571.208, occupant crash protection represent a few examples).*

[51] http://ntl.bts.gov/lib/57000/57000/57076/Review_FMVSS_AV_Scan.pdf

The special environments and enhanced monitoring and crash avoidance features of AV transit vehicles should be given special consideration in order to allow the near-term deployment of AV transit technology in special environments – a step important to advancing R&D initiatives. The following questions illustrate some of the key issues that may need to be addressed:

1. Can the crashworthiness criteria be adjusted for AV technology if/when automation can be shown to significantly improve crash avoidance capabilities of the vehicle?
2. Can provisions with less stringent crashworthiness criteria be made in the near term for AV transit vehicles that operate in protected environments dedicated to transit vehicles and pedestrians (such as campuses, parking lots, and guideways)?
3. Can crash survivability criteria be less stringent for AV transit vehicles operating in protected environments (such as campuses, parking lots, and guideways) when interactions with other roadway vehicles only occurs at signal-protected grade crossings of the transitway with roadways?

The rapid advancement of a several L4 AV transit vehicle designs which do not resemble conventional automobile, truck or bus chassis designs gives an urgency for NHTSA and FTA to identify any decisions on how and where these specialized vehicles will and will not be permitted to operate. Other FMVSS requirements to be placed on AV transit vehicles that generally conform to conventional bus and light truck chassis design will be issued at a point in the future, probably at the same time as standards for HAV automobiles are released by NHTSA.

Security and Privacy Laws

Security Regulations

Cybersecurity is the biggest threat to safety of AVs. As with any other computerized systems with networking capabilities these days, AVs have the potential to be hacked, which could have very serious consequences particularly in the context of transit. Pilot projects across the European Union and United States are testing different cybersecurity and privacy measures. Some vehicle manufacturers are giving “hack-a-thon” prizes to test the security of vehicles. Cybersecurity must take a multi-pronged approach to preventing, identifying, and stopping thefts and attacks.

The private sector manufacturers of AVs have different proprietary algorithms and codes for automation, as well as software and hardware that are manufactured by multiple vendors. There are multiple sources of cyber-threat within one AV. In addition, V2I networks are a possible source of cyberattack. Another source of cyber-threat is the internal network for the AV’s electrical control unit (ECU). Finally, networks within the AV that are linked to external data sources such as radio, navigation, etc. are another source of a potential threat. Because many of the threats to AVs are internal to the vehicle, private manufacturers must take the lead on implementing cybersecurity. However, in the US, in 2014, only two of 16 auto manufacturers had addressed cybersecurity threats by developing the capability to detect hacks in real time.[52]

[52] http://www.markey.senate.gov/news/press-releases/sens-markey-blumenthal-introduce-legislation-to-protect-drivers-from-auto-security-privacy-risks-with-standards-and-cyber-dashboard-rating-system

Because of the major need and the lack of commitment from AV manufacturers, US legislators are attempting to pass legislation to establish federal standards for security and privacy for AVs. The act, entitled “The Security and Privacy in Your Car Act” prescribes vehicle manufacturers to detect, report, and stop hacks that interfere with personal data or vehicle control.[53] The legislation addresses the types of data including location, speed, owner, and passengers and the location of the data – onboard, in transit from vehicle to another location, and off-board data storage. It proposes a “cyber dashboard” to tell consumers the vehicle’s cyber rating above the minimum requirements. It also requires AV manufacturers to notify the owner or user of the vehicle of what data is being collected, how it is stored, for how long, and what the data is used for. It gives the user the ability to opt out of data collection (with specific safety exceptions) without losing AV features. Finally, the legislation prevents the use of data for advertising or marketing without the owner or user’s consent. This legislation has not yet become a law in the US.

In July 2016, the Automotive Information Sharing and Analysis Center (Auto ISAC), a group of Automotive Manufacturers, developed a series of best practices for cybersecurity[54], which is endorsed by NHTSA in its September 2016 Federal Automated Vehicles Policy. The categories addressed include:

- Governance
- Risk Assessment
- Risk Management
- Security by Design
- Threat Detection and Protection
- Collaboration and Engagement

The best practices document recommends identifying and addressing cyber-threats in the design process of the vehicle’s systems with an emphasis on limiting network interactions and separating networks and environments where possible. The governance recommendations include creating or purposing a vehicle cybersecurity organization with regulations and policies for vehicle manufacturers. In probably the best-case result for the US, this would be a federal agency responsibility such as NHTSA. How such regulations would affect the transit industry is not known now, and NHTSA’s AV model policy does not discuss any transit specific issues.

The USDOT has adopted a “security by design” principle as it develops the system architecture for connected vehicles—meaning cybersecurity systems will be built in. In the EU, the recommendations of the C-ITS platform are very clear: one common standardized C-ITS trust model and certificate policy all over the EU, based on a Public Key Infrastructure (PKI) and defined in an appropriate regulatory framework, shall be urgently deployed to support full secure interoperability of C-ITS Day 1 services (including any connected transit systems and vehicles). The "security by design" principle applies to both V2V and V2I systems.

[53] https://www.congress.gov/bill/114th-congress/senate-bill/1806/all-info

[54] https://www.automotiveisac.com/best-practices/

NHTSA's Federal AV Policy addresses data recording and sharing[55]. The policy recommends collecting data for testing and for crash events. For crash events, NHTSA should receive the data itself in case of personal injury and significant damage that requires towing. For testing purposes, NHTSA recommends collecting data on positive events including near misses or when the AV avoided an incident, and sharing the data with other third parties. When the data is shared, it should not be personally identifiable with a person or vehicle. NHTSA acknowledges that data sharing and privacy regarding AVs is still in its infancy and advises the vehicle manufacturers to work with standards organizations for data collecting and sharing.

There is still more work to be done in the public and private sector internationally in developing specific policies and regulations for cybersecurity and data privacy for HAVs in general, and specifically for AV transit systems[56]. A security framework for all AV transit will need to be developed stemming from the NHTSA actions. Where such regulatory responsibilities for transit operations will lie will need to be determined, and how such activities are coordinated with Auto-ISAC and state and federal regulations regarding hacking. Strict punishments will need to be established for cybersecurity breaches commensurate with the level of threat particularly in the case of AV transit (up to and including attempted and actual murder and terrorism).

Privacy Protection Laws

Automated vehicles process sensor readings of the surrounding environment to travel safely. For AVs to make those navigational and operational decisions, the vehicle will need to collect data about itself and/or the driver; then distribute that data between vehicles, infrastructure, and other drivers. The risks lie not only in the data collection, but how that data is communicated whether transmitted between technologies in the vehicle (i.e. smartphone) or V2V or V2I.

