FTA RESEARCH

FEDERAL TRANSIT ADMINISTRATION

Determining Requirements for Automated Transit Bus Test Facilities: Considerations for Practitioners

Final Report

FEBRUARY 2019

FTA Report No. 0131
Federal Transit Administration

PREPARED BY
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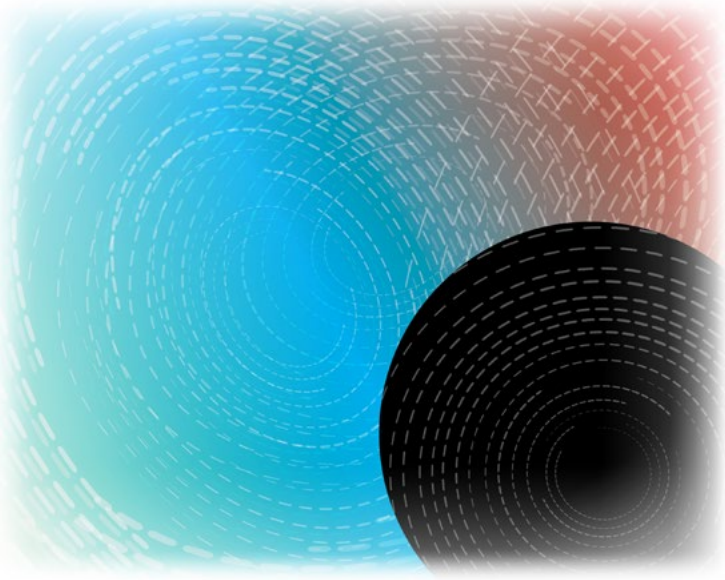

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Federal Transit Administration

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Metric Conversion Table

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC

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13. ABSTRACT

FTA has conducted research on guidelines for test facility requirements to support automated transit vehicle testing and demonstration projects. Stakeholders, including federal agencies, universities, transit agencies and operators, test facilities, and industry representatives, were consulted and, based on those conversations, a list of requirements was compiled in the areas of test facility features, functionality and performance, safety, environmental resilience, human factors, and data collection and management. These requirements were classified as "mandatory," "optional," and "not applicable" with respect to 14 use cases that have been organized into five technology packages—Transit Bus Advanced Driver Assistance Systems; Automated Shuttles; Maintenance, Yard, Parking Operations; Mobility-on-Demand Service; and Automated Bus Rapid Transit.

14. SUBJECT TERMS Test facility requirements, test facility features; functionality and performance; safety, environmental resilience; human factors; data collection and management; Transit Bus Advanced Driver Assistance Systems; Automated Shuttles; Maintenance, Yard, Parking Operations; Mobility-on-Demand Service; and Automated Bus Rapid Transit; Smooth Acceleration and Deceleration; Automatic Emergency Braking and Pedestrian Collision Avoidance; Curb Avoidance; Precision Docking; Narrow Lane/Shoulder Operations; Platooning; Circulator Bus Service; Feeder Bus Service; Precision Movement for Fueling, Service Bays, and Bus Wash; Automated Parking and Recall; Automated First/Last Mile; Automated Americans with Disabilities Act (ADA) Paratransit; On-Demand Shared Ride	15. NUMBER OF PAGES 79

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Abstract

FTA has conducted research on guidelines for test facility requirements to support automated transit vehicle testing and demonstration projects. Stakeholders, including federal agencies, universities, transit agencies and operators, test facilities, and industry representatives, were consulted and, based on those conversations, a list of requirements was compiled in the areas of test facility features, functionality and performance, safety, environmental resilience, human factors, and data collection and management. These requirements were classified as "mandatory," "optional," and "not applicable" with respect to 14 use cases that have been organized into five technology packages—Transit Bus Advanced Driver Assistance Systems; Automated Shuttles; Maintenance, Yard, Parking Operations; Mobility-on-Demand Service; and Automated Bus Rapid Transit.

EXECUTIVE SUMMARY

Vehicle automation capabilities are being developed, and automation of transit buses could deliver numerous benefits in terms of service, cost, and efficiency. Stakeholders will need to see additional research, demonstrations, and guidance to make informed deployment decisions. Proof-of-concept prototypes will be necessary to demonstrate feasibility, maintainability, and effectiveness to the Federal Transit Administration (FTA), transit agencies, manufacturers, and other decisionmakers.

Such testing and demonstration projects will require careful testing and reporting of data. This testing will take place at closed test facilities, local restricted areas (e.g., maintenance yards, parking lots, or closed campuses), and/or on public roads—in many cases, technology will be tested in a range of conditions progressing from less complex environments to more complex environments. Regardless of what facility hosts these tests, there will be requirements to assure that the program can produce meaningful results that can convince stakeholders of feasibility and effectiveness.

To ensure that such projects produce meaningful results, FTA has conducted research on guidelines for test facility requirements. Stakeholders, including federal agencies, universities, transit agencies and operators, test facilities, and industry representatives were consulted and, based on those conversations, a list of requirements was compiled. (See Appendix A for list of stakeholders contacted.) The requirements fall into six broad categories:

- **Test Facility Features** – physical features of the facility needed to support testing
- **Functionality and Performance** – capability to verify and quantify functionality and performance
- **Safety** – safety protocols and resources to verify system safety during testing and deployment
- **Environmental Resilience** – controlling or simulating lighting, visibility, and precipitation
- **Human Factors** – resources to verify and quantify human factors issues for the system
- **Data Collection and Management** – resources to acquire, store, and analyze relevant test data

The requirements were classified as "mandatory," "optional," and "not applicable"[1] with respect to the technology packages and use cases defined in

[1] Requirements that are classified as mandatory or optional for at least one use case in a technology package are explicitly identified in the section for that technology package. Requirements that are classified as not applicable for all use cases in a technology package are not addressed in the text. Appendix B includes matrices linking the requirements to the use cases, including their classifications (mandatory, optional, and not applicable).

previously-published FTA transit automation documents.[2] For a given use case, a requirement was classified as mandatory in cases in which the feature or capability in question is necessary to demonstrate basic functionality of the use case. In cases in which the requirement was considered irrelevant to testing the functionality for a given use case, it was classified as not applicable. Requirements that were not considered necessary to demonstrate basic functionality but could be used to demonstrate a feature useful in some applications were classified as optional. Appendix B contains quick reference matrices of the requirements organized by the above six categories. In the context of this document, mandatory requirements relate to basic operation and testing of automated transit buses, participant safety and privacy, and the collection and management of data.

Most requirements are considered optional depending on the specific goals or other parameters associated with a test. That is, they may be disregarded if the test was not designed or intended to demonstrate functionality under the operational design domain engendered by the requirement. The requirements in this report are intentionally broad to provide flexibility in defining parameters for specific tests and pilot demonstrations; however, requirements for specific projects should contain appropriately detailed specifications. Depending on the organization conducting the testing, product being considered, or use case being tested, users may identify additional requirements beyond those included in this document. Users may opt to take requirements from this document, adapt them, or add additional requirements as needed.

The requirements contained in this document provide a resource and reference for selecting facilities with the appropriate and necessary characteristics for research and development (R&D) testing of automated transit buses for all levels of automation. These requirements may be used by a variety of organizations, including, but not limited to, technology developers and providers, bus manufacturers, integrators, academics, and transit agencies and operators.

[2] FTA's Strategic Transit Automation Research Plan and other resources are available on the FTA Transit Automation Research webpage at https://www.transit.dot.gov/automation-research.

SECTION 1

Introduction

FTA Transit Automation Project

Automation capabilities for motor vehicles have advanced rapidly in recent years and have changed the dialogue around all aspects of surface transportation. Automation of transit buses and related vehicles could deliver numerous benefits, but transit agencies and other stakeholders need to see additional research, demonstrations, and policy guidance to make informed deployment decisions. The U.S. transit industry can be slow to adopt new technologies, services, and business models. A full understanding of the implementation issues and appropriate data from testing and deployment will be necessary for transit agencies to invest in new technologies and undertake new operational models.

To support the development and deployment of automated bus transit services, the Federal Transit Administration (FTA) has developed a five-year Strategic Transit Automation Research (STAR) Plan that outlines FTA's research agenda on automation technologies.[3] One aspect of the research plan is a range of possible demonstration projects conducted by transit industry research and development (R&D) teams consisting of diverse stakeholders. This document supports the testing and evaluation components of these demonstrations.

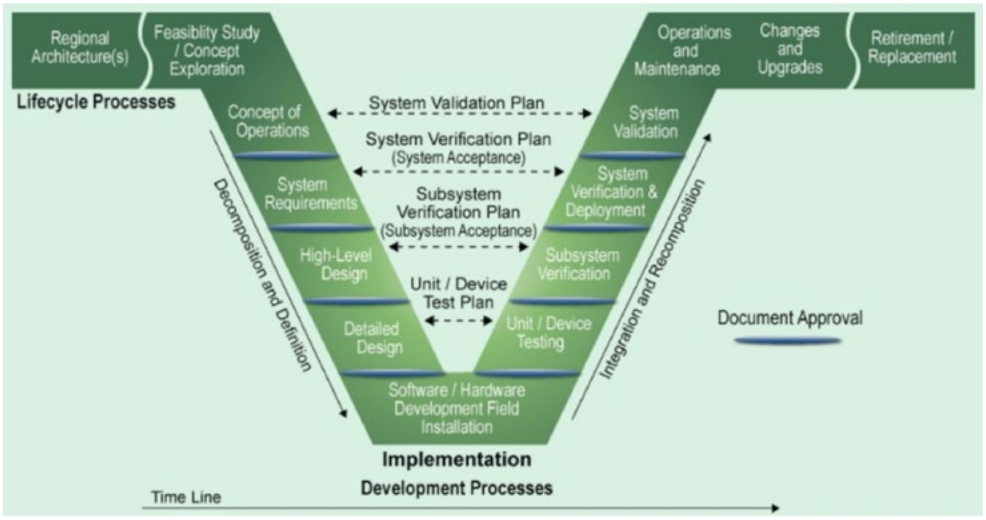
Purpose of Test Facility Requirements Task

The design and development of complex systems inherently includes multiple phases of design, development, testing, and refinement. Systems engineering typically follows a trajectory such as the "V diagram" shown in Figure 1 as described by the Federal Highway Administration (FHWA).[4]

[3] For more information on this work and access to the Strategic Transit Automation Research Plan document, visit FTA's Transit Automation Research webpage at https://www.transit.dot.gov/automation-research.

[4] FHWA, Systems Engineering and ITS Project Development, USDOT Federal Highway Administration, Organizing and Planning for Operations, January 2007, accessed October 2018, https://ops.fhwa.dot.gov/plan4ops/sys_engineering.htm.

Figure 1-1
Systems Engineering "V Diagram"



Source: FHWA 2007

The diagram in Figure 1-1 illustrates how the design process moves from overall conceptualization to detailed component design, with each level requiring testing, validation, and/or verification before it can be successfully deployed. The testing programs considered in this report deal with the evaluation of full scale systems.

Transit industry R&D teams that may partner to perform testing and demonstration projects will need to document the ability of the automated vehicles to meet performance, safety, and economic goals. This requires the collection of quantitative and qualitative test data. This document seeks to inform prospective members of transit R&D teams of the important aspects of testing various automation technologies for a number of automated transit bus use cases.[5] Through stakeholder outreach, the authors have determined the extent of the requirements for test facilities in terms of infrastructure, equipment, and personnel needed to acquire evidence of the efficacy of the demonstrated technologies.

