Working Paper #4:

Operating Agency Policy – Potential Issues and Changes Required

To the

National Highway Cooperative Research Program (NCHRP)

On project

20-102 (02): Impacts of Laws and Regulations on CV and AV Technology Introduction in Transit Operations

March 2017

From

Kimley-Horn – Douglas Gettman, Ph.D.

Texas Southern University –
J. Sam Lott, Principal Investigator and **Gwen Goodwin, Ph.D.**

Cambridge Systematics – Tom Harrington

Table of Contents

List of Appendices

List of Figures

Acknowledgements

Throughout the NCHRP 20-102(02) project work, a group of transit industry stakeholders has assisted in the development of thought on the topic of technology applications to public transit. Several workshops have been held, and review and comment on draft documentation has been provided by this ad hoc group. The following individuals have provided specific guidance and input concerning the content of this working paper throughout the course of the three Stakeholder Workshops.

Louis Sanders – Chief Engineer, American Public Transportation Association (APTA)

Jerome M. Lutin, Ph.D. – Independent Consultant, Retired – New Jersey Transit

Peter Thompson – Senior Technology Program Analyst, SANDAG – San Diego Association of Governments

Other Transit Industry stakeholder workshop participants are listed in **Appendix A**.

These contributors are greatly appreciated. It should be noted that the inclusion of their names herein does not necessarily indicate that they are in complete agreement with the contents of this working paper.

Foreword

This working paper 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.

Focused Nature of the Working Papers – Each working paper has a focused purpose and is not intended to provide a comprehensive set of steps, actions or preparations encompassing the full evolution of AV Transit technology applications in public transit service. Some aspects of this project’s research have focused more on the ultimate operating conditions when AV technology is fully mature in order to understand the long term, ultimate state of automated transit technology, policy and regulations.

Conclusions on AV Transit in the Final Report – The Final Report will address information on the probable benefits and impacts of AV Transit, as well as articulate a roadmap of further research activities that technology, policy and regulations should follow over the next few decades.

[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; revised September 30, 2016.

1. Introduction

With the introduction of automated roadway vehicle (AV) technology over the next few decades, public transit agencies will face changes in their operating policies. Automation, particularly at level 4, will affect employees, agency management structure, transit patrons and other drivers. Several policy issues have been identified in this working paper, and many more will become evident as time progresses. The discussion that follows provides a first glimpse into the changes that appear to be coming as AV technology is deployed in public transit operations.

Throughout the working papers of this project NCHRP 20-102(02), the levels of automation for roadway transit vehicles will be referenced in accord with the NHTSA/SAE definitions (shown to the right).

The levels of automation referenced herein are taken from the NHTSA policy document released in September 2016, as given below. These are in turn based on definitions by Society of Automotive Engineers (SAE).

- **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.

NOTE: These levels of driving automation will be referred to in this document as **L1**, **L2**, **L3**, **L4** and **L5**. Refer to Working Paper #1, Chapter 3 for a more complete discussion.

Introduction to Transit Agency Policy

Transit Agency policies cover a wide range of topics:

- What services will be offered
- Where services will be offered
- The process of how services are modified
- 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

During this project, we have held three transit industry Stakeholder Workshops. The discussion topics, ideas and concerns expressed during those workshops touched on essentially these topics. For many issues, it is clear what changes will be required in operating policy for AV transit technology introduction. Some issues, however, are only able to be identified as questions needing answers at some future time.

This working paper is only an introduction to the dialogue that needs to continue within the public transit industry over the next few years.

Purpose and Organization of the NCHRP 20-102(02) Study

This project will identify 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 from earlier implementation of automated systems.

The project consists 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 operators
3. Identify government regulations and laws impacting AV technology 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, an implementation roadmap for transit automation, and the final report. The first working paper provides an overview of the deployment scenarios for AV technology in transit applications. The second working paper establishes a foundation of technical information concerning safety from which subsequent considerations of operating agency policy and governmental safety regulations are addressed in subsequent working papers.

Working Papers #3 Workforce Deployment and #4 Operating Agency Policy address the implications of automating roadway transit vehicles to local operating agency in terms of labor relations and training, broad operating planning and policy, and response to governmental laws and regulations.