New vehicles including buses beginning in September 2014 in the US are now required to have an event data recorder (EDR) per the National Highway Traffic Safety Administration [57]. NHTSA requires the recorder to obtain information related to 15 variables: speed, airbag deployment, application of brakes, seatbelt worn, engine speed, steering, and others. The recorders are not supposed to be recording audio, GPS, or video within the vehicle (although many transit buses have onboard video that is not strictly part of the EDR). The information is used to assess how well the driver responded in a crash and whether the vehicle was operated properly.[58]

The US has no one specific data protection law but rather a patchwork of complementary and in many cases overlapping regulations. The US has several data privacy laws and regulations that

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[55] NHTSA Federal Automated Vehicle Policy, Sept 2016. http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwiGxKOxhL3PAhUG6mMKHdENDT8QFggkMAA&url=http%3A%2F%2Fwww.nhtsa.gov%2Fnhtsa%2Fav%2Fpdf%2FFederal_Automated_Vehicles_Policy.pdf&usg=AFQjCNHSgKVEpfw_sEOcV6VFGd7uefwI6A&sig2=m-GdAFvdtQlYo8mcuZK11A

[56] https://www.nap.edu/download/23520

[57] https://www.gpo.gov/fdsys/pkg/CFR-2011-title49-vol6/xml/CFR-2011-title49-vol6-part563.xml

[58] http://www.nhtsa.gov/About+NHTSA/Press+Releases/U.S.+DOT+Proposes+Broader+Use+of+Event+Data+Recorders+to+Help+Improve+Vehicle+Safety

are specifically dedicated based on specific industries or specific states (Arizona, Alaska, etc.)[59]. For example, there is the Video Privacy Protection Act, Health Insurance Portability and Accountability Act (HIPAA), as well as the First, Fourth, and Fourteenth Amendments of the Constitution. In 2012, the US administration developed the Consumer Privacy Bill of Rights,[60] identifying or recognizing the Fair Information Practice Principals (FIPP). Data privacy and protection laws are designed so that individuals have a reasonable expectation their private data would not be transmitted to another party without their consent. This would be true for both inside and out of the vehicle; including smartphone and vehicle 'black boxes'.

As an extension of the general principles and legal requirements discussed above, there will need to be additional care given to protecting the personal information of individual transit patrons. New types of on-demand dispatch driverless transit services may use data from the passenger's smart phone or other such personal device when they request a transit vehicle. This information will likely include their origin and intended destination as well as possibly their personal identity and payment information. Such personal data, combined with likely use of real-time audio and video security surveillance in vehicles and stations present privacy protection issues for transit operating agencies.

Currently, transit agencies that accept contactless smart cards for fare payment face many of these issues already today as summarized in recent TCRP Legal Research[61]. Most existing legacy transit smart cards have no PII expressly loaded on them but only a balance of funds available for transit use[62]. As smartphones, have now enabled new ways for merchants to be paid (Samsung Pay, Google Wallet, etc.) through near-field-communications (NFC), this abstraction of PII from location is somewhat removed but is commonly still managed through the merchant payment system. As noted in [29], no legal cases involving privacy violations of transit patron's PII have been encountered to date. In most situations, the transit agency is treated as just another type of merchant. As long as the transit agency has industry-accepted privacy policies and protections in place, there is little argument that driverless transit services will pose any more PII risk than existing payment and service systems.

Similarly, audio and video surveillance and recordings are now commonplace in transit operations. In most states, recording and real-time surveillance is legal since there is no expectation of privacy in a public space (i.e. in the transit vehicle). Such monitoring becomes even more important when there is no driver on board and communications with the remote operator will only be possible through these systems if a problem arises. As long as the transit agency has industry-accepted privacy policies and protections in place, there is little argument that driverless transit services will pose any more risk to personally-identifiable information than existing video and audio surveillance systems on transit vehicles today.

[59] https://www.huntonprivacyblog.com/wp-content/uploads/sites/18/2011/04/DDP2015_United_States.pdf

[60] https://www.whitehouse.gov/sites/default/files/privacy-final.pdf

[61] http://www.trb.org/main/blurbs/175848.aspx

[62] Except in certain programs where cards are used for discounted fares such as senior and children and pre-paid passes. In these cases, the user's ownership information is linked to the card's use at the time of payment for verification that the pass is valid.

Governmental Policy Considerations

The overall policy considerations on L3, L4 and L5 automated roadway vehicle operations which governmental bodies are beginning to address around the world will have major implications for the long-term future of our multimodal transportation systems. There are diverging views on how AV technology will transform and impact both our transportation system and the urban centers of population in which the clear majority of people now live.

The policy question is whether the regulatory management (or intentional lack of regulatory management) elements in their toolbox of proactive transportation master planning will foster utopia or drive dystopia in a future HAV-dominated roadway system. Does policy drive the creation of governing laws/regulations which may be needed to accomplish the goals of a master plan? What is the role of transit systems if mobility in individual HAVs can be provided for comparable cost to individual vehicle ownership? If a current transit rider's commute can be cut by 50% travel time for double the price, would they pay the price?

The essence of this question is whether shaping this future transportation world is important enough to intervene in a regulatory manner – much like a government planning for a future water supply must impose regulatory provisions through water conservation/management combined with the creation of sufficient reservoirs and water distribution systems. Any such regulatory steps to shape the world, whether affecting transportation or basic water supply, can be very controversial.

Findings on Governmental Laws and Regulations

Governmental laws/ordinances and the regulatory constraints that they impose will have a major impact on how and when AV transit technology will affect our society and the communities where we live and work. Even more importantly, any delays resulting from laws and regulatory barriers to AV transit technology deployment within the multimodal transportation system may change forever the extent to which transit is considered in long-range regional urban planning and funding programs.

Employee Protections – A portion of federal laws are intended to protect employees of public transit operating agencies. To some extent, these laws provide for the preservation of jobs and will be critically important to review and possibly modify if AV technology is to have its maximum penetration of this sector of the transportation market.

Section 13c of the Federal Transit Act specifically states "…*must provide for the preservation of rights and benefits of employees under existing collective bargaining agreements, the continuation of collective bargaining rights, the protection of individual employees against a worsening of their positions in relation to their employment, assurances of employment to employees of acquired transit systems, priority of reemployment, and paid training or retraining programs.*"

Some involved in our stakeholder meetings believe that this federal law could be one of the most challenging aspects of bringing AV transit technology into the mainstream of public transit service. The involvement and cooperation of collective bargaining unions and impacted staff employees will determine how a mutually acceptable interpretation and application of the law by each transit operating agency.

OSHA Workplace Safety regulations are primarily applicable to industrial workplace protection, and the entry of robotic machines into the manufacturing industry over the past few decades has been a topic addressed by OSHA in the way of guidelines more than regulations. However, the sudden insertion of robotic machines which move within relatively uncontrolled and relative unprotected environments of transit operations and maintenance facilities (when compared to manufacturing plant assembly lines and factories) may require more precise OSHA directives and guidelines that go beyond the existing guidelines.

Passenger Protections – Intervention of the federal government to protect the most vulnerable and most dependent of public transit passengers from discrimination and from unsafe operating conditions has been an important area of existing laws and regulations. The two demographics that have had specific federal laws created for their protection are the physically disabled and the racial minority communities.

Title VI Nondiscrimination law has significantly impacted the release of federal funds for transit projects over the past 50 years. There can be decisions made with respect to this aspect of federal funding that has some elements of discretion in determining the nuances of discrimination. The application of AV transit technology for some transit operating agencies could potentially result in negative assessment of discrimination in the project funding review process if the deployments unfairly exclude the portions of the population protected by Title VI. However, there is an equally strong potential that AV technology can *significantly help* transit operating agencies more successfully serve the disenfranchised minority populations if a more cost-effective AV transit service can be provided in low density, suburban areas where the population has a high transit dependence.

ADA Transit Regulations are drawn from the Americans with Disability Act in which FTA has developed specific requirements for transit vehicles and transit station facilities. The regulations provide basic criteria that must be accommodated in the vehicle designs, but no regulations are yet in place for L4 AV transit technology vehicles. Wrestling with these issues cannot begin soon enough as more and more agencies contemplate the use of L4 shuttles for first-mile, last-mile services and circulators.

FTA Regulations – FTA has developed regulations specific to public transit systems which are not derived from other primary law such as their regulations covering Title VI or ADA nondiscrimination laws. These areas of regulation may be the most important with respect to implementing AV transit technology by the local transit operating agency since there are typically quantifiable analyses and calculations involved. Failing to demonstrate to FTA a compliance with the regulations to FTA could directly impact FTA funding grants, or even pose the potential for FTA to levy fines for noncompliance.