The requirements contained in this document provide a resource and reference for selecting facilities with the appropriate and necessary characteristics for R&D testing of automated transit buses for all levels of automation. These requirements may be used by a variety of organizations, including, but not limited to, technology developers and providers, bus manufacturers, integrators, academics, and transit agencies and operators.

Technology Packages and Use Cases

The requirements are defined for 14 use cases organized into 5 technology packages. Within each package, there may be significant overlap in requirements

[5] Within the technology packages are one or more transit bus automation use cases where "bus" is defined broadly to consider a range of passenger capacities and both traditional and novel vehicle designs.

across use cases, primarily because they tend to be met by the same or similar automation technology. The technology packages and use cases considered in this report are the following:

- Transit Bus Advanced Driver Assistance Systems
  - Smooth Acceleration and Deceleration
  - Automatic Emergency Braking and Pedestrian Collision Avoidance
  - Curb Avoidance
  - Precision Docking
  - Narrow Lane/Shoulder Operations
  - Platooning
- Automated Shuttles
  - Circulator Bus Service
  - Feeder Bus Service
- Maintenance, Yard, Parking Operations
  - Precision Movement for Fueling, Service Bays, and Bus Wash
  - Automated Parking and Recall
- Mobility-on-Demand Service
  - Automated First/Last Mile
  - Automated Americans with Disabilities Act (ADA) Paratransit
  - On-Demand Shared Ride
- Automated Bus Rapid Transit

Definition of Requirements

Test facility requirements were identified for each of the five technology packages that transit industry R&D teams may explore. The requirements are divided into the following six categories:

- Test Facility Features
- Functionality and Performance
- Safety
- Environmental Resilience
- Human Factors
- Data Collection and Management

Each technology package is discussed in a separate section of this report. Each section covers the requirements for each use case, but several requirements may be consistent across the range of uses cases in the section. Specific differences between related use cases are noted in the appropriate section.

Test Facility Features

The Test Facility Features section describes the physical attributes of the test facility. It can include, for example, physical specifications for pavement, but typically it is concerned with providing sufficient space for the geometry of the functional tests. If the test program requires a particular test capability (e.g., the ability to support testing of navigating through the yard/barn or the ability to support testing of stopping for passenger boarding and alighting), the requirement is designated in the Functionality and Performance section. However, if a general infrastructure attribute (e.g., worn roads with potholes and degraded lane markings) is required, it is included in the Test Facility Features section. Actual field operational tests on public roads will require that those roadways meet the geometric and infrastructure requirements, but public safety considerations will also be important.

Permanent or temporary aspects of the operational domain (e.g., lane markings, striping, mock-ups and other experimental devices for defining a bus path) will need to be supported by the facility but are specified in the appropriate requirements section. For example, a test of a vehicle designed to operate in a dedicated lane will minimally require the facility have the space for defining the appropriate lane configurations and geometries but not necessarily the pre-existence of temporary or permanent infrastructure. The Functionality and Performance requirements more closely specify the capabilities of such a temporary or permanent lane. Similarly, if the automated vehicle employs GPS technology, the test facility and/or the mocked-up route should be mapped with sufficient accuracy and precision. The accuracy and precision will depend on the technologies to be used and other parameters of a given test or demonstration, so these specifications would need to be determined in the appropriate context.

Functionality and Performance

The test facility should be able to support testing that represents the full range of test conditions under consideration. If that involves evaluation and reaction to the presence of fixed or moving objects or road users, the facility will need access to the appropriate equipment. Requirements under the Functionality and Performance category focus on the test facility's capability to support testing of movements, maneuvers, and services. The test facility should be able to support the evaluation of systems and components through repeatable tests.

Safety

Test facilities should have an appropriate safety plan for the demonstration being considered. The plan should define procedures and protocols to protect all stakeholder participants, including members of the public in a field operational test or simulated revenue service. Beyond that, the test plan should contain tests that demonstrate and verify that the system being tested will maintain public and

employee safety in deployment. The facility should, therefore, have the capability to conduct tests of relevant "edge case" scenarios in which reasonable misuse of the system might inadvertently endanger individual safety as well as foreseeable interactions with other safety-related activities, such as providing appropriate right-of-way to emergency vehicles.

Environmental Resilience

Some tests will add value by demonstrating successful application under challenging environmental conditions. These may include actual or simulated precipitation (rain, snow, etc.), temperature (heat and cold), lighting conditions (glare and darkness), and visibility (e.g., fog, smoke, haze). Providing these conditions may not require permanent infrastructure.

Human Factors

Human factors testing of operators and passengers of vehicles with advanced driving assistance systems (ADAS, SAE Levels 1 and 2) and automated driving systems (ADS, SAE Levels 3-5) will be undertaken. Typically this includes measurements of:

- how drivers and passengers interact with the human-machine interface (HMI)
- whether drivers become overly reliant on the automated technology
- whether drivers understand the operational design domain of the automated driving assistance systems (SAE Levels 1 and 2) and the automated driving systems (Levels 3-5)
- whether drivers become disengaged from driving due to the presence of automated technologies, and, if so, how long it takes them to become re-engaged

The measures needed to evaluate the above human factors concerns include technologies and devices that can record:

- driver behaviors (e.g., foot position, hand position, head position)
- eye behaviors (e.g., fixation location, duration)
- vehicle behaviors (e.g., braking, velocity, acceleration, steering, lane position)

The facility may need to have the resources and protocols for testing of systems with naïve users as well. A comprehensive testing program may also explore issues such as the effects of control system algorithms on vehicle dynamics and subsequently passenger safety (i.e., automated shuttles) or the effects of unexpected automatic emergency braking and standing passenger safety. Internal Review Boards and Paperwork Reduction Act legislation prescribe strict rules for human subject testing, and the facility needs to be prepared if volunteers are to be part of the testing.

Data Collection and Management

The success of a test or demonstration will be difficult to substantiate with only qualitative data. Stakeholders will need accurate and precise measures of meaningful metrics to assess whether the technology or system can meet the stated goals and, ultimately, whether any appropriate cost-benefit criterion is met. The metrics and measurement devices will be dependent on the purpose of the test. For example, if the position of the vehicle is critical, there should be a method for measuring and recording that data. Similarly, in dynamic evasion events, the position and speed of various objects, people, and vehicles should be monitored and recorded. Some tests and demonstrations may require substantial data collection instruments and data storage facilities. Tests that require only a pass/fail rating will have lower requirements. Funding organizations may impose specific requirements for a data collection and management plan and may have guidelines or requirements related to the content of the plan.[6]

Mandatory and Optional Requirements

The requirements listed within each requirement category for each technology package and use case are divided into mandatory and optional. The designation of optional is not meant to denote that a requirement is never mandatory; instead, it is meant to indicate that test facility requirements will be highly dependent on the systems being tested. In choosing to define the test program for any qualification project, the requirements documentation should carefully evaluate whether each of the optional requirements should be considered mandatory for the specific test program. That is, vehicles in a particular technology package may not be designed to perform every possible function in every possible use case or condition. Thus, many of the listed requirements may not be appropriate for testing and demonstrating vehicles without full functionality.

Requirement Specificity

In general, requirements should contain specific and measurable statements that are precise and quantifiable. The requirements that are derived from this document should meet this threshold. Nonetheless, the requirements listed for each technology package and use case in this document are intentionally written with limited specificity to provide flexibility in defining the operating domain of the vehicle and thus the testing program. The authors of this document do not presume *a priori* to define acceptable performance for these test programs, particularly without insight into the intended long-term utility of the program. For example, proof-of-concept vehicles will likely not be held to the same standard as prototypes being tested as part of a procurement evaluation. Thus, when a requirement pertains to, for example, being able to simulate urban roads, the requirements document should contain quantitative specifications of

[6] For example, USDOT guidance on data management plans is available at https://ntl.bts.gov/public-access/creating-data-management-plans-extramural-research.

the salient aspects of the urban roads (e.g., intersection dimensions) needed to evaluate the vehicle under consideration.

Organization of Report

Section 2 discusses the approach taken to discuss issues and concerns of various stakeholders (including transit agencies, original equipment manufacturers, test facilities, and subject matter experts) regarding the type of testing and relevant equipment, infrastructure, and procedures as well as data requirements to provide convincing evidence of demonstration efficacy. Sections 3 through 7 delineate the requirements for each of the technology packages. Section 8 provides a summary with concluding remarks, key takeaways, and potential implications for the transit industry.

SECTION 2

Approach

Stakeholder Engagement

As a part of the research to develop a comprehensive set of test facility requirements, the research team interviewed both internal U.S. Department of Transportation (USDOT) stakeholders (including FTA and other modal administrations) and external stakeholders (bus manufacturers, suppliers, transit agencies, associations, and existing test facilities). Appendix A lists the organizations contacted for this report.

Stakeholder information was gathered via phone interviews and site visits. The research team sought to understand testing needs for previous projects, for ongoing work, and for planned work, as well as challenges and lessons learned. Site visits focused on test facilities. These visits informed the research team (authors of this report) on existing features at current test facilities and important features that do not currently exist.

USDOT Modal Administrations

The research team reached out to those in the FTA Office of Research, Demonstration and Innovation who are involved in current testing of buses and bus systems. These meetings were important for understanding baseline bus testing as it exists today and for understanding needs and challenges as they relate to testing and new bus technologies.

The team reached out to other modal administration stakeholders, such as offices within FHWA, the Federal Motor Carrier Safety Administration (FMCSA), and the National Highway Traffic Safety Administration (NHTSA). NHTSA stakeholders included both technology researchers and test facility operators at the Vehicle Research and Test Center. Discussions with other modal administrations helped the research team understand testing requirements as they relate to the other parts of USDOT and modal priorities (e.g., infrastructure, driver certification and enforcement, and vehicle safety).

Bus Manufacturers and Suppliers

Previous engagement with industry has indicated that bus manufacturers and their suppliers are interested in automation systems for transit buses. Some companies are working to develop partnerships with other organizations to further research and development in this area, and some have used their own test facilities or are building dedicated test facilities to test automation for transit buses. These companies have varying levels of in-house experience in testing

automation systems, so they are carefully considering how to test such systems. The companies provided insight into desirable test facility features and their current availability.

Transit Agencies

Since automated systems for transit buses generally are not yet commercially available, few transit agencies have deployed them. Some are beginning to pilot Advanced Driver Assistance Systems (ADAS) that provide warnings and guidance but do not have automated actuation. A few are working to pilot systems with automated emergency braking, and some have been involved in testing of prototype systems, such as Vehicle Assist and Automation (VAA) for automated lane-keeping and precision docking, and Driver Assist Systems (DAS) for bus-on-shoulder operations. Outreach to these transit agencies provided context on which tests have been conducted in the past and which will need to be conducted to test future transit bus automation systems.

Academia

Some universities are partnering with other organizations to conduct R&D and to deploy early versions of transit bus automation systems. Many have been part of such partnerships in the past, and some are just beginning to do work in this area. Contacts at these academic institutions provided information on testing needs for systems at various levels of development (e.g., basic research, development, validation, and initial deployment).