Working Paper #5 addresses issues and changes that suggest a structure for research to be pursued by the federal and state governments concerning laws and regulations over public transit. Finally, Working Paper #6 addresses the preliminary timeline for deployment of progressive transit automation in overall consideration of technology, policy and regulatory changes that will be required.

Then in the final report for the project, an assessment will be discussed of the overall benefits and impacts of AV technology on public transit, and a proposed “roadmap” for further research will be described.

Organization of this Working Paper

AV technology applications in public transit have major ramifications for local transit agency policies. This working paper addresses several key areas of policy considerations that would be most impacted when the deployments of full automated transit vehicles are accomplished. Although a comprehensive, step-by-step progression of policy changes as technology progresses in the coming decades is not possible to cover within the scope of this study, the discussion will address some aspects of the near and medium term as well as the long-term policy considerations.

The content of this paper is organized to first discuss the aspects of *planning* policy and *operations* policy considerations that should be addressed with the application of AV transit technology. Early policy decisions made in anticipation of the long-term policy considerations will frame how a transit agency begins investing time and resources into preparations for deploying AV transit technology.

Then the discussion addresses the considerations of *safety* policy and consideration of *other governmental laws and regulations* concerning AV technology application to public transit. Finally, policy implications of *contracting some public transit services* to transportation network companies (TNCs) are discussed.

2. 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. **Working Paper #1 Automated Vehicle Technology Deployment Scenarios for Public Transit** provides 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 should begin to address 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.

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 should consider 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 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 Bus Rapid Transit 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 un-protected 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 O&M cost implications are for AV transit system dedicated lanes and stations with additional ROW, 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[2].

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 Metropolitan Planning Organization (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 should be addressed as part of the regional transportation planning process include:

- Commitment to deployment of intelligent transportation systems infrastructure to enable and vehicle-to-infrastructure (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

[2] http://orfe.princeton.edu/mwg-internal/de5fs23hu73ds/progress?id=IlwQIPRptnVw3pMVwC5ypYo9uC-ocLTKfudSfIQAdF4,

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[3]. 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 towards 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 (refer to **Working Paper #3 Workforce Deployment** for more discussion of this aspect of policy).

---

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

3. 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. For example, an automated bus may be certified for safe operations at an L4 level of automation, but only within specific districts of a given city and only on major arterial streets (or transitways with specific characteristics) specifically identified for AV operation by the bus manufacturer[4]. 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. Locations where the vehicle exits its prescribed area of automated operations (SAE J3016 calls this the Operational Design Domain – ODD) may need to provide a specific place where the transit vehicles can safely bring themselves to a stop with an extended dwell time should the designated human driver not take over the driving task in a timely manner. SAE J3016 calls this a Dynamic Driving Task Fallback to achieve a minimum risk condition when exiting the ODD.

This transition from automated driving to human driving requires provisions such as expanded roadway ROW, removal of curb parking and/or installation of additional lighting for safety and security of passengers. Policy decisions of the public transit operating agency must consider

[4] Such determinations of operating limits relate directly to the vehicle manufacturers safety certifications of L4 operations for a given location, in accord with the NHTSA policy guidelines and SAE J3016 definitions.

these aspects, along with coordination of the changes affecting urban districts/developments, local governments and regional transportation agencies.

Another example of a near term AV transit application is bus-on-shoulder (BOS) operations[5]. Several states already allow manually-driven BOS. Several others are conducting BOS demonstrations with ADAS and CV equipment (notably under a necessary Categorical Exemption). A natural next step could be demonstration of L2-L4 AV operation while on the shoulder. Due to the new types of safety risks that automation may bring when transit vehicles are moving in proximity to non-automated vehicles, deployment of AV technology in BOS applications may involve policy decisions to determine if additional right-of-way that must be obtained before L4 operations could begin. Other similar practical limitations may require policy level decisions to proceed with deployments only after the risks have been demonstrated to be mitigated in other markets (i.e. trucking and private autos).

These types of operational provisions will be driven largely by the establishment of policies. Similar to how legislative rules and regulations on AV driving are evolving on a State by State basis, it is likely that AV transit policies will evolve in a regional manner. 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.