Buy America requirements will be a critically important set of regulations directly impact which foreign suppliers of AV transit vehicles can be solicited for proposals/bids once the early phase of research and development is passed and the full FTA regulatory framework is being applied. The Buy America regulations could also foster the creation of more U.S. owned manufacturers of AV transit vehicles, perhaps accelerated with additional incentives for US companies to enter the market such as tax credits, deductions, or other subsidies.

Transit System Safety Program Plans have been an important part of FTA requirements and guidelines for fixed guideway rail transit systems for several decades. The FTA regulations/guidelines, and the associated State Safety Oversight responsibilities will need careful coordination by FTA over the near to medium term for AV transit systems to have operational safety that equals that of automated fixed guideway transit systems.

NHTSA Regulations – The Federal Motor Vehicle Safety Standards comprise the regulatory law that governs the federal government's oversight and control of the automotive industry and the automobile products that are sold in the United States. FMVSS cover basic safety aspects of vehicular crash avoidance, vehicular crashworthiness and crash survivability of passengers. Other FMVSS which require features allowing the vehicle to be driven in a conventional way by a human operator are also included in the regulations.

FMVSS requirements have been under review by NHTSA for several years with respect to the new technology developments of what has been defined in the USDOT/NHTSA 2016 Policy Statement as "highly automated vehicles". At this point in time, there have not been any specifically proposed changes or additions to FMVSS to define safety design requirements, test procedures or performance criteria under fully automated or semi-automated vehicle controls. However, it is anticipated that such changes will be forthcoming over the next several years.

The rapid advancement of several L4 AV transit vehicle designs which do not resemble conventional automobile, truck or bus chassis designs gives an urgency for NHTSA and FTA to identify any decisions on how and where these specialized vehicles will or will not be permitted to operate. Other FMVSS requirements to be placed on AV transit vehicles that generally conform to conventional bus and light truck chassis design will be issued at a point in the future, probably at the same time as standards for HAV automobile standards begin to be by NHTSA.

Security and Privacy Law – Cybersecurity is the biggest threat to safety of AVs. Cybersecurity must take a multi-pronged approach to preventing, identifying, and stopping thefts and attacks. Because of the major need and the lack of commitment from AV manufacturers, US legislators are attempting to pass legislation to establish federal standards for security and privacy for AVs. The act, entitled "The Security and Privacy in Your Car Act" prescribes vehicle manufacturers to detect, report, and stop hacks that interfere with personal data or vehicle control.[63]

In July 2016, the Automotive Information Sharing and Analysis Center, a group of Automotive Manufacturers, developed a series of best practices for cybersecurity[64], which is endorsed by NHTSA in its September 2016 Federal Automated Vehicles Policy. In probably the best-case result for the US, this would be a federal agency responsibility such as NHTSA. How such regulations would affect the transit industry is not known now, and NHTSA's AV model policy does not discuss any transit specific issues.

Research Projects and Policy Studies on AV Transit Laws and Regulations – The prospects of a transit operating agency losing federal FTA funding due to a compliance issue with the variety of laws and regulations described in this working paper would seem to lead to significant impediments to AV Transit deployment. The following key policy studies, based on the considerations and findings of this working paper, would be beneficial.

1. **Hypothetical Study of Transit Automation Allowing Withdrawal from Federal Funding** – Assessment of the operational cost reduction prospects for a medium sized

[63] https://www.congress.gov/bill/114th-congress/senate-bill/1806/all-info

[64] https://www.automotiveisac.com/best-practices/

transit operating agency (i.e., "typical" local transit agency) could be studied with the objective of withdrawing from all Federal funding support and operational subsidies. The extent of automation could be defined as a series of hypothetical exercises to determine if this premise of financial independence from federal funds is possible and under what combination of service types using only ridership fares and local tax funding subsidies.

2. **Possible Changes to Section 13c of Federal Transit Act** – Investigation of the possible changes to the federal law 49 U.S.C. § 5333(b) known as "Section 13c" could be performed. The work will assess how a progressive process within a transit operating agency for retraining of its employees and a gradual decreasing is total staff could be accommodated under the law. Possible changes deemed necessary to prevent the constraint of AV transit deployment due to the potential violation of Section 13c will be the key study results.
3. **Applicability of Laws and Regulations to Private Contractors** – Assessment of the applicability of the laws and regulations that apply to public transit operating agencies could be made to determine if these same laws/regulations might be applied to those companies that provide contracted "transit" services. The applicability of these laws/regulations to transportation network companies could be assessed, and the long-term implications for federal funding used for contracted services could be evaluated. Regulations of importance appear to be Buy America stipulations, transit employee labor laws, FTA safety requirements and FTA's ADA regulations.
4. **OSHA Regulations for Robotic Vehicles in the Workplace** – Compilation could be performed of technical articles, standards and guidelines relevant to the presence of robotic vehicles in the workplace. This catalogue of materials relevant to robotic machines in the workplace could be assessed for safety procedures and design features applicable to the transit operations and maintenance workplace where AV transit vehicles are present with humans.
5. **Minority Population Involvement** – A working plan is needed by which minority populations can be engaged and involved in the public outreach process as planning for AV Transit deployment begins. Developed for guidance of transit operating agencies, the study documents could establish a framework for any transit agency to accomplish the required public involvement process with minority communities, as well as provide an initial assessment of how AV Transit can be deployed without violating Title VI Civil Rights law.
6. **Title VI Adjustments and Incentives** – A study could be performed of the benefits to providing allowances or exceptions to the Title VI requirements for advancing the progress of AV technology during the early years of transit deployment. Similarly, the study could assess the use of incentives to encourage AV transit deployment in the combined conditions of low population density and high transit dependency – conditions which are increasingly common in suburban communities.
7. **Automated Boarding Features for Wheelchair Passengers** – This technical study would address the design requirements, challenges and new potential hazards/risks in providing automated ramp deployment and automated wheelchair lift deployment. The study could include an investigation of the means for automated wheelchair securement, and the potential technology required to allow remote operator involvement in the process.

8. **Boarding Requirements and Possible ADA Exceptions** – An assessment of ADA requirements and the apparent required changes to vehicle designs would be beneficial as a means to provide equivalent accommodations and safety as human-operated transit vehicles, using features such as precision docking at level-platform station berths. Based on the design and cost implications of the required changes, the project work could evaluate the basis for considering exceptions to the ADA requirements and how those can be addressed within the service needs of passengers with disabilities.
9. **Buy America Challenges** – This study could evaluate the current status of viable suppliers of AV Transit vehicles and supporting ITS systems to determine how much of the supplier market will have trouble meeting Buy America regulations. The work could provide an assessment of whether the provisions of the Buy America law should be changed to adjust minimum percentages during the early period of AV Transit deployments, and whether incentives should be considered to improve the sources of supply from American vehicle suppliers – such as tax credits, tax deductions or other subsidies. The study could also address the need for FTA creating a special oversight support office, specifically dedicated to supporting operating agencies and managing the Buy America requirements during the period when new applications of AV Transit technology are coming on line.
10. **Vehicle/Station Supplemental Systems Necessary for Safe Operations** – A technical study is needed which performs research that begins with a functional definition of the supporting systems necessary for safety in the passenger/vehicle/system interface at station boarding and alighting locations. The work could address the potential need for new subsystems and associated safety provisions (e.g., propulsion/braking interlocks with door systems) to protect passengers during the period of active boarding/alighting as an integral part of vehicle designs sufficient to meet FTA safety program goals. These provisions may be on the vehicle, in the station, through remote monitoring and intervention by personnel in an operations control center, or some combination of these means and methods.
11. **Semi-Automated Operations Hazards Assessment and Mitigation** – Safety requirements could be studied for the period during which there is partial automation or transitions from automation to human driver/operator control at a point of failure or leaving of the ODD for the AV transit vehicle. The relative safety of AV transit operations under conditions of a human operator onboard the vehicle, a human operator in a remote OCC, and the various conditions when partial automation or transitions form automated operations could be assessed with respect to hazards and risk mitigation through design features and operating procedures.
12. **Applicability and Implications of FMVSS Requirements from NHTSA** – A combined policy and technical study would be beneficial to assess the impacts of NHTSA's Federal Motor Vehicle Safety Standards on low-speed L4 AV transit vehicles that do not conform to conventional automotive, truck and bus chassis design. As a concession to allow near-term operations of these specialized vehicles in special operating environments, the work could assess whether the crashworthiness specifications should be given special provisions in the near term to advance AV technology applications. As an extension of this assessment, the consideration of whether low-speed L4 AV Transit should be granted more lenient crashworthiness standards on a permanent basis when the vehicles only operate in protected environments such as campuses, parking facilities