Test Facilities

The research team contacted several test track and proving ground facilities, some of which are specifically designed to test buses and some specifically designed to test automated vehicles. A few test facilities already have tested low-speed automated shuttles, and, as bus manufacturers consider developing and integrating automated systems into their vehicles, they will need to test automated buses.

The research team focused on the most relevant testing facilities for testing of transit bus automation systems. These meetings helped to gain an understanding of the features considered when designing these facilities, and an understanding of the shortcomings of existing facilities and challenges of testing automated transit buses. These facilities were the prime candidates for site visits.

Content Analysis and Generalization of Requirements for Use Cases

The research team conducted 24 interviews and 3 site visits with stakeholders. The discussions generally were fruitful and informed the determination of the

requirements for test facilities when hosting various types of testing. The insights gained were then used to identify requirements across the five technology packages and the six categories of requirements defined in Section 1. Depending on the organization conducting the testing, product being considered, or use case being tested, users may identify additional requirements beyond those included in this document. Users may opt to take requirements from this document, adapt them, or add additional requirements as needed.

Appendix B contains quick reference matrices of the requirements and their classifications (mandatory, optional, and not applicable) organized by requirement category (test facility features, functionality and performance, safety, etc.) and technology package and use case. When appropriate, specific requirements were determined for individual use cases within a technology package. These requirements are discussed and tabulated for the appropriate technology packages in Sections 3 through 7.

SECTION 3

Transit Bus Advanced Driver Assistance Systems

Use Cases

The Transit Bus Advanced Driver Assistance Systems (ADAS) technology package uses SAE Level 0–2 automation technologies to provide assistance to drivers by automating longitudinal (acceleration and braking) or lateral (steering) functions. This technology package contains six use cases, including Smooth Acceleration and Deceleration (Level 1), Automatic Emergency Braking and Pedestrian Collision Avoidance (Level 0), Curb Avoidance (Level 0), Precision Docking (Level 1–2), Narrow Lane/Shoulder Operations (Level 1–2), and Platooning (Level 1–2). These use cases are described in the following subsections.

Smooth Acceleration and Deceleration

This use case adjusts the bus speed on the approach and departure from an intersection to improve fuel economy—for example, maintaining speed to be able to pass through on a green phase or decelerating to a red signal in an efficient way. This helps to reduce idling as well as the excess fuel that is consumed when a vehicle accelerates toward an intersection only to have the signal turn red. With partial automation of longitudinal control, acceleration and deceleration can be coordinated with the signal phase and optimized, with greater fuel savings relative to manual driving. The use case can use vehicular communications (e.g., vehicle-to-vehicle or vehicle-to-infrastructure) or can rely on onboard sensors to determine when to speed up or slow down based on signal status or traffic flows.

Automatic Emergency Braking and Pedestrian Collision Avoidance

Automatic Emergency Braking (AEB) and pedestrian collision avoidance combine vehicle-based sensors with automated braking. Similar functions are available in light-duty vehicles and may include warnings/alerts before triggering brake application. The primary benefit of this use case is safety improvement through the avoidance of collisions with other vehicles, pedestrians, and other vulnerable road users.

Curb Avoidance

In this use case, sensor information is employed to assist bus drivers in avoiding curb strikes at bus stops or during turns. Benefits to the transit agency include

reduced wheel and tire damage from curb strikes and reduced driver stress and workload. This use case may be particularly valuable for vehicles maneuvering in tight spaces, vehicles operating in areas with uncommon curb configurations, or vehicles with limited curb visibility.

Precision Docking

Precision docking uses sensor information to assist bus operators in aligning vehicles with the boarding platform or curb at bus stops. The partially automated system can achieve precise longitudinal and/or lateral alignment between the vehicle and boarding platform much more consistently than human operators, improving the ease of boarding and alighting, particularly for riders with mobility impairments.

Narrow Lane/Shoulder Operations

Several U.S. transit agencies have tested or implemented "bus-on-shoulder" operations, in which a transit bus uses the highway shoulder as a type of exclusive bus lane, avoiding congested peak-hour conditions in regular traffic lanes. This use case involves partial automation of vehicle control, particularly lateral control, to assist bus operators in maintaining appropriate positioning in a narrow lane, such as a highway shoulder or exclusive bus lane. Making the vehicle's movements more precise reduces driver workload and stress, ameliorates the safety issues associated with narrow lane and shoulder usage, and permits slightly higher average vehicle speeds.

Platooning

Platooning has been discussed as a use case for partial vehicle automation, particularly for trucking, as closer vehicle spacing at highway speeds can improve aerodynamics and fuel economy. A similar logic could apply for transit vehicles operating expressway-type services, where aerodynamic improvements from platooning could yield fuel savings. For most urban transit services, speeds are not high enough for this to be an important factor, and transit services also typically aim to distribute their available vehicles across regularly spaced headways, rather than in close platoons. In exclusive busways with very high throughput, bus spacing can approach the limits of safe operation under human control, and platooning potentially could help increase throughput. Similarly, bus platooning may be applied to accommodate surges in demand during special events, such as concerts and sporting events.

Requirements

The following subsections identify mandatory and optional requirements in the six categories of Test Facility Features, Functionality and Performance, Safety, Environmental Resilience, Human Factors, and Data Collection and Management.

Requirements that are optional for some use cases but mandatory or not applicable for others are also identified.

Test Facility Features

The following requirements are considered mandatory for all use cases in this technology package:

- The test facility shall have sufficiently heavy-duty pavements and multiple wide lanes that can accommodate large, heavy-duty vehicles, such as transit buses.
- The test facility shall be adequately equipped to store, maintain, refuel, and charge the transit vehicles being tested.

The following requirements are considered optional for all use cases in this technology package:

- The test facility shall have or be able to physically simulate worn roads with potholes and degraded lane markings.
- The test facility shall have or be able to physically simulate unusual or non-standard lane markings, including old lane markers with new lane markers painted offset, tar strips, Botts dots, bicycle lanes, construction zone barrels and cones, and emergency flares or emergency vehicles that temporarily close lanes.
- The test facility shall have or be able to physically simulate a variety of road signs (including signs for bus stops, pedestrian crossings, stop signs, speed limit signs, and construction signs).
- The test facility shall have or be able to physically simulate a variety of building facades, alleys, ramps, sidewalks, and roadside furniture (e.g., posts/poles, signs, benches, rails, barriers, fire hydrants, and trash cans) with either temporary or permanent features.

The following requirements are generally considered mandatory for use cases in the Transit Bus ADAS technology package, but are considered optional for the Curb Avoidance use case and not applicable for two use cases (Narrow Lane/Shoulder Operations; Platooning):

- The test facility shall have or be able to physically simulate loading zones/passenger pickup zones. (Smooth Acceleration and Deceleration; Automatic Emergency Braking and Pedestrian Collision Avoidance)
- The test facility shall have or be able to physically simulate bus stops/shelters. (Smooth Acceleration and Deceleration; Automatic Emergency Braking and Pedestrian Collision Avoidance)

The following requirement is generally considered optional for use cases in the Transit Bus ADAS technology package, but is considered mandatory for the Precision Docking use case:

- The test facility shall have or be able to physically simulate curbs and boarding platforms with various geometries.

The following requirements are generally considered optional for use cases in the Transit Bus ADAS technology package, but are considered not applicable for two use cases (Curb Avoidance; Precision Docking):

- The test facility shall have or be able to physically simulate highways.
- The test facility shall have or be able to physically simulate rural roads (including dirt and gravel surfaces).

The following requirements are generally considered optional for use cases in the Transit Bus ADAS technology package, but are considered not applicable for two use cases (Precision Docking; Narrow Lane/Shoulder Operations):

- The test facility shall have or be able to physically simulate residential roads.
- The test facility shall have or be able to physically simulate roundabouts/ traffic circles.
- The test facility shall have or be able to physically simulate intersections (signalized and unsignalized).

The following requirements are generally considered optional for use cases in the Transit Bus ADAS technology package, but are considered not applicable for the Precision Docking use case:

- The test facility shall have or be able to physically simulate urban roads.
- The test facility shall have or be able to physically simulate suburban roads.
- The test facility shall have or be able to physically simulate curvy roads.
- The test facility shall have or be able to physically simulate uphill/downhill roads.
- The test facility shall have or be able to physically simulate bridges.
- The test facility shall have or be able to physically simulate rail crossings.
- The test facility shall have or be able to physically simulate dedicated bus lanes.

Functionality and Performance

The following requirements are considered mandatory for all use cases in this technology package:

- The test facility shall be able to support testing of nominal bus motions, including starting, slowing and stopping (including crossing lane markers), turning (may include crossing lane markings such as double yellow line), stop and go traffic, steady speed, obeying local traffic laws and traffic control signs/devices, and signaling.
- The test facility shall be able to support closed-track testing.
- The test facility shall be able to support evaluation of the efficacy of different sensor systems and redundant systems to sense and interpret the vehicle's surrounding environment (e.g., simultaneous use of GPS, lidar, radar, cameras, and other technologies).
- The test facility shall be able to conduct repeatable tests. This requirement may necessitate software control over the environment (e.g., traffic control signals, weather simulation, lighting conditions, etc.).
- The test facility shall be able to develop and conduct pre-trip inspection (validation and diagnostic) procedures to check sensor and actuator functions to ensure they are performing to specifications and assess degradation/ failures over a range of conditions.

The following requirements are considered optional for all use cases in this technology package:

- The test facility shall be able to support testing of navigating with building or chain link fence in close proximity.
- The test facility shall be able to conduct shock and vibration testing on electronic systems that support automation (e.g., in line with the requirements for electrical automotive components in SAE J1211).
- The test facility shall be able to support testing of challenging driving situations in mixed traffic, such as left turns with heavy oncoming traffic from opposite and lateral directions.
- The test facility shall be able to support testing of intermodal trips (i.e., those where a traveler switches form one mode to another), such as bus/rail stations, park-and-ride lots, and transit centers.
- The test facility shall be able to support testing of 40' or smaller transit buses.
- The test facility shall be able to support testing of 60' and 80' articulated buses.
- The test facility shall be able to support open roads testing.
- The test facility shall be able to support computer simulation testing (e.g., hardware-in-the-loop simulations).
- The test facility shall make available or have a control center that can support monitoring and remote take-over of an automated vehicle.

The following requirements are generally considered optional for use cases in the Transit Bus ADAS technology package, but are considered mandatory for the Automatic Emergency Braking and Pedestrian Collision Avoidance use case:

- The test facility shall be able to support testing of operation around moving objects requiring avoidance, including animal mockups, bouncing balls, boxes falling out of a moving vehicle, debris, and other items.
- The test facility shall be able to support testing of operation alongside either real or simulated dynamic road users (e.g., moving vehicles, bicyclists, pedestrians, and other vulnerable road users - VRUs). Elements could include human-driven vehicles, robotically controlled vehicles and pedestrian mockups (e.g., guided soft targets), and actual humans posing as VRUs.

The following requirement is generally considered optional for use cases in the Transit Bus ADAS technology package, but is considered mandatory for the Precision Docking use case:

- The test facility shall be able to support testing of stopping for passenger boarding and alighting, including at bus stops with various configurations (e.g., dedicated curbside bus stop, roadside bus stop with and without adjacent parking, station platforms, curb-cut and curved or otherwise anomalous bus stop geometry).