As an example, **Appendix B** provides a more detailed discussion of high-precision docking systems for AV transit stops. High-precision docking is likely required of AV transit systems to meet current ADA requirements for automated guideway transit systems. The subsystem(s) to provide high-precision “localization” of each vehicle may need to be purchased as a supplemental system to the automated roadway transit vehicles purchased from a vehicle manufacturer. Similarly, the connected vehicles aspect of precision docking systems involves the physical placement and operations/maintenance of the differential GPS connection

[5] The State Legislature of Minnesota has provided a special policy dispensation to allow BOS operations around Minneapolis with L1 ADAS features being used. Similarly, BOS operations are being planned with ADAS features in San Diego.

beacon(s). Available locations could have policy-related considerations, as well as associated inter-local agreements with other governing entities.

Industry Stakeholder Questions/Comments Indicative of Key Policy Issues

The stakeholder meetings with transit industry representatives have identified additional questions that will need to be addressed within each operating agency before clear policy decisions can be made to implement AV technology.

Human-Operator/AV Technology Interface – With L3 automation, why disable the automation when a driver is doing the driving? Why not reduce "handoffs" by not ever "turning it off" and using the features as automated driver assistance systems (ADAS)?

During the time of transition over the next 10 to 20 years as full deployment of AV technology is progressing from L2 automation to L4 automation, the investments to install L3 equipment in transit vehicles will increase overall operating costs even though the vehicles will still require an operator onboard. The issues and questions that will have an effect on policy decisions to implement L2, L3 or L4 are significant.

Benefit/Cost Analysis – Benefit/cost analyses need to be done to define the potentially large benefits of operating cost reductions for L4 as compared to L3, as well as cost benefits resulting from the significantly reduced transit vehicle crashes – e.g., reductions of insurance premiums, legal costs, and crash repair costs.

- Are the savings in fuel and crashes enough to introduce the technology building blocks in the L2-L3 transition phase, since 30%-40% of operating costs are currently driver expenses?
- Why implement L3 at all? Why not wait for L4 vehicles to become available and then implement AV technology?

Automation/Management of Human-Operator Roles Beyond Driving – Other duties of the onboard employee other than driving which must be handled either by the transit system automation features and/or by the supervisory system and remote operations personnel need to be defined, developed and assessed, including:

- Attention to ADA concerns such as assisting the elderly and persons with disability in the boarding and alighting process, securing wheelchairs from movement while the vehicle is traveling, and answering questions about the bus route and station stops.
- Checking to ensure all passengers have properly paid their fares.
- Providing orderly and safe transport of all transit patrons.
- Handling of urgent or emergency situations that may arise onboard the vehicle.

Cyber Security Concerns – Cyber security issues could significantly constrain the rapid deployment of AV on a large scale. In making policy decisions to implement AV transit, these issues must be solved before it will be possible to implement AV technology in the way ultimately envisioned. Policy considerations may need to address:

- Cyber security technology may not yet be fully vetted with sufficient capabilities to support the operation of AV transit in mixed traffic with vehicles traveling in close proximity at high speeds.
- Can an AV deployment in transit service provide a more controllable research and development environment(s) most suitable to advance cyber security research, even before the solutions are found for general AV technology applications? If so who will pay for these R&D demonstration costs and what risk is assumed with respect to transit patrons' safety?

Implications for Small/Medium Scale Transit Operators – Small/medium sized public transit operators have several key questions that their transition to AV transit technology will need to address over the long term:

- If you have AV buses gradually integrated into your fleet, how will the Operating department be transitioned to the ultimate form of managing fully automated buses with no operations staff onboard, and how will fully automated dispatching systems affect the transit operations center staff responsibilities?
- It may be necessary to record all vehicle operating parameters of AVs in public transit service (e.g., maintaining on-board black box data records and streaming of diagnostic data). How will small agencies maintain those records and what will be the liability implications to the transit agency?
- Over the long term, what new challenges will Operations Control Center (OCC) staff face as they oversee the bus dispatching and operating fleet management being conducted by an automated supervisory control system?