and dedicated transitways. The study could also assess the design impacts and deployment hindrances of the alternate approach in which full compliance with FMVSS for any L4 vehicle is mandated, no matter what the operating speed or environment – including those vehicles with non-conventional designs and specifically intended to operate within an L4 AV transit system in a semi-protected operating environment.

13. **Development of AV Transit Cybersecurity and Data Privacy Regulatory Framework** – Performance of a policy oriented study would be helpful to define a catalogue of issues, perform appropriate research studies and then evaluate draft laws/regulations being considered within the AV technology world. The applicability to AV Transit would have to be determined, and a framework of laws and regulations that are probable would then be prepared for reference by transit regulatory agencies, transit operating agencies, transit services contractors and AV vehicle/technology suppliers. The importance of protecting personal data of the transit users, and the data processing and storage requirements for local transit operators could also be addressed.
14. **Broad Policy Considerations of AV Transit in Regional Transportation Planning** – A broad policy study that would be helpful is one which develops a generic regional transportation master plan incorporating the possible scenarios of AV Transit deployment and the associated multimodal transportation infrastructure for metropolitan areas of different sizes and densities. Working also from information gained through surveys of U.S. and international sources on regional transportation master planning concepts, the study work would then develop a framework of policy issues and information for use in the informing and guiding of decision making on broad policy positions by transit operating agencies, local municipalities, metropolitan planning organizations and regional transportation policy councils.

IMPLEMENTATION OF RESEARCH FINDINGS AND PROJECTS

AV Technology Evolution in Transit

Actions identified related to technology include:

1. Assessment of restrictions on transit platooning strategies
2. Research identifying possible changes to transit facilities and stations
3. Research on transit vehicle sizing, dynamic "entrainment," and other innovations enabled by automation
4. Research on design of platform edge protection and automated entry for vehicle berths

Assessment of Restrictions on Transit Platooning Strategies

Description – Platooning of transit vehicles has been demonstrated as feasible more than 14 years ago. Several states have restrictions on following distances that may preclude platooning of vehicles at short headways. This applies to both trucks and buses. AV/CV technologies enable platooning of vehicles that can have many benefits including fuel usage and increased capacity, without need for articulated coaches in BRT guideways. This review of existing regulations would focus on identifying the safety case for relaxation of such restrictions to deliver the anticipated benefits. Differences between truck and bus platooning would also be highlighted.

Urgency – May resolve naturally as the trucking industry demonstrates that platooning has significant benefits for interstate travel. Not a critical path element, but worthy of attention in 2018-2020 time frame.

Related activities – Studies on virtual entrainment, design of multi-berth stations, and use of AV for high-speed BRT

Budget/Schedule – Small-scale study, $150K, nine months

Changes to Transit Facilities and Stations

Description – Dynamic-dispatch, direct route systems of smaller shuttle-type vehicles will likely need station and intermodal center designs that are much different from existing transit facilities. AV transit vehicles without human attendants will need station designs that safely accommodate all types of passengers.

Urgency – AV transit shuttle systems are not yet proven at speeds that can perform as large-scale revenue service systems without dedicated guideways. As transit agencies gain more experience with small-scale point-to-point systems and simple loops, this issue will be more relevant as network possibilities are realized. 2020-2022 target date.

Related activities – Studies on virtual entrainment, design of multi-berth stations, and use of AV for high-speed BRTs

Budget/Schedule – Medium-scale study, $1M, 18 months

Transit Vehicle Sizing, Entrainment, and Other Innovations

Description – Dynamic-dispatch, direct route systems of smaller shuttle-type vehicles may allow new concepts such as virtual entrainment that can increase capacity of highly traveled routes without operation of today's traditional coaches, articulated coaches, or even light rail. Groups of smaller vehicles may be able to be coupled dynamically to serve different demands between specific stations without the limitations of traditional operations that stop at all stops in-between.

Urgency – AV transit shuttle systems are not yet proven at speeds that can perform as large-scale revenue service systems without dedicated guideways. As transit agencies gain more experience with networks of dynamically dispatched individual vehicles, this issue will be more relevant. 2022-2025 target date.

Related activities – Studies on design of multi-berth stations, technology evolution, progress of safe shuttle operations at arterial speeds

Budget/Schedule – Large-scale study, $1M, 24 months; may also take form of "AV transit challenge" similar to DARPA grand challenge, Smart City challenge, etc.

Platform Door Protection and Automated Entry at AV Berths

Description – AV transit vehicles without human attendants will need station designs that safely accommodate the loading and unloading of all types of passengers including the disabled and elderly.

Urgency – As transit agencies gain more experience with networks of dynamically-dispatched individual vehicles, this issue will be more relevant. 2020-2022 target date.

Related activities – Studies on design of multi-berth stations, progress of safe shuttle operations at arterial speeds

Budget/Schedule – Pilot projects: $5M-$20M, 24 months

Safety Considerations for AV Transit

Actions identified related to safety include:

1. Categories of hazards and risks for L3 and L4 AV transit
2. Hazards analysis methodology for L3 and L4 AV transit implementation
3. New consensus safety standard(s) for AV transit systems
4. Transit operational design domain definitions
5. Hazards assessment and mitigations for L3 operations

Categories of Hazards and Risks for L3 and L4 AV Transit

Description – This study would comprehensively itemize all categories of risks and hazards in AV transit operations as defined by MIL Std. 882 and its derivatives. All phases of transit service would be covered including stations, berths, boarding and alighting, dedicated guideways, mixed traffic operations, and so on.

Urgency – As the popularity of low-speed L4 shuttles is growing, this guidance is needed imminently before systems are introduced into regular revenue service. 2018-2019 target date.

Related activities – Generic hazards analysis methodology, consensus safety standard

Budget/Schedule – Medium-scale study, $250K; 12 months

Hazards Analysis Methodology for L3/L4 AV Transit Implementation

Description – This study would follow the definition of hazards and risks. The design guidelines would be used by transit agencies to plan the implementation of AV transit routes. Separate yet compatible guidelines are needed for L3 and L4 systems. All phases of transit service would be covered including stations, berths, boarding and alighting, dedicated guideways, mixed traffic operations, and so on.

Urgency – As the popularity of low-speed L4 shuttles is growing, this guidance is needed imminently before systems are introduced into regular revenue service. 2018-2019 target date. L4 operations dependent upon regulatory issue resolutions.