The following requirement is generally considered optional for use cases in the Transit Bus ADAS technology package, but is considered mandatory for the Smooth Acceleration and Deceleration and Platooning use cases:

- The test facility shall be able to support testing of connected vehicle applications (e.g., signal phase and timing and transit signal priority) with appropriately equipped vehicles or infrastructure.

The following requirement is generally considered optional for use cases in the Transit Bus ADAS technology package, but is considered mandatory for the Curb Avoidance use case and not applicable for the Smooth Acceleration and Deceleration use case:

- The test facility shall be able to support testing of operation around fixed objects requiring avoidance, including different objects above, below, to the side, and ahead of the vehicle.

The following requirements are generally considered optional for use cases in the Transit Bus ADAS technology package, but are considered not applicable for the Narrow Lane/Shoulder Operations and Platooning use cases:

- The test facility shall be able to support testing of loading/unloading and securing/unsecuring passengers with mobility devices.

- The test facility shall be able to support testing of flagged service (passengers must indicate intent to board/alight for the bus to stop).

Safety

The following requirement is considered mandatory for all use cases in this technology package:

- The test facility shall draft a safety plan to ensure safety of all participants and plan contingencies in the case of system failure. The safety plan shall include a hazard assessment that identifies mitigations, with reassessment of the mitigations to determine if additional actions need to be taken.

The following requirements are considered optional for all use cases in this technology package:

- The test facility shall be able to support testing of transit vehicles in the event of a traffic control device failure.
- The test facility shall be able to support testing of emergency evacuation procedures (e.g., in the event of a vehicle fire or other disaster on the bus).
- The test facility shall be able to support testing of corner and edge cases as identified in simulations and real-world incidents.
- The test facility shall be able to support testing of operations in the presence of and interactions with first responders (e.g., allowing a fire truck to overtake the bus or providing appropriate distance when passing a police cruiser on the side of the road).
- The test facility shall be able to support crash-type testing of transit vehicles.
- The test facility shall be able to support testing of transit vehicles with respect to cybersecurity.
- The test facility shall be able to support testing of transit vehicles with respect to physical security (of vehicle occupants).

Environmental Resilience

The following requirements are considered optional for all use cases in this technology package:

- The test facility shall be able to support testing of operations in the presence of electromagnetic interference (EMI) as there will be many sensors and communications equipment on board.
- The test facility shall be able to support testing of operations in the presence of reflective surfaces (e.g., chrome surfaces on trailers, other vehicles, or infrastructure).

- The test facility shall be able to support testing of operations in the presence of various lighting conditions (e.g., solar glare, darkness, external lighting from various types of street lamps at various heights).
- The test facility shall be able to support testing of operations in the transitioning between extreme lighting conditions (e.g., entering or exiting a tunnel on a bright day).
- The test facility shall be able to support testing of operations in the presence of precipitation (e.g., rain, sleet, snow, and hail) to various degrees (e.g., sprinkling, drizzle, and heavy rain).
- The test facility shall be able to support testing of operations in the presence of various ambient temperatures (e.g., hot and cold).
- The test facility shall be able to support testing of operations in the presence of various visibility conditions (e.g., fog, smoke, and haze).
- The test facility shall be able to support testing of operations in the presence of flooding (deep or shallow).
- The test facility shall be able to support testing of operations in the presence of various traction conditions (e.g., in accumulations of ice, snow, slush, and sand).
- The test facility shall be able to support measurement of the impact of environmental conditions on the battery life of electric automated vehicles (e.g. how battery life is affected by extreme heat or cold).
- The test facility shall be able to support testing of operations in the presence of various combinations of environmental conditions (e.g., dark and rainy, glare and snowy).
- The test facility shall be able to support testing of operations in the presence of heavy wind.

Human Factors

The following requirement is considered mandatory for all use cases in this technology package:

- The test facility shall comply with requirements for human subject testing (e.g., Institutional Review Board process).

The following requirements are considered optional for all use cases in this technology package:

- The test facility shall be able to support evaluation of how different infrastructure (e.g., station platforms) and vehicle design (e.g., communicating automated vehicle intent) influences user behavior (e.g., passengers, operators, and other road users).

- The test facility shall be able to support evaluation of the vehicle's ability to provide service to users with mobility limitations or other disabilities (e.g., vision, hearing, or cognitive limitations).
- The test facility shall be able to support evaluation of the effects of automated service and technologies on passengers, including standees, while the vehicle is in motion.
- The test facility shall be able to support evaluation of the usability and effects of the vehicle interface on passengers (e.g., display screen, buttons, and smartphone/tablet applications).
- The test facility shall be able to support human factors research on automated technologies (e.g., evaluating operators' understanding of these technologies, the effectiveness of driver state monitoring devices and methods designed to return operator's attention to driving, and the quality of the transfer of control back to the operator).
- The test facility shall be able to support evaluation of how pedestrians and other road users perceive an automated vehicle and how they react to it.
- The test facility shall be able to support collection of information from pre- and post-ride user surveys (e.g., rider comfort, user acceptance, and other perceptions).

The following requirement is generally considered optional for use cases in the Transit Bus ADAS technology package, but is considered not applicable for the Curb Avoidance, Narrow Lane/Shoulder Operations, and Platooning use cases:

- The test facility shall be able to support testing of recognizing passenger intent (e.g., intent to board or alight) at bus stop locations (both inside and outside the bus).

The following requirement is considered not applicable for other use cases in the Transit Bus ADAS technology package, but is considered optional for the Smooth Acceleration and Deceleration and Precision Docking use cases:

- The test facility shall be able to support human factors research on boarding and alighting processes.

Data Collection and Management

The following requirements are considered mandatory for all use cases in this technology package:

- The test facility shall be able to support transmission of data (either wirelessly or through wired connections) collected from devices in vehicles and infrastructure and store it for future research use.

- The test facility shall be able to support collection of information on the technical accuracy and performance of the systems (e.g., false alarms, emergency interventions, and frequency of failure).
- The test facility shall be able to calibrate the test equipment to ensure that it is able to take accurate measurements of test vehicles, environment, and other relevant factors.
- The test facility shall be able to support collection of information on operations (e.g., wait times, communications, vehicle availability, serviceability, and energy use and charging).
- The test facility shall have protocols for developing an effective test plan. Specific use cases could inform the performance requirements, which, in turn, could inform metrics for testing and the test plan.
- The test facility shall have protocols for developing an effective plan for data collection, storage, and use (or reuse).

The following requirements are considered optional for all use cases in this technology package:

- The test facility shall be able to support collection of data from testing in various environmental conditions (e.g., rain, snow), with sensors that can operate in those conditions.
- The test facility shall be able to support wireless transmission of data collected from devices in vehicles and infrastructure for use in real-time applications.
- The test facility shall be able to support remote, real-time monitoring (e.g., visual supervision) of the vehicle and its occupants.
- The test facility shall be able to remotely monitor the functionality of the entire system, including the status of vehicles, the infrastructure, and all relevant sensors.
- The test facility shall be able to provide or create regularly-updated high-definition maps of the site that automated test vehicles can use during operation.

SECTION
4

Automated Shuttle

Use Cases

The Automated Shuttle technology package uses a SAE Level 4 vehicle, such as a low-speed automated shuttle or an automated passenger van. Although automated shuttles typically have been thought of as smaller vehicles, 30' or 40' transit buses could also be used for this application. The Automated Shuttle technology package contains two use cases—Circulator Bus Service and Feeder Bus Service.

Circulator Bus Service

Circulator Bus Service provides rides along a single route with pre-defined stops and a set schedule. The route may be limited to closed environments, such as parking lots, busways, campuses, and retirement communities, or it may operate in mixed traffic on public roads in areas, such as business parks or downtown districts.

Feeder Bus Service

Feeder Bus Service provides a similar service along a single route or multiple routes with pre-defined stops and a set schedule. The major difference between Feeder Bus Service and Circulator Bus Service is that Feeder Bus Service is specifically designed to connect riders to other transit options, such as fixed-route transit buses, light rail, or heavy rail / subway service, so shuttles will provide rides between areas of high demand (e.g., office buildings, parking lots, shopping centers) and existing transit stops.

Requirements

The following subsections identify mandatory and optional requirements in the six categories of Test Facility Features, Functionality and Performance, Safety, Environmental Resilience, Human Factors, and Data Collection and Management. Requirements that are optional for some use cases but mandatory or not applicable for others are also identified.

Test Facility Features

The following requirements are considered mandatory for all use cases in this technology package:

- The test facility shall have or be able to physically simulate loading zones/ passenger pickup zones.

- The test facility shall have or be able to physically simulate bus stops/shelters.
- The test facility shall be adequately equipped to store, maintain, refuel, and charge the transit vehicles being tested.

The following requirements are considered optional for all use cases in this technology package:

- The test facility shall have sufficiently heavy-duty pavements and multiple wide lanes that can accommodate large, heavy-duty vehicles, such as transit buses.
- The test facility shall have or be able to physically simulate urban roads.
- The test facility shall have or be able to physically simulate suburban roads.
- The test facility shall have or be able to physically simulate residential roads.
- The test facility shall have or be able to physically simulate curvy roads.
- The test facility shall have or be able to physically simulate uphill/downhill roads.
- The test facility shall have or be able to physically simulate bridges.
- The test facility shall have or be able to physically simulate rail crossings.
- The test facility shall have or be able to physically simulate roundabouts/ traffic circles.
- The test facility shall have or be able to physically simulate intersections (signalized and unsignalized).
- The test facility shall have or be able to physically simulate curbs and boarding platforms with various geometries.
- The test facility shall have or be able to physically simulate worn roads with potholes and degraded lane markings.
- The test facility shall have or be able to physically simulate unusual or non-standard lane markings, including old lane markers with new lane markers painted offset, tar strips, Botts dots, bicycle lanes, construction zone barrels and cones, and emergency flares or emergency vehicles that temporarily close lanes.
- The test facility shall have or be able to physically simulate a variety of road signs (including signs for bus stops, pedestrian crossings, stop signs, speed limit signs, and construction signs).
- The test facility shall have or be able to physically simulate a variety of building facades, alleys, ramps, sidewalks, and roadside furniture (e.g., posts/ poles, signs, benches, rails, barriers, fire hydrants, and trash cans) with either temporary or permanent features.
- The test facility shall have or be able to physically simulate dedicated bus lanes.

The following requirements are considered optional for the Feeder Bus Service use case, but are considered not applicable for the Circulator Bus Service use case:

- The test facility shall have or be able to physically simulate highways.
- The test facility shall have or be able to physically simulate rural roads (including dirt and gravel surfaces).