Implications for Large Scale Transit Operators – Large Operators probably have a better understanding of operational issues since they have established OCCs for their rail and bus systems. But even rail operators do not typically have OCC capabilities that match the requirements of L4 operations with hundreds of individual vehicles in services. For example:

- In the CitiMobil2 pilot in Greece, it was required that 8-12 cameras be placed on every vehicle for safety/security purposes[6]. This will require potentially thousands of camera positions to be recorded and monitored from the OCC.
- The "Big Data" implications of video/audio, command and control signaling, vehicle-system diagnostic data and "black box" on-board operational data recording for each vehicle in the AV operating fleet are of major concern, and policy decisions on the rescaling of a transit operating agency's data processing capabilities will be an important aspect to consider.
- Remote vehicle operators (SAE J3016 refers to them as "remote drivers") must be accommodated within the OCC(s) to allow the intervening control of vehicles that have passed out of their defined automation area (Operational Design Domain) or which have had a driving automation system failure event. The quantification of remote operator positions necessary within the OCC will certainly be an important area of

[6] Source: Adriano Alessandrini, Project Manager of CityMobil2 project

further research, and remains an unknown factor at this time (i.e. how many vehicles can reasonably be supervised by one remote operator at once; how do they distribute their duties, how do they shift from one task to another; the FAA Air Traffic Control model may offer some insights).

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. These means of optimization will be able to address current inefficiencies such as the continual operation of large transit vehicles during times of the day and on portions of the transit network where there are few riders onboard. This of course assumes that the cost of maintenance of four-six vehicle sizes does not overwhelm the benefits of having this flexibility. One reason current transit agencies do not provide different size vehicles in the fleet is simply for standardization. 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.

4. 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[7] (SMS) 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

In order 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 take action 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 and, 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.

The topic of "Safety Assurance Considerations" is discussed in substantial detail in Working Paper #2 and the systems engineering process of hazards analyses and risk assessments. Regardless of the technical approach that proves or assures that a system is safe at a certain level, there will always be the public's perception of risk to deal with from a policy perspective.

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 in light of such concerns in order to reassure the public that the system is safe. There should be policy considerations of demonstration projects, public information programs, and focus

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

groups to ensure that the transit users are prepared to utilize the new technology when it is deployed.

Accident 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:

1. How will accidents that are caused by something within the operating environment but not caused strictly by an AV equipment or system failure be judged with regard to 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". Transit operating agency executive management and boards of directors should be monitoring these developments at the federal level. Initiating a review and assessment of their agency's current capabilities to execute a rigorous Safety Management System in accord with FTA guidelines for safety assurance will provide a good foundation for addressing the coming complexities of AV technology deployment. Under the current USDOT safety program it will be the state governments that each designate their specific safety oversight agency, which will in turn determine the related requirements of the safety programs in their state under which the local transit agency's safety assurance program will be specifically monitored.

5. Government Regulations and Funding Considerations

Policy makers at the local level are continually assessing their agency's actions in response to federal government agency regulations. Some key aspects that local transit operating agencies should be monitoring as they consider AV technology deployments are noted in this section. This topic is of major importance even as AV transit projects are in the conceptual definition stage of development, since federal funding of transit projects is typically contingent on satisfaction of FTA regarding the local compliance with federal regulations.

The subsequent **Working Paper #5 Governmental Laws and Regulatory Requirements** specifically addresses the anticipated issues and changes that could occur at the federal level.

Title VI

The FTA website addresses Title VI protection of minority populations under the 1964 Civil Rights Act. The summary statement by FTA is as follows[8]:

> *Title VI of the Civil Rights Act of 1964 protects people from discrimination based on race, color, and national origin in programs and activities receiving federal financial assistance. The Federal Transit Administration works to ensure nondiscriminatory transportation in support of our mission to enhance the social and economic quality of life for all Americans. The FTA Office of Civil Rights is responsible for monitoring FTA recipients' Title VI programs and ensuring their compliance with Title VI requirements.*

The Justice Department's overview commentary[9] on Title VI states the following:

> *If a recipient of federal assistance is found to have discriminated and voluntary compliance cannot be achieved, the federal agency providing the assistance should either initiate fund termination proceedings or refer the matter to the Department of Justice for appropriate legal action.*

There has not been significant research into the effects of AV technology deployments in public transit on services across all demographics, and the determination of how advanced automation will affect minority and economically disadvantaged populations. The policy makers at the local transit agency should carefully monitor this aspect of federal regulatory determinations. It will be critically important for local policy to ensure the planning for AV deployments is in line with the determinations and guidelines at the federal level for Title VI compliance as these aspects are studied further.