Related activities – Hazards and risks identification, consensus safety standard

Budget/Schedule – Medium-scale study, $500K; 18 months

Consensus Safety Standard(s) for AV Transit Systems

Description – Existing automated guideway transit safety standards would be adapted for rubber-tire L4 AV systems. The design standards would assist transit agencies in system procurement, installation, and safe operations. Separate standards may also be needed for L3 systems. All phases of transit service would be covered in the standards including stations, berths, boarding and alighting, dedicated guideways, mixed traffic operations, and so on. Some pilot project experiences may be needed before developing ratified standards.

Urgency – As the popularity of low-speed L4 shuttles is growing, this guidance is needed imminently before systems are introduced into regular revenue service. 2021-2023 target date. L4 operations dependent upon regulatory issue resolutions.

Related activities – Hazards and risks identification, consensus safety standard

Budget/Schedule – Large-scale effort, $1.5M; 24 months

Transit Operational Design Domain Definitions

Description – Relative to the definition of safety standards and hazards analysis, it would be helpful to define a standard set of AV transit operational design domains (ODDs). This concept proposed by NHTSA in the AV model guidance is a helpful construct for everyone to "speak the same language". This set of standard definitions would help agencies with procurement and discussing issues with a common vernacular. This activity could be developed in conjunction with the hazards analysis and safety standard definitions, or precede those activities.

Urgency – As the popularity of low-speed L4 shuttles is growing, a set of standard definitions could be helpful to focus conversations. 2018-2020 target date. L4 operations dependent upon regulatory issue resolutions.

Related activities – Hazards and risks identification, consensus safety standard

Budget/Schedule – Small-scale effort, $150K; 9 months

Hazards Assessment and Mitigations for L3 AV Transit

Description – L3 systems pose significant challenges as the AV system is not in full control all the time. The handoff between vehicle and user control poses some risk, and potentially more risk for transit operations than for private vehicles. This study would identify mitigations to L3 handoff risks and define a standardized mitigation strategy for use of L3 AV transit.

Urgency – AV BRT systems are nearing introduction into service in Europe and the Middle East. Although regulatory issues need resolution for introduction of L3 AV in the U.S., at least one pilot project has already been conducted with L1 AV. Medium term target 2020-2023.

Related activities – Hazards and risks identification, consensus safety standard

Budget/Schedule – Medium-scale effort, $350K; 15 months

Workforce Deployment Issues

Actions identified in workforce deployment include:

1. Definition of AV transit employee roles and responsibilities
2. Employee involvement guidelines
3. Union Contracting Guidelines
4. Automation of employee actions in compliance with ADA

Definition of AV Transit Employee Roles and Responsibilities

Description – While there is much concern about AV transit systems displacing vehicle drivers, there will be plenty of other jobs and positions at transit agencies to manage the operations of AV systems. This includes staff to remote-pilot the vehicles, security monitoring, station attendants, cleaning, and maintenance and repair. The role of remote pilots is a particularly important one that requires careful design and specification. Staff training and KSAs will need attention as well. Standards will need to be developed for retraining.

Urgency – As transit agencies gain more experience with pilot deployments of low-speed L4 shuttles, this issue will require attention if/when agencies decide to scale up operations to revenue service and networked operation. 2020-2022 target date.

Related activities – Employee involvement guidelines, union contracting guidelines

Budget/Schedule – Medium-scale effort; $350K: 18 months

Employee Involvement Guidelines

Description – While there is much concern about AV transit systems displacing vehicle drivers, there will be plenty of other jobs and positions at transit agencies to manage the operations of AV systems. As an agency begins to adopt AV transit services, interactions with union representatives and employee advocates will ensue. This planning guide may assist new agencies in following best practices for resolving issues with win-win outcomes.

Urgency – As transit agencies gain more experience with pilot deployments of low-speed L4 shuttles, this issue will require attention if/when agencies decide to scale up operations to revenue service and networked operation. 2021-2023 target date.

Related activities – AV transit employee roles and responsibilities, union contracting guidelines

Budget/Schedule – Small-scale effort; $200K: 12 months

Union Contracting Guidelines

Description – While there is much concern about AV transit systems displacing vehicle drivers, there will be plenty of other jobs and positions at transit agencies to manage the operations of AV systems. As an agency begins to adopt AV transit services, interactions with union representatives and employee advocates will ensue. This effort would develop, in conjunction with existing union representatives, draft language for future union contracts that include provisions for AV transit services.

Urgency – As transit agencies gain more experience with pilot deployments of low-speed L4 shuttles, this issue will require attention if/when agencies decide to scale up operations to revenue service and networked operation. 2021-2023 target date.

Related activities – AV transit employee roles and responsibilities, employee involvement guidelines

Budget/Schedule – Medium-scale effort; $500K: 18 months

Automation of Employee Actions in Compliance with ADA

Description – AV transit is particularly challenged by ADA requirements. This study would document existing employee actions and responsibilities for ADA compliance and identify potential technology functions and features that could assist in providing win-win solutions.

Urgency – Deeper analysis of ADA requirements beyond what was done in this project can be started at any time, and it is important to resolve ADA issues as soon as possible for realization of benefits. 2019-2020 target date.

Related activities – AV transit employee roles and responsibilities

Budget/Schedule – Small-scale effort; $250K: 15 months

Agency Operating Policies

Actions identified related to operating policies include:

1. Long-range planning AV transit benefit/cost analysis guidelines
2. Integration of AV transit scenarios in regional transit master planning
3. AV transit service types and operational planning parameters
4. Benefit/cost analysis of conversion from L3 to L4 operations
5. AV Cybersecurity issues affecting transit agencies
6. Management of “big data” in AV transit systems
7. AV Operations Control Center Concept of Operations
8. Investigation of risk, liability, and insurance for AV transit operations

Long-Range Planning AV Transit Benefit/Cost Analysis Guidelines

Description – While conceptually it appears that dynamically-dispatched, point-to-point L4 AV transit service will provide mobility benefits (i.e. reducing travel time for transit patrons), it is unclear if operating costs will also be reduced for agencies. In addition, there are no existing tools for sizing of vehicles, fleets, stops, and designing networks and routes (which is not surprising, since the systems do not yet exist except in limited locations). This project would develop such a tool(s) for use by transit agencies in determining cost estimates for system delivery and benefit comparisons with existing services. Simulation tools will likely be required to develop trade-off formulas that can then be used by lower fidelity planning tools for agency planning activities.

Urgency – As transit agencies gain more experience with small demonstration projects of L4 AV transit in loops and single routes, networks are the next logical step. 2020-2022 target date.

Related activities – Integration of AV transit scenarios in regional transit master planning

Budget/Schedule – Large-scale effort, $1M; 24 months

Integration of AV Transit Scenarios in Regional Transit Master Planning

Description – Regional master plans, wither they be for transit or for all transportation, generally look 10-20 years into the future. AV transit technologies will likely be available in that time frame. No current master planning tools consider L4 AV transit capabilities. Assuming regulatory issues can be mitigated, these services need to be included in long term master planning of transit network design. This project would evaluate the current state of the art in transit master planning and identify gaps that need to be addressed for agencies to properly consider L4 AV transit services in future scenarios. The project would also implement these functionalities in prototype planning tools and demonstrate the results on test cases with real-world transit agencies.

Urgency – As soon as practicable. 2019 target date.