Functionality and Performance

The following requirements are considered mandatory for all use cases in this technology package:

- The test facility shall be able to support testing of nominal bus motions, including starting, slowing and stopping (including crossing lane markers), turning (may include crossing lane markings such as double yellow line), stop and go traffic, steady speed, obeying local traffic laws and traffic control signs/devices, and signaling.
- The test facility shall be able to support testing of stopping for passenger boarding and alighting, including at bus stops with various configurations (e.g., dedicated curbside bus stop, roadside bus stop with and without adjacent parking, station platforms, curb-cut and curved or otherwise anomalous bus stop geometry).
- The test facility shall be able to support testing of operation around fixed objects requiring avoidance, including different objects above, below, to the side, and ahead of the vehicle.
- The test facility shall be able to support testing of operation around moving objects requiring avoidance, including animal mockups, bouncing balls, boxes falling out of a moving vehicle, debris, and other items.
- The test facility shall be able to support testing of operation alongside either real or simulated dynamic road users (e.g., moving vehicles, bicyclists, pedestrians, and other vulnerable road users - VRUs). Elements could include human-driven vehicles, robotically controlled vehicles and pedestrian mockups (e.g., guided soft targets), and actual humans posing as VRUs.
- The test facility shall be able to support closed-track testing.
- The test facility shall be able to support evaluation of the efficacy of different sensor systems and redundant systems to sense and interpret the vehicle's surrounding environment (e.g., simultaneous use of GPS, lidar, radar, cameras, and other technologies).
- The test facility shall be able to conduct repeatable tests. This requirement may necessitate software control over the environment (e.g., traffic control signals, weather simulation, lighting conditions, etc.).

- The test facility shall be able to develop and conduct pre-trip inspection (validation and diagnostic) procedures to check sensor and actuator functions to ensure they are performing to specifications and assess degradation/ failures over a range of conditions.

The following requirements are considered optional for all use cases in this technology package:

- The test facility shall be able to support testing of loading/unloading and securing/unsecuring passengers with mobility devices.
- The test facility shall be able to support testing of flagged service (passengers must indicate intent to board/alight for the bus to stop).
- The test facility shall be able to support testing of navigating with building or chain link fence in close proximity.
- The test facility shall be able to conduct shock and vibration testing on electronic systems that support automation (e.g., in line with the requirements for electrical automotive components in SAE J1211).
- The test facility shall be able to support testing of challenging driving situations in mixed traffic, such as left turns with heavy oncoming traffic from opposite and lateral directions.
- The test facility shall be able to support testing of on-demand service, including path planning, hailing (cellphone app or kiosk) and curb use for pick-ups and drop-offs.
- The test facility shall be able to support testing of connected vehicle applications (e.g., signal phase and timing and transit signal priority) with appropriately equipped vehicles or infrastructure.
- The test facility shall be able to support testing of smaller vehicles, such as cutaway vans for paratransit.
- The test facility shall be able to support testing of 40' or smaller transit buses.
- The test facility shall be able to support open roads testing.
- The test facility shall be able to support computer simulation testing (e.g., hardware-in-the-loop simulations).
- The test facility shall make available or have a control center that can support monitoring and remote take-over of an automated vehicle.

The following requirement is considered optional for the Circulator Bus Service use case, but is considered mandatory for the Feeder Bus Service use case:

- The test facility shall be able to support testing of intermodal trips (i.e., those where a traveler switches form one mode to another), such as bus/rail stations, park-and-ride lots, and transit centers.

Safety

The following requirement is considered mandatory for all use cases in this technology package:

- The test facility shall draft a safety plan to ensure safety of all participants and plan contingencies in the case of system failure. The safety plan shall include a hazard assessment that identifies mitigations, with reassessment of the mitigations to determine if additional actions need to be taken.

The following requirements are considered optional for all use cases in this technology package:

- The test facility shall be able to support testing of transit vehicles in the event of a traffic control device failure.
- The test facility shall be able to support testing of emergency evacuation procedures (e.g., in the event of a vehicle fire or other disaster on the bus).
- The test facility shall be able to support testing of corner and edge cases as identified in simulations and real-world incidents.
- The test facility shall be able to support testing of operations in the presence of and interactions with first responders (e.g., allowing a fire truck to overtake the bus or providing appropriate distance when passing a police cruiser on the side of the road).
- The test facility shall be able to support crash-type testing of transit vehicles.
- The test facility shall be able to support testing of transit vehicles with respect to cybersecurity.
- The test facility shall be able to support testing of transit vehicles with respect to physical security (of vehicle occupants).

Environmental Resilience

The following requirements are considered optional for all use cases in this technology package:

- The test facility shall be able to support testing of operations in the presence of electromagnetic interference (EMI) as there will be many sensors and communications equipment on board.
- The test facility shall be able to support testing of operations in the presence of reflective surfaces (e.g., chrome surfaces on trailers, other vehicles, or infrastructure).
- The test facility shall be able to support testing of operations in the presence of various lighting conditions (e.g., solar glare, darkness, external lighting from various types of street lamps at various heights).

- The test facility shall be able to support testing of operations in the transitioning between extreme lighting conditions (e.g., entering or exiting a tunnel on a bright day).
- The test facility shall be able to support testing of operations in the presence of precipitation (e.g., rain, sleet, snow, and hail) to various degrees (e.g., sprinkling, drizzle, and heavy rain).
- The test facility shall be able to support testing of operations in the presence of various ambient temperatures (e.g., hot and cold).
- The test facility shall be able to support testing of operations in the presence of various visibility conditions (e.g., fog, smoke, and haze).
- The test facility shall be able to support testing of operations in the presence of flooding (deep or shallow).
- The test facility shall be able to support testing of operations in the presence of various traction conditions (e.g., in accumulations of ice, snow, slush, and sand).
- The test facility shall be able to support measurement of the impact of environmental conditions on the battery life of electric automated vehicles (e.g. how battery life is affected by extreme heat or cold).
- The test facility shall be able to support testing of operations in the presence of various combinations of environmental conditions (e.g., dark and rainy, glare and snowy).
- The test facility shall be able to support testing of operations in the presence of heavy wind.

Human Factors

The following requirement is considered mandatory for all use cases in this technology package:

- The test facility shall comply with requirements for human subject testing (e.g., Institutional Review Board process).

The following requirements are considered optional for all use cases in this technology package:

- The test facility shall be able to support evaluation of how different infrastructure (e.g., station platforms) and vehicle design (e.g., communicating automated vehicle intent) influences user behavior (e.g., passengers, operators, and other road users).
- The test facility shall be able to support evaluation of the vehicle's ability to provide service to users with mobility limitations or other disabilities (e.g., vision, hearing, or cognitive limitations).

- The test facility shall be able to support evaluation of the effects of automated service and technologies on passengers, including standees, while the vehicle is in motion.
- The test facility shall be able to support evaluation of the usability and effects of the vehicle interface on passengers (e.g., display screen, buttons, and smartphone/tablet applications).
- The test facility shall be able to support human factors research on boarding and alighting processes.
- The test facility shall be able to support testing of recognizing passenger intent (e.g., intent to board or alight) at bus stop locations (both inside and outside the bus).
- The test facility shall be able to support evaluation of how pedestrians and other road users perceive an automated vehicle and how they react to it.
- The test facility shall be able to support collection of information from pre- and post-ride user surveys (e.g., rider comfort, user acceptance, and other perceptions).

Data Collection and Management

The following requirements are considered mandatory for all use cases in this technology package:

- The test facility shall be able to support transmission of data (either wirelessly or through wired connections) collected from devices in vehicles and infrastructure and store it for future research use.
- The test facility shall be able to support collection of information on the technical accuracy and performance of the systems (e.g., false alarms, emergency interventions, and frequency of failure).
- The test facility shall be able to calibrate the test equipment to ensure that it is able to take accurate measurements of test vehicles, environment, and other relevant factors.
- The test facility shall be able to support collection of information on operations (e.g., wait times, communications, vehicle availability, serviceability, and energy use and charging).
- The test facility shall have protocols for developing an effective test plan. Specific use cases could inform the performance requirements, which, in turn, could inform metrics for testing and the test plan.
- The test facility shall have protocols for developing an effective plan for data collection, storage, and use (or reuse).

The following requirements are considered optional for all use cases in this technology package:

- The test facility shall be able to support collection of data from testing in various environmental conditions (e.g., rain, snow), with sensors that can operate in those conditions.
- The test facility shall be able to support wireless transmission of data collected from devices in vehicles and infrastructure for use in real-time applications.
- The test facility shall be able to support remote, real-time monitoring (e.g., visual supervision) of the vehicle and its occupants.
- The test facility shall be able to remotely monitor the functionality of the entire system, including the status of vehicles, the infrastructure, and all relevant sensors.
- The test facility shall be able to provide or create regularly-updated high-definition maps of the site that automated test vehicles can use during operation.

SECTION 5

Maintenance, Yard, Parking Operations

Use Cases

The Maintenance, Yard, Parking Operations technology package includes SAE Level 4 automation technologies that could be added to buses in a transit agency's fleet to be used within the confines of the bus yard when the vehicles are not in revenue service. This package contains two use cases—Precision Movement for Fueling, Service Bays, and Bus Wash; and Automated Parking and Recall. These use cases are described in the following subsections.

Precision Movement for Fueling, Service Bays, and Bus Wash

This use case allows buses to move in a precise, fully-automated way through the maintenance yard, including movements to or through the fueling island, service bay, and bus wash. The bus operator would not be required to be onboard or to operate the vehicle during this time, potentially streamlining operations such as refueling, maintenance, and cleaning activities.

Automated Parking and Recall

This use case allows for buses to position themselves within the bus yard in ways that optimize the flow of buses during pull-out and pull-in. Buses could move in a fully-automated mode from their parking space to the departure point at the start of the shift. Buses that are returning to the facility from revenue service could move in automated mode to a designated parking space. In both cases, the bus operator would not be required to be onboard or to operate the vehicle during this time.

Requirements

The following subsections identify mandatory and optional requirements in the six categories of Test Facility Features, Functionality and Performance, Safety, Environmental Resilience, Human Factors, and Data Collection and Management. Requirements that are optional for some use cases but mandatory or not applicable for others are also identified.

Test Facility Features

The following requirements are considered mandatory for all use cases in this technology package:

- The test facility shall have sufficiently heavy-duty pavements and multiple wide lanes that can accommodate large, heavy-duty vehicles, such as transit buses.
- The test facility shall have or be able to physically simulate a bus yard.
- The test facility shall be adequately equipped to store, maintain, refuel, and charge the transit vehicles being tested.

The following requirements are considered optional for all use cases in this technology package:

- The test facility shall have or be able to physically simulate curbs and boarding platforms with various geometries.
- The test facility shall have or be able to physically simulate worn roads with potholes and degraded lane markings.
- The test facility shall have or be able to physically simulate unusual or non-standard lane markings, including old lane markers with new lane markers painted offset, tar strips, Botts dots, bicycle lanes, construction zone barrels and cones, and emergency flares or emergency vehicles that temporarily close lanes.
- The test facility shall have or be able to physically simulate a variety of building facades, alleys, ramps, sidewalks, and roadside furniture (e.g., posts/poles, signs, benches, rails, barriers, fire hydrants, and trash cans) with either temporary or permanent features.

The following requirements are generally considered optional for the Automated Parking and Recall use case, but are considered mandatory for the Precision Movement for Fueling, Service Bays, and Bus Wash use case:

- The test facility shall have or be able to physically simulate a bus maintenance and service facility.
- The test facility shall have or be able to physically simulate refueling and electrical charging areas.

Functionality and Performance

The following requirements are considered mandatory for all use cases in this technology package:

- The test facility shall be able to support testing of nominal bus motions, including starting, slowing and stopping (including crossing lane markers), turning (may include crossing lane markings such as double yellow line), stop and go traffic, steady speed, obeying local traffic laws and traffic control signs/devices, and signaling.
- The test facility shall be able to support closed-track testing.