Americans with Disabilities Act

It is currently undetermined how the ADA law and related regulations will be interpreted and applied to AV transit deployments. Specific requirements have been codified in federal law concerning the access to transit vehicles when the fully automated transit technology operates on fixed guideways. Will these regulations be extended to apply to any AV transit system? As mentioned in Chapter 3 and expanded in the discussion within **Appendix B**, these strict

8 https://www.transit.dot.gov/regulations-and-guidance/civil-rights-ada/title-vi-civil-rights-act-1964

9 https://www.justice.gov/crt/fcs/TitleVI-Overview

requirements could have significant implications for automated roadway vehicle deployed in public transit service. This matter is explored more fully in Working Paper #5.

Buy America

Buy America regulations under federal law are in the process of being changed such that in the future the minimum requirements will be raised to stipulate that 70% of the vehicle and related system equipment content must have its manufacturing origin in the United States. Transit vehicle manufacturers typically address these requirements by focusing on U.S. subsystem equipment supply sources, combined with performing the final assembly of the vehicles in the United States.

However, many of the current AV technology manufacturers and early developers of sensor technology are from outside the U.S. (particularly those companies that are focusing on FM/LM shuttle operations). It remains to be seen if these suppliers will be able to move their assembly operations and subsystem equipment suppliers to U.S points of manufacture, or if new agreements can be forged with U.S.-based vehicle makers.

Conventional automotive OEMs cannot necessarily relocate their assembly process to factories on U.S soil in the same way that has been common for rail/fixed guideway car manufacturers to open car assembly plants on U.S. soil. There could be major disruptions, therefore, within the AV supply chain that prove untenable for some open procurements to remain cost competitive and still comply FTA Buy America regulations.

Local operating agencies should begin to consider the implications to their policy decisions as the Buy America regulations are vetted within the new spectrum of AV technology sources of supply.

6. Contracted AV Taxis and TNC Services Considerations

There has been considerable discussion within the transit industry about the contracting of ancillary services to transportation network companies (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 is 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 – Assuming that local transit operators are able to 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.

7. Findings and Recommendations on Operating Agency Policy

This working paper has applied a broad interpretation of "Policy" as being the decision-making process accomplished at the executive management and board of directors level in local transit operating agencies. This interpretation of policy has allowed the discussion of a range of issues, challenges and opportunities that AV technology will bring to the entire spectrum of public transportation agencies, ranging from small local bus operators to large mega-regional transit authorities.

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.

Equally important is the fact that policy decisions of the nature discussed in this working paper have major implications of long term planning coordination on a regional scale between the transit operating agency and the other agencies and governmental bodies.

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. These medium-term requirements of retaining drivers on duty even after highly automated vehicles are deployed could have policy ramifications throughout the organization. Near term positive benefits of policy decisions to implement automated technology which allow transit services to be deployed much more safely than is possible with only human operators could allow new concepts of service, even services in new types of right-of-way such as bus-on-shoulder operations in freeway corridors.

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 cyber security, large data management and creation of a sophisticated operations center need policy-level decisions to proceed with implementation. Over the long term the overall operation of transit services will be able to be optimized by deploying different size vehicles to service patterns that are tailored more efficiently to ridership demand patterns, which in turn will require early policy considerations as operating fleet management plans are projected for future years.

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 must commit the necessary resources and give authority to personnel assigned safety responsibilities to execute a Safety Management System acceptable to FTA and to the appropriate state safety oversight agency. Both the safety engineering aspects as well as the public perception of safety will have a bearing on the local agency policy decision making process. Many new dimensions of safety and the related liability issues are being thought about as AV technology is entering the more advanced development phases. How the law makers and the courts will address these liability issues is only beginning to be evaluated, and policy makers in the local public transit agencies should be monitoring these developments.