Related activities – Long-range planning benefit/cost analysis

Budget/Schedule – Large-scale effort, $750K; 24 months

AV Transit Service Types and Operational Parameters

Description – Transit ridership suffers greatest from the first-mile, last-mile problem. Several types of AV transit operations can resolve these issues and likely boost ridership, or replace the need for high-capacity line-haul systems by operating point-to-point. In this research study, several types of services would be identified and detailed operational plans developed to illustrate how the services would be managed daily. Simulation tools may be needed to identify vehicle fleet sizing, dispatch characteristics, passenger service performance (e.g., station wait times) and other operational aspects such as recharging and refueling, maintenance, and deadheading.

Urgency – As transit agencies gain more experience with small demonstration projects of L4 AV transit in loops and single routes, using such systems for first-mile, last-mile solutions is a logical next step. 2019-2021 target date.

Related activities – Long-range planning benefit/cost analysis

Budget/Schedule – Large-scale effort, $1M; 24 months

Benefit/Cost Analysis of L3 to L4 Conversion

Description – Removing the operator may be generally considered a cost-saving measure, but it may be offset by other costs such as liability insurance, technology, and station enhancements. In this study, the benefits and costs associated with L3 and L4 operations would be compared.

Urgency – L3 transit BRT systems are only now being piloted in Europe and the Middle East. Confidence in L4 transit for standard and articulated coaches may require many more years of L3 experience. 2021-2022 target date.

Related activities – Integration of AV transit scenarios in long-range transit master planning

Budget/Schedule – Small-scale effort, $250K; 12 months

AV Cybersecurity Issues Affecting Transit Agencies

Description – Cybersecurity of AVs is one of the most challenging technology issues faced by developers today. It is inherently necessary in transit operations that remote connections to the vehicle must be available, much more so than that for privately operated AVs. At the same time, those remote connections need to be strongly protected. In this study, the security risks to the vehicle, the communications system, and the operations center should be identified. Technically feasible mitigations should be designed and a standards guide and technical architecture for cybersecurity protections for transit should be developed. Experiences in cybersecurity measures as developed for CVs in the USDOT pilot programs currently ongoing in Tampa, New York City, and Wyoming will be a starting point for this work.

Urgency – Confidence in cyber-protection of AV transit systems is paramount to their successful introduction into revenue service. 2019-2020 target date.

Related activities – Security Operation Concepts in USDOT CV Pilots, AUTO-ISAC standards

Budget/Schedule – Medium-scale effort, $750K; 18 months

Management of "Big Data" in AV Transit Systems

Description – The connected vehicle data available from AV transit systems including video/audio, location and status, command and controls, and diagnostics will be many orders of magnitude larger than any operations data collected by transit agencies today. Big data tools and technologies are currently mainstreamed in many commercial markets to manage huge data sets while gaining "actionable insights" through analytics and data science. In this study, guidance for transit agencies on use of big data systems for managing CV data from transit operations will be developed. The guide will educate transit agencies on use of the current state of the art, and identify strategies for integration of new tools and technologies with legacy systems and new operations practices.

Urgency – Even without AV systems, CV technologies are opening analytics opportunities for transit agencies already today. 2019-2020 target date.

Related activities – Operations control center concept of operations

Budget/Schedule – Medium-scale effort, $350K; 18 months

AV Operations Control Center Concept of Operations

Description – L4 AV transit systems will require constant remote monitoring to ensure safety and security of the patrons. Vehicles may need to be remote piloted during unusual circumstances, and communications will need to be available always. This type of operation is much different than current OCC operations of a typical transit agency. New operating principles will need to be developed to ensure staff roles and responsibilities are appropriate and human factors issues are mitigated. It is unlikely that one operator will be needed for each vehicle (this would defeat the basic purpose of removing drivers from the shuttles), but it is currently unknown how many vehicles a single operator could monitor simultaneously (4? 8? 16?). Human factors research is needed to simulate a variety of situations in determining guidance for OCC staffing levels and operating principles to ensure safe operations.

Urgency – As L4 shuttles are gaining in popularity and being tested in single routes and loops, the next logical step is networks and larger fleets of shuttles which will require concerted efforts to develop formalized operations concepts. 2020-2021 target date.

Related activities – Operations control center concept of operations

Budget/Schedule – Medium-scale effort, $350K; 18 months

Investigation of Risk, Liability, And Insurance for AV Operations

Description – It is anticipated that automation will increase safety of vehicle operations with 360-degree situational awareness and standardized vehicle behaviors, but this is currently unproven. Initially, insurance and liability protection of AV transit systems may be costlier. As technology is proven, liability claims will likely drop and self-insurance costs will be reduced, affording agencies to pay for the technologies. Some of these liabilities may then be passed to the manufacturer. A primer on liability and insurance issues in AV transit is needed to educate the community and identify models for technology introduction that can be adopted by agencies as they consider providing AV transit services.

Urgency – The motivation for AV adoption in transit operations to reduce liability claim costs is profound. 2018-2019 target date.

Related activities – Categories of hazards and risks for L3/L4 AV transit systems

Budget/Schedule – Small-scale effort, $150K; 12 months

Laws and Regulations

Actions identified related to laws and regulations include:

1. Scenario analysis of AV transit operations without federal funding
2. Possible changes to Section 13c of Federal Transit Act
3. Evaluation of Applicability of transit-related laws and regulations to private contractors (e.g., “TNCs”)
4. Evaluation of OSHA regulations for robotic vehicles in the workplace
5. Evaluation of Minority population involvement and environmental justice in AV transit
6. Evaluation of Title VI adjustments and incentives
7. Evaluation of boarding requirements and exceptions to ADA compliance
8. Evaluation of Buy America requirements
9. Evaluation of Implications of FMVSS for low-speed L4 AV transit vehicles
10. Safety management system development guidance

Scenario Analysis of AV Transit Operations Without Federal Funding

Description – L4 AV transit systems may reduce operational costs significantly enough that a transit agency could operate without federal funds. As many of the regulatory challenges existing today stem from the provisions of federal funds, it is conceptually possible that many of these issues could be mitigated by operating without federal subsidy. However, this is merely conjecture without detailed analysis. This study would assess this possibility for small and perhaps medium sized transit agencies to operate without federal support through PPPs and a variety of other fiscal and operational innovations.

Urgency – As the issues related to AV operations under receipt of federal funds are considerable, it is of high curiosity to analyze such scenarios sooner rather than later. 2019-2020 target date.

Related activities – Changes to Section 13c of Federal Transit Act, Evaluation of Title VI adjustments and incentives

Budget/Schedule – Small-scale study, $150K; 12 months

Possible Changes to Section 13c of Federal Transit Act

Description – As many of the regulatory challenges existing today stem from the provisions of federal funds, identifying potential mitigations are critical to evaluate. This study would further analyze transit regulations related to employee protections and propose innovative mitigations that may allow AV operations by public agencies. Issues include replacement and retraining of employees and how the use of contracted services that supply L4 AVs may or may not be subject to the rules.

Urgency – As the issues related to AV operations under receipt of federal funds are considerable, the study is needed as soon as practicable. 2018 target date.

Related activities – Evaluation of Title VI adjustments and incentives

Budget/Schedule – Medium-scale study, $350K; 12 months

Evaluation of Applicability of Transit Regulations on Private Contractors (e.g., “TNCs”)

Description – Currently in some states TNCs are considered taxi services and in others they are not. Without a driver, their argument that the service is “ride sharing” becomes less defendable, and may be considered a transit service, particularly if they service multiple strangers at the same time (who may or may not be going to the same place). This study would identify the legal applicability of transit regulations on TNCs, or private providers that contract such services to a public agency.

Urgency – As the issues related to AV operations under receipt of federal funds are considerable, the study is needed as soon as practicable. The recently released TCRP project on PPPs between TNCs and transit agencies may address some of these issues. 2019 target date.