- The test facility shall be able to support evaluation of the efficacy of different sensor systems and redundant systems to sense and interpret the vehicle's surrounding environment (e.g., simultaneous use of GPS, lidar, radar, cameras, and other technologies).
- The test facility shall be able to conduct repeatable tests. This requirement may necessitate software control over the environment (e.g., traffic control signals, weather simulation, lighting conditions, etc.).
- The test facility shall be able to develop and conduct pre-trip inspection (validation and diagnostic) procedures to check sensor and actuator functions to ensure they are performing to specifications and assess degradation/ failures over a range of conditions.

The following requirements are considered optional for all use cases in this technology package:

- The test facility shall be able to support testing of navigating with building or chain link fence in close proximity.
- The test facility shall be able to conduct shock and vibration testing on electronic systems that support automation (e.g., in line with the requirements for electrical automotive components in SAE J1211).
- The test facility shall be able to support testing of operation around fixed objects requiring avoidance, including different objects above, below, to the side, and ahead of the vehicle.
- The test facility shall be able to support testing of connected vehicle applications (e.g., signal phase and timing and transit signal priority) with appropriately equipped vehicles or infrastructure.
- The test facility shall be able to support testing of smaller vehicles, such as cutaway vans for paratransit.
- The test facility shall be able to support testing of 40' or smaller transit buses.
- The test facility shall be able to support testing of 60' and 80' articulated buses.
- The test facility shall be able to support computer simulation testing (e.g., hardware-in-the-loop simulations).
- The test facility shall make available or have a control center that can support monitoring and remote take-over of an automated vehicle.

The following requirement is generally considered optional for the Automated Parking and Recall use case, but is considered mandatory for the Precision Movement for Fueling, Service Bays, and Bus Wash use case:

- The test facility shall be able to support testing of bus yard maneuvers, including pulling in/out/docking in the bus barn, fueling station, and storage facilities.

The following requirements are generally considered optional for the Precision Movement for Fueling, Service Bays, and Bus Wash use case, but are considered mandatory for the Automated Parking and Recall use case:

- The test facility shall be able to support testing of navigating through the yard/barn to and through the maintenance station (e.g., lift arms and pit) and bus washing station.
- The test facility shall be able to support testing of navigating through the yard/barn to the yard exit.

Safety

The following requirement is considered mandatory for all use cases in this technology package:

- The test facility shall draft a safety plan to ensure safety of all participants and plan contingencies in the case of system failure. The safety plan shall include a hazard assessment that identifies mitigations, with reassessment of the mitigations to determine if additional actions need to be taken.

The following requirement is considered optional for all use cases in this technology package:

- The test facility shall be able to support testing of transit vehicles with respect to cybersecurity.

Environmental Resilience

The following requirements are considered optional for all use cases in this technology package:

- The test facility shall be able to support testing of operations in the presence of electromagnetic interference (EMI) as there will be many sensors and communications equipment on board.
- The test facility shall be able to support testing of operations in the presence of reflective surfaces (e.g., chrome surfaces on trailers, other vehicles, or infrastructure).
- The test facility shall be able to support testing of operations in the presence of various lighting conditions (e.g., solar glare, darkness, external lighting from various types of street lamps at various heights).

- The test facility shall be able to support testing of operations in the transitioning between extreme lighting conditions (e.g., entering or exiting a tunnel on a bright day).
- The test facility shall be able to support testing of operations in the presence of precipitation (e.g., rain, sleet, snow, and hail) to various degrees (e.g., sprinkling, drizzle, and heavy rain).
- The test facility shall be able to support testing of operations in the presence of various ambient temperatures (e.g., hot and cold).
- The test facility shall be able to support testing of operations in the presence of various visibility conditions (e.g., fog, smoke, and haze).
- The test facility shall be able to support testing of operations in the presence of flooding (deep or shallow).
- The test facility shall be able to support testing of operations in the presence of various traction conditions (e.g., in accumulations of ice, snow, slush, and sand).
- The test facility shall be able to support measurement of the impact of environmental conditions on the battery life of electric automated vehicles (e.g., how battery life is affected by extreme heat or cold).
- The test facility shall be able to support testing of operations in the presence of various combinations of environmental conditions (e.g., dark and rainy, glare and snowy).
- The test facility shall be able to support testing of operations in the presence of heavy wind.

Human Factors

The following requirement is considered mandatory for all use cases in this technology package:

- The test facility shall comply with requirements for human subject testing (e.g., Institutional Review Board process).

The following requirement is considered optional for all use cases in this technology package:

- The test facility shall be able to support evaluation of how different infrastructure (e.g., station platforms) and vehicle design (e.g., communicating automated vehicle intent) influences user behavior (e.g., passengers, operators, and other road users).

Data Collection and Management

The following requirements are considered mandatory for all use cases in this technology package:

- The test facility shall be able to support transmission of data (either wirelessly or through wired connections) collected from devices in vehicles and infrastructure and store it for future research use.
- The test facility shall be able to support collection of information on the technical accuracy and performance of the systems (e.g., false alarms, emergency interventions, and frequency of failure).
- The test facility shall be able to calibrate the test equipment to ensure that it is able to take accurate measurements of test vehicles, environment, and other relevant factors.
- The test facility shall be able to support collection of information on operations (e.g., wait times, communications, vehicle availability, serviceability, and energy use and charging).
- The test facility shall have protocols for developing an effective test plan. Specific use cases could inform the performance requirements, which, in turn, could inform metrics for testing and the test plan.
- The test facility shall have protocols for developing an effective plan for data collection, storage, and use (or reuse).

The following requirements are considered optional for all use cases in this technology package:

- The test facility shall be able to support collection of data from testing in various environmental conditions (e.g., rain, snow), with sensors that can operate in those conditions.
- The test facility shall be able to support wireless transmission of data collected from devices in vehicles and infrastructure for use in real-time applications.
- The test facility shall be able to support remote, real-time monitoring (e.g., visual supervision) of the vehicle and its occupants.
- The test facility shall be able to remotely monitor the functionality of the entire system, including the status of vehicles, the infrastructure, and all relevant sensors.
- The test facility shall be able to provide or create regularly-updated high-definition maps of the site that automated test vehicles can use during operation.

SECTION 6

Mobility-on-Demand Service

Use Cases

The Mobility-on-Demand (MOD) Service technology package uses SAE Level 4 automation in a small- to medium-size vehicle (such as a minibus on a cutaway van chassis, although new designs may emerge) to provide on-demand service between any two addresses within a defined service area. The concept is similar to the Automated Shuttle technology package; however, it is not restricted to predefined routes and waypoints, and users can request pick-ups and drop-offs (e.g., using an application on a smartphone, tablet, or kiosk) on demand rather than being restricted to scheduled service. MOD Service can provide rides to users in urban areas and other less-dense areas such as suburban and rural communities. The MOD Service technology package contains three use cases—Automated First/Last-Mile, Automated ADA Paratransit, and On-Demand Shared Ride. These use cases are described in the following subsections.

Automated First/Last-Mile

This use case is conceptually similar to the Feeder Bus Service use case in the Automated Shuttle technology package, but with flexibility to serve a wider geographic area and range of operational environments. This type of first/last-mile service is designed to connect a transit station with a wider catchment area, particularly for travelers whose origin or destination is beyond walking distance from the station. These types of services can operate as fully-fixed routes or incorporate various forms of route deviation.

Automated ADA Paratransit

Under the Americans with Disabilities Act (ADA), transit agencies providing fixed-route public transportation are required to provide comparable paratransit service to persons with disabilities. Transit operators generally use smaller vehicles to provide their paratransit services, and the vehicles need to include specialized equipment to assist riders with disabilities. Automated ADA Paratransit may or may not include an on-board attendant, although if the vehicle is entirely unmanned, it will need specialized systems for functions such as automated ramp deployment and securement for wheelchair users and intuitive visual, auditory, and haptic interfaces for users to access information and make requests.

On-Demand Shared Ride

This use case represents a large paradigm shift in which some transit services move from a fixed-route, fixed-schedule model to a point-to-point, on-demand,

shared ride model using a fleet of fully-automated SAE Level 4 smaller vehicles. Applications of this model include, but are not limited to, rural uses, as On-Demand Shared Ride service is expected to be able to provide coverage in low-density areas.

Requirements

The following subsections identify mandatory and optional requirements in the six categories of Test Facility Features, Functionality and Performance, Safety, Environmental Resilience, Human Factors, and Data Collection and Management. Requirements that are optional for some use cases but mandatory or not applicable for others are also identified.

Test Facility Features

The following requirements are considered mandatory for all use cases in this technology package:

- The test facility shall have or be able to physically simulate intersections (signalized and unsignalized).
- The test facility shall have or be able to physically simulate curbs and boarding platforms with various geometries.
- The test facility shall have or be able to physically simulate worn roads with potholes and degraded lane markings.
- The test facility shall have or be able to physically simulate unusual or non-standard lane markings, including old lane markers with new lane markers painted offset, tar strips, Botts dots, bicycle lanes, construction zone barrels and cones, and emergency flares or emergency vehicles that temporarily close lanes.
- The test facility shall have or be able to physically simulate a variety of road signs (including signs for bus stops, pedestrian crossings, stop signs, speed limit signs, and construction signs).
- The test facility shall have or be able to physically simulate a variety of building facades, alleys, ramps, sidewalks, and roadside furniture (e.g., posts/poles, signs, benches, rails, barriers, fire hydrants, and trash cans) with either temporary or permanent features.
- The test facility shall have or be able to physically simulate loading zones/passenger pickup zones.
- The test facility shall have or be able to physically simulate bus stops/shelters.
- The test facility shall be adequately equipped to store, maintain, refuel, and charge the transit vehicles being tested.

The following requirements are considered optional for all use cases in this technology package:

- The test facility shall have sufficiently heavy-duty pavements and multiple wide lanes that can accommodate large, heavy-duty vehicles, such as transit buses.
- The test facility shall have or be able to physically simulate highways.
- The test facility shall have or be able to physically simulate urban roads.
- The test facility shall have or be able to physically simulate rural roads (including dirt and gravel surfaces).
- The test facility shall have or be able to physically simulate suburban roads.
- The test facility shall have or be able to physically simulate residential roads.
- The test facility shall have or be able to physically simulate curvy roads.
- The test facility shall have or be able to physically simulate uphill/downhill roads.
- The test facility shall have or be able to physically simulate bridges.
- The test facility shall have or be able to physically simulate rail crossings.
- The test facility shall have or be able to physically simulate roundabouts/ traffic circles.

Functionality and Performance

The following requirements are considered mandatory for all use cases in this technology package:

- The test facility shall be able to support testing of nominal bus motions, including starting, slowing and stopping (including crossing lane markers), turning (may include crossing lane markings such as double yellow line), stop and go traffic, steady speed, obeying local traffic laws and traffic control signs/devices, and signaling.
- The test facility shall be able to support testing of stopping for passenger boarding and alighting, including at bus stops with various configurations (e.g., dedicated curbside bus stop, roadside bus stop with and without adjacent parking, station platforms, curb-cut and curved or otherwise anomalous bus stop geometry).
- The test facility shall be able to support testing of operation around fixed objects requiring avoidance, including different objects above, below, to the side, and ahead of the vehicle.
- The test facility shall be able to support testing of operation around moving objects requiring avoidance, including animal mockups, bouncing balls, boxes falling out of a moving vehicle, debris, and other items.
- The test facility shall be able to support testing of operation alongside either real or simulated dynamic road users (e.g., moving vehicles, bicyclists, pedestrians, and other vulnerable road users - VRUs). Elements could

include human-driven vehicles, robotically controlled vehicles and pedestrian mockups (e.g., guided soft targets), and actual humans posing as VRUs.