Federal Regulations and Funding – All policy decision makers in public transit agencies are continually assessing their compliance with federal regulations to ensure that federal funding can continue unimpeded. How Title VI and ADA regulations will be applied or modified to specifically address AV technology applications in public transit has not yet been addressed by the government, and policy makers should be monitoring how these matters impact their local operating agency compliance. Similarly, Buy America laws must also be considered, and currently the requirements for a very high percentage of U.S. manufactured content in the supply of vehicles and equipment for federally funded projects may disrupt the existing supply chain for AV technology. Policies concerning AV deployment should be considered in light of these current unknowns.

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 transportation network companies (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.

In Conclusion – The benefits of dramatically improved safety of operations and customer service levels over the long term give a strong impetus to the application of automated roadway vehicle technology in transit service. When coupled with the potentials of operational cost reductions and sustainability benefits, the issues and challenges that policy makers will face are well worth engaging in the near term – at least at the planning level in preparation for the coming changes that will transform the transit industry over the next several decades.

Recommended 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 are recommended 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 should 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 must 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 should 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 is needed to develop definitions of services 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 should 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 should 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 will 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 should be researched to properly reflect the man-machine control transition issues as transitions to and from automated driving modes are continually occurring.
4. **Cyber Security Issues Affecting Transit Operating Agencies** – Research is needed 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 should address the risks and mitigations that are practical cyber security 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” on-board 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 is necessary to define an operations control center and supporting local/subregional 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 should 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 should also be prepared.

APPENDIX A
Attendees at NCHRP 20-102(02) Industry Stakeholder Meetings

Attendance Roster – NCHRP 20-102(02) Transit Industry Stakeholder Meeting #1,

July 21, 2016, San Francisco CA

NAME	ORGANIZATION	PROJECT ROLE
Jerry Spears	Washington State Transit Insurance Pool	Stakeholder
Jane Schroter	Capital Metro	Stakeholder
Lou Sanders	APTA	Stakeholder
Peter Thompson	SANDAG	Stakeholder
Gary Miskell	VTA	Stakeholder
Marla Westervelt	LA Metro	Stakeholder
Brian Sherlock	Amalgamated Transit Union	Panel
Jerry Lutin	NJT	Panel
Adriano Alessandrini	University of Florence	Panel
Ray Derr	TRB	Project Team
Doug Gettman	Kimley-Horn	Project Team
J. Sam Lott	Texas Southern University	Project Team

Attendance Roster – NCHRP 20-102(02) Transit Industry Stakeholder Meeting #2

September 12, 2016 – JW Marriott LA Live, Los Angeles CA

NAME	ORGANIZATION	PROJECT ROLE
Vincent Valdes	Federal Transit Administration	
Joe Calabrese	Greater Cleveland RTA	Stakeholder
Marlene Connor	Marlene Connor Associates LLC	Stakeholder
Lou Sanders	American Public Transportation Association	Stakeholder
Art Guzzetti	American Public Transportation Association	Stakeholder
Gary Miskell	Santa Clara Valley Transportation Authority	Stakeholder
Marla Westervelt	LA Metro	Stakeholder
Brian Sherlock	Amalgamated Transit Union	Panel Member
Bill Churchill	County Connection, Concord CA	Stakeholder
Lisa Darnall	Jacksonville Transportation Authority	Stakeholder
Dave Hudson	County Connection, Concord CA	Stakeholder
James Garner	Pace Suburban Bus	Stakeholder
Rick Ramacier	County Connection, Concord CA	Stakeholder
Pete Gould	Shared Mobility Strategies	Stakeholder
Jim Hunter	Golden Empire Transit District, GETBus	Stakeholder
Doug Gettman	Kimley-Horn	Project Team
J. Sam Lott	Texas Southern University	Project Team
Gwen Goodwin	Texas Southern University	Project Team

APPENDIX B
Examples of Station Precision-Docking Subsystems

There are three examples discussed in this appendix of projects deploying precision docking systems for automated and semi-automated roadway transit vehicles. Each has been demonstrated in projects using different approaches to achieving longitudinal and lateral location determination for the automated vehicles. These projects have been chosen as potential technology applications that can accomplish a precision docking of the vehicle with a station platform in a manner that is similar in accuracy achieved by automated fixed guideway transit systems.