Related activities – Changes to Section 13c of Federal Transit Act

Budget/Schedule – Small-scale study, $150K; 12 months

Evaluation of OSHA Regulations for Robotic Vehicles in the Workplace

Description – OSHA 29 CFR Part 1910 contains *Robotics in the Workplace from OSHA Publication 3067 – Concepts and Techniques of Machine Safeguarding*[65]. This aspect of OSHA regulations is worthy of further studies to determine if specific requirements are necessary for AV transit for operations facilities (dispatching and storage yards), as well as maintenance facilities where AVs must be "aware" of human(s) in the vicinity and communicate desired automated actions through some means (audio, lights, text, etc.).

Urgency – As L4 shuttles are gaining in popularity and being tested in single routes and loops, the next logical step is networks and larger fleets of shuttles which will require concerted efforts to develop formalized operations concepts. 2020-2021 target date.

Related activities – Changes to Section 13c of Federal Transit Act

Budget/Schedule – Small-scale study, $150K; 12 months

Evaluation of Minority Populations and Environmental Justice in AV Transit

Description – A working plan could be prepared by which minority populations can be engaged and involved in the public outreach process as planning for AV Transit deployment begins. Developed as guidance of transit operating agencies, the study documents would establish a framework for any transit agency to accomplish the required public involvement process with minority communities, as well as provide an initial assessment of how AV Transit can be deployed without violating Title VI Civil Rights law.

Urgency – Widespread acceptance of L4 transit operations is dependent upon resolution of environmental justice issues. 2020-2021 target date.

Related activities – Evaluation of changes to Title VI of the Civil Rights Act

Budget/Schedule – Small-scale study, $150K; 12 months

Evaluation of Title VI Adjustments and Incentives

Description – The benefits to providing allowances or exceptions to the Title VI requirements could be studied to evaluate advancement of the progress of AV technology during the early years of transit deployment. The study could also assess the use of incentives to encourage AV transit deployment in low density, high transit dependency conditions.

Urgency – Widespread acceptance of L4 transit operations is dependent upon resolution of Title VI issues. 2020-2021 target date.

Related activities – Evaluation of environmental justice issues

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65 https://www.osha.gov/Publications/Mach_SafeGuard/chapt6.html

Budget/Schedule – Small-scale study, $150K; 12 months

Evaluation Of Boarding Requirements and Exceptions to ADA Compliance

Description – L4 AV transit vehicles will have no operator to assist disabled patrons. In this study, the options for ADA compliance exceptions and boarding operations could be evaluated. In addition, technical design requirements, challenges and new potential hazards/risks to providing automated ramp deployment and automated wheelchair lift deployment could be identified. The means for automated wheelchair securement, and the potential technology required to allow remote operator involvement in the process could be identified.

Urgency – ADA requirements require resolution for wide-scale adoption of L4 AV transit operations. 2019-2021 target date.

Related activities – Evaluation of environmental justice issues

Budget/Schedule – Medium-scale study, $500K; 18 months

Evaluation of Buy America Requirements

Description – FTA funding for New Starts transit projects is normally contingent on compliance with Buy America regulations in the procurement of systems, facilities and rolling stock. The stipulations of the regulations generally require that equipment and construction materials be purchased from American manufacturing sources specified as a percentage of total content for the subsystems and component parts. To address the evolution of AV technology and to not constrain innovation, this approach of the federal government granting waivers may be a key path to moving forward in the near term. This study would identify the potential for alternative requirements and revisions for L4 AV operations.

Urgency – The issue may resolve itself as foreign suppliers work within the existing regulations, but is still worthy of evaluation. 2021-2023 target date.

Related activities – N/A

Budget/Schedule – Small-scale study, $150K; 12 months

Evaluation of Implication of FMVSS for Low-Speed AVs

Description – The National Highway Traffic Safety Administration (NHTSA) establishes and maintains safety standards known as the FMVSS for the automobile industry in the United States. The FMVSS are only one part of NHTSA's responsibility, but the ultimate regulation of AV technology will likely come through new FMVSS regulations. A study would be helpful to evaluate if the crashworthiness criteria can be adjusted for AV technology and if less stringent crashworthiness and crash survivability criteria be made in the near term for AV transit vehicles that operate in protected environments dedicated to transit vehicles and pedestrians (such as campuses, parking lots, and guideways).

Urgency – Low-speed shuttles currently do not adhere to FMVSS for operation in mixed traffic facilities. As the interest in L4 AV shuttles is growing quickly, this evaluation study is needed sooner rather than later. 2019-2021 target date.

Related activities – N/A

Budget/Schedule – Small-scale study, $150K; 12 months

Safety Management System Development Guidance

Description – Recent updates to these FTA safety programs have included a SMS component which has drawn extensively from the safety program experience of the FAA. As with other FTA regulatory guidelines, noncompliance with these safety rules by a transit operating agency could potentially jeopardize FTA New Start funding or conceivably even incur fines or other penalties imposed by FTA if unsafe practices and/or designs are determined to be deployed. Many operators that do not have fixed guideway transit and have never implemented such a thorough safety program as part of their bus operations will likely face a reorganization of their decision-making process, as well as enacting policies and procedures to develop, implement and maintain a comprehensive system safety program plan. Guidance would be helpful for these agencies on the establishment of SMS for AV transit.

Urgency – As the interest in L4 AV shuttles is growing quickly, this guidance is needed in the next few years. 2019-2021 target date.

Related activities – Hazard and risk identification, Safety assurance procedures

Budget/Schedule – Medium-scale study, $350K; 18 months

Summary of Activities

Over 30 activities were identified in the research. **Table 3** summarizes this list of actions. Other actions may arise because of these studies in the future.

Table 3. Identified Activities and List of Actions

Activity	Budget	Schedule (months)	Timeframe
Assessment of restrictions on transit platooning strategies	$150K	9	2018-2020
Research identifying possible changes to transit facilities and stations	$1M	18	2020-2022
Research on transit vehicle sizing, dynamic “entrainment”, and other innovations enabled by automation	$1M	24	2022-2025
Research on design of platform edge protection and automated entry for vehicle berths	$5M-$20M	24	2020-2022
Categories of hazards and risks for L3 and L4 AV transit	$250K	12	2018-2019
Hazards analysis methodology for L3 and L4 AV transit implementation	$500K	18	2018-2019
New consensus safety standard(s) for AV transit systems	$1.5M	24	2021-2023
Transit operational design domain definitions	$150K	9	2018-2020
Hazards assessment and mitigations for L3 operations	$350K	15	2020-2023
Definition of AV transit employee roles and responsibilities	$350K	18	2020-2022
Employee involvement guidelines	$200K	12	2021-2023
Union Contracting Guidelines	$500K	18	2021-2023
Automation of employee actions in compliance with ADA	$250K	15	2019-2020
Long-range planning AV transit benefit/cost analysis guidelines	$1M	24	2020-2022
Integration of AV transit scenarios in regional transit master planning	$750K	24	2019
AV transit service types and operational planning parameters	$1M	24	2019-2021
Benefit/cost analysis of conversion from L3 to L4 operations	$250K	12	2021-2022

Activity	Budget	Schedule (months)	Timeframe
AV Cybersecurity issues affecting transit agencies	$750K	18	2019-2020
Management of “big data” in AV transit systems	$350K	18	2019-2020
AV Operations Control Center Concept of Operations	$350K	18	2020-2021
Investigation of risk, liability, and insurance for AV transit operations	$150K	12	2018-2019
Scenario analysis of AV transit operations without federal funding	$150K	12	2019-2020
Possible changes to Section 13c of Federal Transit Act	$350K	12	2018
Evaluation of Applicability of transit-related laws and regulations to private contractors (e.g., “TNCs”)	$150K	12	2020-2021
Evaluation of OSHA regulations for robotic vehicles in the workplace	$150K	12	2020-2021
Evaluation of Minority population involvement and environmental justice in AV transit	$150K	12	2020-2021
Evaluation of Title VI adjustments and incentives	$150K	12	2020-2021
Evaluation of boarding requirements and exceptions to ADA compliance	$500K	18	2019-2020
Evaluation of Buy America requirements	$150K	12	2021-2023
Evaluation of Implications of FMVSS for low-speed L4 AV transit vehicles	$150K	12	2019-2021
Safety management system development guidance	$350K	18	2019-2021

References and Notes

[1] SAE J3016 is the Society of Automotive Engineers Standard titled – Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles; the standard was revised September 30, 2016.