- The test facility shall be able to support testing of challenging driving situations in mixed traffic, such as left turns with heavy oncoming traffic from opposite and lateral directions.
- The test facility shall be able to support closed-track testing.
- The test facility shall be able to support evaluation of the efficacy of different sensor systems and redundant systems to sense and interpret the vehicle's surrounding environment (e.g., simultaneous use of GPS, lidar, radar, cameras, and other technologies).
- The test facility shall be able to conduct repeatable tests. This requirement may necessitate software control over the environment (e.g., traffic control signals, weather simulation, lighting conditions, etc.).
- The test facility shall be able to develop and conduct pre-trip inspection (validation and diagnostic) procedures to check sensor and actuator functions to ensure they are performing to specifications and assess degradation/ failures over a range of conditions.

The following requirements are considered optional for all use cases in this technology package:

- The test facility shall be able to support testing of navigating with building or chain link fence in close proximity.
- The test facility shall be able to conduct shock and vibration testing on electronic systems that support automation (e.g., in line with the requirements for electrical automotive components in SAE J1211).
- The test facility shall be able to support testing of connected vehicle applications (e.g., signal phase and timing and transit signal priority) with appropriately equipped vehicles or infrastructure.
- The test facility shall be able to support open roads testing.
- The test facility shall be able to support computer simulation testing (e.g., hardware-in-the-loop simulations).
- The test facility shall make available or have a control center that can support monitoring and remote take-over of an automated vehicle.

The following requirement is generally considered optional for use cases in the MOD Service technology package, but is considered mandatory for the Automated First/Last-Mile use case:

- The test facility shall be able to support testing of intermodal trips (i.e., those where a traveler switches form one mode to another), such as bus/rail stations, park-and-ride lots, and transit centers.

The following requirements are generally considered optional for use cases in the MOD Service technology package, but are considered mandatory for the Automated ADA Paratransit use case:

- The test facility shall be able to support testing of loading/unloading and securing/unsecuring passengers with mobility devices.
- The test facility shall be able to support testing of smaller vehicles, such as cutaway vans for paratransit.

The following requirement is generally considered optional for use cases in the MOD Service technology package, but is considered mandatory for the On-Demand Shared Ride use case:

- The test facility shall be able to support testing of flagged service (passengers must indicate intent to board/alight for the bus to stop).

The following requirement is generally considered optional for use cases in the MOD Service technology package, but is considered mandatory for the Automated ADA Paratransit and On-Demand Shared Ride use cases:

- The test facility shall be able to support testing of on-demand service, including path planning, hailing (cellphone app or kiosk) and curb use for pick-ups and drop-offs.

Safety

The following requirement is considered mandatory for all use cases in this technology package:

- The test facility shall draft a safety plan to ensure safety of all participants and plan contingencies in the case of system failure. The safety plan shall include a hazard assessment that identifies mitigations, with reassessment of the mitigations to determine if additional actions need to be taken.

The following requirements are considered optional for all use cases in this technology package:

- The test facility shall be able to support testing of transit vehicles in the event of a traffic control device failure.
- The test facility shall be able to support testing of emergency evacuation procedures (e.g., in the event of a vehicle fire or other disaster on the bus).
- The test facility shall be able to support testing of corner and edge cases as identified in simulations and real-world incidents.
- The test facility shall be able to support testing of operations in the presence of and interactions with first responders (e.g., allowing a fire truck to

overtake the bus or providing appropriate distance when passing a police cruiser on the side of the road).

- The test facility shall be able to support crash-type testing of transit vehicles.
- The test facility shall be able to support testing of transit vehicles with respect to cybersecurity.
- The test facility shall be able to support testing of transit vehicles with respect to physical security (of vehicle occupants).

Environmental Resilience

The following requirements are considered optional for all use cases in this technology package:

- The test facility shall be able to support testing of operations in the presence of electromagnetic interference (EMI) as there will be many sensors and communications equipment on board.
- The test facility shall be able to support testing of operations in the presence of reflective surfaces (e.g., chrome surfaces on trailers, other vehicles, or infrastructure).
- The test facility shall be able to support testing of operations in the presence of various lighting conditions (e.g., solar glare, darkness, external lighting from various types of street lamps at various heights).
- The test facility shall be able to support testing of operations in the transitioning between extreme lighting conditions (e.g., entering or exiting a tunnel on a bright day).
- The test facility shall be able to support testing of operations in the presence of precipitation (e.g., rain, sleet, snow, and hail) to various degrees (e.g., sprinkling, drizzle, and heavy rain).
- The test facility shall be able to support testing of operations in the presence of various ambient temperatures (e.g., hot and cold).
- The test facility shall be able to support testing of operations in the presence of various visibility conditions (e.g., fog, smoke, and haze).
- The test facility shall be able to support testing of operations in the presence of flooding (deep or shallow).
- The test facility shall be able to support testing of operations in the presence of various traction conditions (e.g., in accumulations of ice, snow, slush, and sand).
- The test facility shall be able to support measurement of the impact of environmental conditions on the battery life of electric automated vehicles (e.g., how battery life is affected by extreme heat or cold).

- The test facility shall be able to support testing of operations in the presence of various combinations of environmental conditions (e.g., dark and rainy, glare and snowy).
- The test facility shall be able to support testing of operations in the presence of heavy wind.

Human Factors

The following requirement is considered mandatory for all use cases in this technology package:

- The test facility shall comply with requirements for human subject testing (e.g., Institutional Review Board process).

The following requirements are considered optional for all use cases in this technology package:

- The test facility shall be able to support evaluation of how different infrastructure (e.g., station platforms) and vehicle design (e.g., communicating automated vehicle intent) influences user behavior (e.g., passengers, operators, and other road users).
- The test facility shall be able to support evaluation of the effects of automated service and technologies on passengers, including standees, while the vehicle is in motion.
- The test facility shall be able to support evaluation of the usability and effects of the vehicle interface on passengers (e.g., display screen, buttons, and smartphone/tablet applications).
- The test facility shall be able to support human factors research on automated technologies (e.g., evaluating operators' understanding of these technologies, the effectiveness of driver state monitoring devices and methods designed to return operator's attention to driving, and the quality of the transfer of control back to the operator).
- The test facility shall be able to support human factors research on boarding and alighting processes.
- The test facility shall be able to support testing of recognizing passenger intent (e.g., intent to board or alight) at bus stop locations (both inside and outside the bus).
- The test facility shall be able to support evaluation of how pedestrians and other road users perceive an automated vehicle and how they react to it.
- The test facility shall be able to support collection of information from pre- and post-ride user surveys (e.g., rider comfort, user acceptance, and other perceptions).

The following requirement is generally considered optional for use cases in the MOD Service technology package, but is considered mandatory for the Automated ADA Paratransit use case:

- The test facility shall be able to support evaluation of the vehicle's ability to provide service to users with mobility limitations or other disabilities (e.g., vision, hearing, or cognitive limitations).

Data Collection and Management

The following requirements are considered mandatory for all use cases in this technology package:

- The test facility shall be able to support transmission of data (either wirelessly or through wired connections) collected from devices in vehicles and infrastructure and store it for future research use.
- The test facility shall be able to support collection of information on the technical accuracy and performance of the systems (e.g., false alarms, emergency interventions, and frequency of failure).
- The test facility shall be able to calibrate the test equipment to ensure that it is able to take accurate measurements of test vehicles, environment, and other relevant factors.
- The test facility shall be able to support collection of information on operations (e.g., wait times, communications, vehicle availability, serviceability, and energy use and charging).
- The test facility shall have protocols for developing an effective test plan. Specific use cases could inform the performance requirements, which, in turn, could inform metrics for testing and the test plan.
- The test facility shall have protocols for developing an effective plan for data collection, storage, and use (or reuse).

The following requirements are considered optional for all use cases in this technology package:

- The test facility shall be able to support collection of data from testing in various environmental conditions (e.g., rain, snow), with sensors that can operate in those conditions.
- The test facility shall be able to support wireless transmission of data collected from devices in vehicles and infrastructure for use in real-time applications.
- The test facility shall be able to support remote, real-time monitoring (e.g., visual supervision) of the vehicle and its occupants.

- The test facility shall be able to remotely monitor the functionality of the entire system, including the status of vehicles, the infrastructure, and all relevant sensors.
- The test facility shall be able to provide or create regularly-updated high-definition maps of the site that automated test vehicles can use during operation.

SECTION 7

Automated Bus Rapid Transit

Use Case

The Automated Bus Rapid Transit (BRT) technology package uses a full-size or articulated bus with SAE Level 4 automation. This technology package contains a single use case, called Automated BRT, which is described in the following subsection.

Automated BRT

BRT applies rail transit concepts to bus service to deliver fast and efficient service. These concepts focus on eliminating causes of delay that typically slow regular bus services and may include dedicated lanes, busways, traffic signal priority, off-board fare collection, platforms and enhanced stations. This use case would provide BRT service without a driver on board the vehicle. In addition to operating without a driver, the system would support functions such as lane centering in narrow lanes and precision docking at boarding platforms. This use case may involve bus platooning to dynamically couple two or more buses during periods of demand surges.

Requirements

The following subsections identify mandatory and optional requirements in the six categories of Test Facility Features, Functionality and Performance, Safety, Environmental Resilience, Human Factors, and Data Collection and Management. Requirements that are optional for some use cases but mandatory or not applicable for others are also identified.

Test Facility Features

The following requirements are considered mandatory for the Automated BRT use case:

- The test facility shall have sufficiently heavy-duty pavements and multiple wide lanes that can accommodate large, heavy-duty vehicles, such as transit buses.
- The test facility shall have or be able to physically simulate loading zones/ passenger pickup zones.
- The test facility shall have or be able to physically simulate bus stops/shelters.
- The test facility shall have or be able to physically simulate dedicated bus lanes.

- The test facility shall be adequately equipped to store, maintain, refuel, and charge the transit vehicles being tested.

The following requirements are considered optional for the Automated BRT use case:

- The test facility shall have or be able to physically simulate highways.
- The test facility shall have or be able to physically simulate urban roads.
- The test facility shall have or be able to physically simulate rural roads (including dirt and gravel surfaces).
- The test facility shall have or be able to physically simulate suburban roads.
- The test facility shall have or be able to physically simulate residential roads.
- The test facility shall have or be able to physically simulate curvy roads.
- The test facility shall have or be able to physically simulate uphill/downhill roads.
- The test facility shall have or be able to physically simulate bridges.
- The test facility shall have or be able to physically simulate rail crossings.
- The test facility shall have or be able to physically simulate roundabouts/ traffic circles.
- The test facility shall have or be able to physically simulate intersections (signalized and unsignalized).
- The test facility shall have or be able to physically simulate curbs and boarding platforms with various geometries.
- The test facility shall have or be able to physically simulate worn roads with potholes and degraded lane markings.
- The test facility shall have or be able to physically simulate unusual or non-standard lane markings, including old lane markers with new lane markers painted offset, tar strips, Botts dots, bicycle lanes, construction zone barrels and cones, and emergency flares or emergency vehicles that temporarily close lanes.
- The test facility shall have or be able to physically simulate a variety of road signs (including signs for bus stops, pedestrian crossings, stop signs, speed limit signs, and construction signs).
- The test facility shall have or be able to physically simulate a variety of building facades, alleys, ramps, sidewalks, and roadside furniture (e.g., posts/ poles, signs, benches, rails, barriers, fire hydrants, and trash cans) with either temporary or permanent features.