Current ADA requirements for automated fixed guideway transit systems[10] stipulate a not-to-exceed gap between the vehicle threshold and the platform edge. If the same criteria is ultimately used for AV transit applications (a hypothetical since this regulation has not yet been determined), the law would require docking accuracy as follows:

1. Systems with operating speeds no more than 20 mph (32.2 kph)
    a. Horizontal gap at door threshold no greater than 1 inch (2.54 cm)
    b. Height of vehicle floor within 1/2 inch (1.27 cm) of platform height
2. Systems with operating speeds greater than 20 mph (32.2 kph)
    a. Horizontal gap at door threshold no greater than 2 inches (5.08 cm)
    b. Height of vehicle floor within 5/8 inch (1.59 cm) of platform height

Whether there are ADA regulations issued that require some type of docking accuracy, the following brief descriptions illustrate how additional subsystem equipment may be required to augment the basic AV technology onboard control systems.

Rivium Park Shuttle, Netherlands

An L4 fully-automated bus system operating in the Rivium Office Park was designed by 2getthere, a company based in the Netherlands. The current vehicle technology was installed in 2005 and operates along a dedicated transitway, although there is some exposure to other vehicular traffic. The automated vehicles stop at station locations with defined vehicle berths at each boarding location (**see Figure 1**). As vehicles travel they periodically recalibrate their precise location in the vehicle's memory map as they cross magnetic markers within the transitway. The vehicles are not "following" the markers in the same way as other guided bus demonstrations have done in the U.S. Rather, the vehicles operate in a "free-ranging" manner.

[10] ASCE 21-13 Automated People Mover Standard, Section 7.3 Clearance in Stations

Source: 2getthere

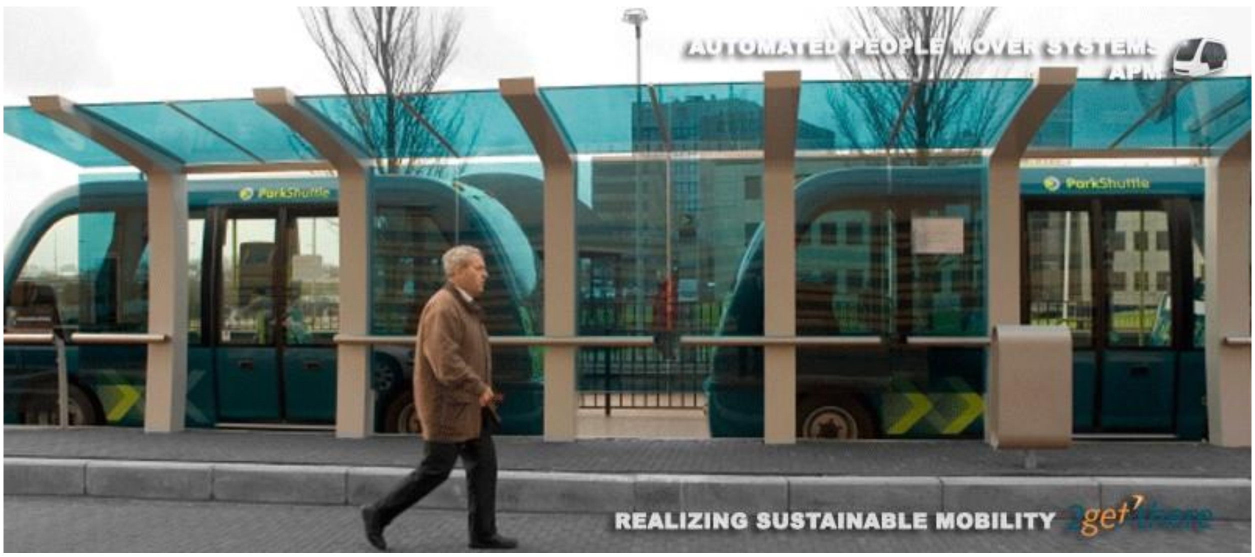

Figure 1. Rivium Park Shuttle Vehicles at Berths Along a Station Platform

This vehicle location system was developed by a sister company of 2getthere and this control technology is called FROG – Free Ranging on Grid. The magnetic marker system provides accuracy for station docking that has a general capability for compliance with the fixed guideway ADA requirements listed above.