[2] http://onlinepubs.trb.org/onlinepubs/sr/sr253.html

[3] https://en.wikipedia.org/wiki/DARPA_Grand_Challenge

[4] http://www.its.dot.gov/landing/cv.htm

[5] http://www.nhtsa.gov/Research/Crash+Avoidance/Vehicle-to-Vehicle+Communications+for+Safety

[6] http://www.its.dot.gov/safety_pilot/

[7] http://www.its.dot.gov/pilots/

[8] http://www.path.berkeley.edu/sites/default/files/documents/IM_15-1_low%20%282%29.pdf

[9] https://en.wikipedia.org/wiki/Automated_guideway_transit

[10] https://www.transit.dot.gov/funding/applying/notices-funding/mobility-demand-mod-sandbox-program

[11] Observatory of Automated Metros, http://metroautomation.org/.

[12]http://orfe.princeton.edu/~alaink/SmartDrivingCars/Stanford_TRB_Conf_July2013/Transit&SharedMobility/Lott_TRB_Stanford.pdf

[13] Safety analyses of AGT/APM systems identify hazards which describe a condition that could result in an accident, without identifying an accident or potential causes. Distinguishing the hazard from the accident and its causes facilitates hazard analysis and selection of the mitigations designed to eliminate or reduce risk. Examples of hazards are train-to-train collision, train-to-structure collision, train collision with other object, and person struck by a train.

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[16] http://www.path.berkeley.edu/sites/default/files/publications/PRR-2009-12.pdf

[17] https://company.here.com/automotive/intelligent-car/here-hd-live-map/

[18] https://www.eutruckplatooning.com/About/default.aspx

[19] http://www.citymobil2.eu/en/

[20] http://arstechnica.com/cars/2016/01/finally-over-the-air-software-updates-for-your-car-are-becoming-a-reality/

[21] http://www.nhtsa.gov/nhtsa/av/

[22] CAMP – Crash Avoidance Metrics Partnership (CAMP) Automated Vehicle Research (AVR) Consortium http://www-esv.nhtsa.dot.gov/Proceedings/24/files/24ESV-000451.PDF

[23] James Martin, et al; University of North Carolina, Certification for Autonomous Vehicles https://www.cs.unc.edu/~anderson/teach/comp790a/certification.pdf

[24] http://ntl.bts.gov/lib/57000/57000/57076/Review_FMVSS_AV_Scan.pdf

[25] https://www.gpo.gov/fdsys/pkg/FR-2016-08-11/pdf/2016-18920.pdf

[26] https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/FTA_SMS_Framework.pdf

[27] https://www.gpo.gov/fdsys/pkg/FR-2016-03-16/pdf/2016-05489.pdf

[28] Text combined from the descriptions found to NHTSA reports, with web links provided in Section 1 above – see page 2 in NHTSA Assessment of Safety Standards for Automotive Electronic Control Systems, and pp. 7-9 in NHTSA Report to Congress: "Electronic Systems Performance in Passenger Motor Vehicles".

[29] Table 1 Definition of Safety and Hazard, p. 11; NHTSA Assessment of Safety Standards for Automotive Electronic Control Systems; DOT HS 812 285, June 2016

[30] http://ascelibrary.org/doi/book/10.1061/9780784412985

[31] In Figure 10, PFH = "probable failures per hour" and MTBHE = "mean time between hazardous events"

[32] P. 23, Section 3.11 Review, Audit, and Certification; NHTSA Assessment of Safety Standards for Automotive Electronic Control Systems; DOT HS 812 285, June 2016

[33] P. 9, Section 3.1.1 Process Prescription, Ibid

[34] https://www.nhtsa.gov/DOT/NHTSA/NVS/Public%20Meetings/SAE/2015/2015SAE-Hommes-SafetyAnalysisApproaches.pdf

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[37] http://reason.com/archives/2015/03/07/automation-may-be-labor-union-death-knel

[38] http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_lrd_04.pdf

[39] https://www.dol.gov/olms/regs/compliance/statute-sect5333b.htm

[40] Note that NCHRP 20-102 (09) *Providing Support to the Introduction of CV/AV impacts into Regional Transportation Planning and Modeling* is currently on-going and anticipated for completion in 2018.

[41] http://orfe.princeton.edu/mwg-internal/de5fs23hu73ds/progress?id=IIwQlPRptnVw3pMVwC5ypYo9uC-ocLTKfudSflQAdF4,

[42] http://www.theatlantic.com/politics/archive/2016/01/will-driverless-cars-become-a-dystopian-nightmare/459222/

[43] Refer to Working Paper #2 Safety Assurance Consideration, Chapter 2 USDOT Safety Initiatives

[44] https://www.dol.gov/olms/regs/compliance/compltransit.htm

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[48] https://www.epa.gov/environmentaljustice/federal-interagency-working-group-environmental-justice-ej-iwg

[49] https://www.transit.dot.gov/regulations-and-guidance/civil-rights-ada/ada-regulations

[50] https://www.transit.dot.gov/regulations-and-guidance/fta-circulars/americans-disabilities-act-guidance-pdf

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[53] https://www.congress.gov/bill/114th-congress/senate-bill/1806/all-info

[54] https://www.automotiveisac.com/best-practices/

[55] NHTSA Federal Automated Vehicle Policy, Sept 2016. http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwiGxKOxhL3PAhUG6mMKHdENDT8QFggkMAA&url=http%3A%2F%2Fwww.nhtsa.gov%2Fnhtsa%2Fav%2Fpdf%2FFederal_Automated_Vehicles_Policy.pdf&usg=AFQjCNHSgKVEpfw_sEOcV6VFGd7uefwI6A&sig2=m-GdAFvdtQlYo8mcuZK11A

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[57] https://www.gpo.gov/fdsys/pkg/CFR-2011-title49-vol6/xml/CFR-2011-title49-vol6-part563.xml

[58]http://www.nhtsa.gov/About+NHTSA/Press+Releases/U.S.+DOT+Proposes+Broader+Use+of+Event+Data+Recorders+to+Help+Improve+Vehicle+Safety

[59] https://www.huntonprivacyblog.com/wp-content/uploads/sites/18/2011/04/DDP2015_United_States.pdf

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[61] http://www.trb.org/main/blurbs/175848.aspx

[62] Except in certain programs where cards are used for discounted fares such as senior and children and pre-paid passes. In these cases, the user's ownership information is linked to the card's use at the time of payment for verification that the pass is valid.

[63] https://www.congress.gov/bill/114th-congress/senate-bill/1806/all-info

[64] https://www.automotiveisac.com/best-practices/

[65] https://www.osha.gov/Publications/Mach_SafeGuard/chapt6.html

Abbreviations, Acronyms, Initialisms, and Symbols