Lane County Oregon

Research by Caltrans PATH dating back to 2003 demonstrated several automated transit functions, including automated platooning and automated steering on transit vehicles[11]. The vehicle guidance approach used magnetic nails/markers embedded in the pavement along the bus route (an approach originally tested in freeway tests dating back to the 1990s). The vehicles followed the sequence of markers to continuously guide their path as the onboard controls sensed the markers and adjusted the steering. This type of guidance allowed very precise location and trajectory control, including the ability to dock the BRT vehicle at stations

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

with an accuracy that placed the vehicle door thresholds only a few centimeters from the station platform edge.

In 2013 this guidance technology using magnetic parkers was applied to a research project at Lane County Transit on the Emerald Express BRT line in Eugene Oregon (**see Figure 2**). The demonstration project did not utilize automated throttle control, but the buses did use automated steering over a 1.5-mile segment (3 lane-miles along the bi-directional route). The demonstration highlighted precise docking capabilities at several stations within the semi-automated segment.

Several opinions expressed during project stakeholder meetings by people very familiar with the demonstration project were as follows.

1. The drivers involved in the demonstration project were pleased with the technology.
2. Precision docking alone may be enough to justify the introduction of AV steering.
3. The specific equipment installed on the limited number of buses and station docking locations used in the pilot demonstration project have now been decommissioned.

Figure 2. Emerald Express BRT Demonstration Project – Eutene Oregon, 2009

Source: Caltrans PATH

CitiMobil2

Citymobil2 achieved “localization” accuracy of less than 1cm through combination of DGPS/SLAM and IMU/SLAM[12]. To obtain this level of accuracy with DGPS, CitiMobil2 used GLONASS and Chinese satellites as well as the official US GPS constellation. In addition, the project used fixed base “beacon” stations to generate the GPS corrections within the project area. However, when failures or environmental conditions degraded any aspects of signal integrity for the vehicle location combined technologies, the localization systems could not provide the highest level of accuracy as would be needed for precision docking. When this

[12] Source: Adriano Alessandrini, project manager of the CitiMobil2 project

occurred, the system operations were lowered to a degraded mode until the failed system equipment was restored.

Figure 3 shows the two operating environments (dedicated lane and mixed traffic operations) that were demonstrated throughout the CitiMobil2 project in six different cities within the European Union.

Figure 3. CitiMobil2 Demonstration Projects – Vehicles Operated in Protected Lanes at 20 kph and in Mixed Traffic at 10 kph

source: CitiMobil2

The specific subsystems/technologies that were applied to provide each vehicle the desirable high-precision accuracy of vehicle location during CitiMobil2 were as follows:

- **DGPS – Differential global positioning system** – This is a common GPS enhancement technology that utilizes fixed “beacon” locations within the operating area. The DGPS beacons must be integrated into the urban environment in locations that allow the vehicles to receive direct transmissions of GPS correction data.
- **SLAM – simultaneous localization and mapping** – These features worked in conjunction with DGPS and a highly-detailed map of the operating area maintained in the vehicle’s control system memory.
- **IMU – Inertial measurement unit** – An IMU supplements a GPS receiver onboard the vehicles during times when GPS-signals are unavailable, such as in tunnels, inside buildings, within urban “canyons” created by tall buildings, or when electronic interference is present.

General Comments on Magnetic Marker Guidance Systems – It is the opinion of the authors that the magnetic marker path guidance technologies are highly reliable and relatively “low tech.” This simple technology has been effectively used since the early 1990s and could be very valuable for providing high precision guidance in transit station berthing/docking areas. It seems reasonable to consider their application as complimentary to the GPS-based vehicle localization technologies that are now being commonly provided in AV deployments.

This type of blended technology that would use a dedicated subsystem to deliver extra precision for determining the vehicle’s location during the approach to the station docking berth is like subsystems used in automated guideway transit systems over the last 40 years. In AGT applications where vehicles must align precisely with the platform edge automated doors, a separate subsystem – often using fixed electromagnetic markers – provides supplemental signaling that allows precise longitudinal location stopping accuracy to be reliably accomplished by the vehicle.