Functionality and Performance

The following requirements are considered mandatory for the Automated BRT use case:

- The test facility shall be able to support testing of nominal bus motions, including starting, slowing and stopping (including crossing lane markers), turning (may include crossing lane markings such as double yellow line), stop and go traffic, steady speed, obeying local traffic laws and traffic control signs/devices, and signaling.
- The test facility shall be able to support testing of stopping for passenger boarding and alighting, including at bus stops with various configurations (e.g., dedicated curbside bus stop, roadside bus stop with and without adjacent parking, station platforms, curb-cut and curved or otherwise anomalous bus stop geometry).
- The test facility shall be able to support testing of operation around fixed objects requiring avoidance, including different objects above, below, to the side, and ahead of the vehicle.
- The test facility shall be able to support testing of 60' and 80' articulated buses.
- The test facility shall be able to support closed-track testing.
- The test facility shall be able to support evaluation of the efficacy of different sensor systems and redundant systems to sense and interpret the vehicle's surrounding environment (e.g., simultaneous use of GPS, lidar, radar, cameras, and other technologies).
- The test facility shall be able to conduct repeatable tests. This requirement may necessitate software control over the environment (e.g., traffic control signals, weather simulation, lighting conditions, etc.).
- The test facility shall be able to develop and conduct pre-trip inspection (validation and diagnostic) procedures to check sensor and actuator functions to ensure they are performing to specifications and assess degradation/ failures over a range of conditions.

The following requirements are considered optional for the Automated BRT use case:

- The test facility shall be able to support testing of loading/unloading and securing/unsecuring passengers with mobility devices.
- The test facility shall be able to support testing of flagged service (passengers must indicate intent to board/alight for the bus to stop).
- The test facility shall be able to support testing of navigating with building or chain link fence in close proximity.

- The test facility shall be able to conduct shock and vibration testing on electronic systems that support automation (e.g., in line with the requirements for electrical automotive components in SAE J1211).
- The test facility shall be able to support testing of operation around moving objects requiring avoidance, including animal mockups, bouncing balls, boxes falling out of a moving vehicle, debris, and other items.
- The test facility shall be able to support testing of operation alongside either real or simulated dynamic road users (e.g., moving vehicles, bicyclists, pedestrians, and other vulnerable road users - VRUs). Elements could include human-driven vehicles, robotically controlled vehicles and pedestrian mockups (e.g., guided soft targets), and actual humans posing as VRUs.
- The test facility shall be able to support testing of challenging driving situations in mixed traffic, such as left turns with heavy oncoming traffic from opposite and lateral directions.
- The test facility shall be able to support testing of intermodal trips (i.e., those where a traveler switches form one mode to another), such as bus/rail stations, park-and-ride lots, and transit centers.
- The test facility shall be able to support testing of connected vehicle applications (e.g., signal phase and timing and transit signal priority) with appropriately equipped vehicles or infrastructure.
- The test facility shall be able to support testing of 40' or smaller transit buses.
- The test facility shall be able to support open roads testing.
- The test facility shall be able to support computer simulation testing (e.g., hardware-in-the-loop simulations).
- The test facility shall make available or have a control center that can support monitoring and remote take-over of an automated vehicle.

Safety

The following requirement is considered mandatory for the Automated BRT use case:

- The test facility shall draft a safety plan to ensure safety of all participants and plan contingencies in the case of system failure. The safety plan shall include a hazard assessment that identifies mitigations, with reassessment of the mitigations to determine if additional actions need to be taken.

The following requirements are considered optional for the Automated BRT use case:

- The test facility shall be able to support testing of transit vehicles in the event of a traffic control device failure.

- The test facility shall be able to support testing of emergency evacuation procedures (e.g., in the event of a vehicle fire or other disaster on the bus).
- The test facility shall be able to support testing of corner and edge cases as identified in simulations and real-world incidents.
- The test facility shall be able to support testing of operations in the presence of and interactions with first responders (e.g., allowing a fire truck to overtake the bus or providing appropriate distance when passing a police cruiser on the side of the road).
- The test facility shall be able to support crash-type testing of transit vehicles.
- The test facility shall be able to support testing of transit vehicles with respect to cybersecurity.
- The test facility shall be able to support testing of transit vehicles with respect to physical security (of vehicle occupants).

Environmental Resilience

The following requirements are considered optional for the Automated BRT use case:

- The test facility shall be able to support testing of operations in the presence of electromagnetic interference (EMI) as there will be many sensors and communications equipment on board.
- The test facility shall be able to support testing of operations in the presence of reflective surfaces (e.g., chrome surfaces on trailers, other vehicles, or infrastructure).
- The test facility shall be able to support testing of operations in the presence of various lighting conditions (e.g., solar glare, darkness, external lighting from various types of street lamps at various heights).
- The test facility shall be able to support testing of operations in the transitioning between extreme lighting conditions (e.g., entering or exiting a tunnel on a bright day).
- The test facility shall be able to support testing of operations in the presence of precipitation (e.g., rain, sleet, snow, and hail) to various degrees (e.g., sprinkling, drizzle, and heavy rain).
- The test facility shall be able to support testing of operations in the presence of various ambient temperatures (e.g., hot and cold).
- The test facility shall be able to support testing of operations in the presence of various visibility conditions (e.g., fog, smoke, and haze).
- The test facility shall be able to support testing of operations in the presence of flooding (deep or shallow).

- The test facility shall be able to support testing of operations in the presence of various traction conditions (e.g., in accumulations of ice, snow, slush, and sand).
- The test facility shall be able to support measurement of the impact of environmental conditions on the battery life of electric automated vehicles (e.g., how battery life is affected by extreme heat or cold).
- The test facility shall be able to support testing of operations in the presence of various combinations of environmental conditions (e.g., dark and rainy, glare and snowy).
- The test facility shall be able to support testing of operations in the presence of heavy wind.

Human Factors

The following requirement is considered mandatory for the Automated BRT use case:

- The test facility shall comply with requirements for human subject testing (e.g., Institutional Review Board process).

The following requirements are considered optional for the Automated BRT use case:

- The test facility shall be able to support evaluation of how different infrastructure (e.g., station platforms) and vehicle design (e.g., communicating automated vehicle intent) influences user behavior (e.g., passengers, operators, and other road users).
- The test facility shall be able to support evaluation of the vehicle's ability to provide service to users with mobility limitations or other disabilities (e.g., vision, hearing, or cognitive limitations).
- The test facility shall be able to support evaluation of the effects of automated service and technologies on passengers, including standees, while the vehicle is in motion.
- The test facility shall be able to support evaluation of the usability and effects of the vehicle interface on passengers (e.g., display screen, buttons, and smartphone/tablet applications).
- The test facility shall be able to support human factors research on boarding and alighting processes.
- The test facility shall be able to support testing of recognizing passenger intent (e.g., intent to board or alight) at bus stop locations (both inside and outside the bus).
- The test facility shall be able to support evaluation of how pedestrians and other road users perceive an automated vehicle and how they react to it.

- The test facility shall be able to support collection of information from pre- and post-ride user surveys (e.g., rider comfort, user acceptance, and other perceptions).

Data Collection and Management

The following requirements are considered mandatory for the Automated BRT use case:

- The test facility shall be able to support transmission of data (either wirelessly or through wired connections) collected from devices in vehicles and infrastructure and store it for future research use.
- The test facility shall be able to support collection of information on the technical accuracy and performance of the systems (e.g., false alarms, emergency interventions, and frequency of failure).
- The test facility shall be able to calibrate the test equipment to ensure that it is able to take accurate measurements of test vehicles, environment, and other relevant factors.
- The test facility shall be able to support collection of information on operations (e.g., wait times, communications, vehicle availability, serviceability, and energy use and charging).
- The test facility shall have protocols for developing an effective test plan. Specific use cases could inform the performance requirements, which, in turn, could inform metrics for testing and the test plan.
- The test facility shall have protocols for developing an effective plan for data collection, storage, and use (or reuse).

The following requirements are considered optional for the Automated BRT use case:

- The test facility shall be able to support collection of data from testing in various environmental conditions (e.g., rain, snow), with sensors that can operate in those conditions.
- The test facility shall be able to support wireless transmission of data collected from devices in vehicles and infrastructure for use in real-time applications.
- The test facility shall be able to support remote, real-time monitoring (e.g., visual supervision) of the vehicle and its occupants.
- The test facility shall be able to remotely monitor the functionality of the entire system, including the status of vehicles, the infrastructure, and all relevant sensors.
- The test facility shall be able to provide or create regularly-updated high-definition maps of the site that automated test vehicles can use during operation.

SECTION

8

Stakeholder Implications

A variety of organizations (e.g., original equipment/bus manufacturers, integrators, test facility operators, academicians, transit agencies, and representatives from local, state, and federal governments) may be interested in performing or otherwise participating in automated transit bus tests and pilot demonstrations to assess the ability of these vehicles to meet performance, safety, and economic goals. To conduct testing and evaluation, such projects will need test facilities that meet various requirements in terms of infrastructure, equipment, and personnel.

This document may be used as a guide or resource for identifying requirements and considerations for testing the capabilities of automated transit buses. The document may have multiple audiences and serve a variety of purposes. For instance, the requirements in this document may represent potential considerations for those who may wish to conduct automated transit bus testing or those issuing a request for proposals (RFP) to solicit interest in conducting a pilot demonstration or deployment. Transit agencies or other organizations may consider the requirements listed in the document to help guide plans for their own pilots and demonstrations. Other industry representatives may find the document useful in terms of thinking about how to test, what to test, and what to consider in terms of capabilities for future products. Test facilities may use the document to help in terms of identifying missing elements of current facilities and planning for development of additional test capabilities.

A few requirements are considered mandatory for most or all of the technology packages and use cases considered in this report. These common requirements relate to a test facility's capacity to:

- Support basic operation and testing of automated transit buses
- Ensure both the safety and privacy of all participants
- Collect, manage, store, and use data from testing activities

Outside of the common mandatory requirements, most requirements listed in this report are only mandatory for certain technology packages and use cases (e.g., physically simulating a bus yard for Maintenance, Yard, Parking Operations) or they are considered optional depending on the specific goals of a test or demonstration.

The requirements listed in this report are intentionally left as broad categories to provide flexibility in defining the operating domain of the automated vehicle and thus the testing program. Requirements for testing automated transit buses

for actual demonstration pilots and deployments should contain specific and measurable statements that are precise and quantifiable. Depending on the organization conducting the testing, product being considered, or use case being tested, users may identify additional requirements beyond those included in this document. Users may opt to take requirements from this document, adapt them, or add additional requirements as needed.

APPENDIX

A

Stakeholder Outreach

The following sections list phone interviews and site visits that were undertaken to inform the development of requirements for test facilities when hosting various types of testing for automated transit buses.

Phone Interviews

Federal Agencies

- FTA
- NHTSA (Vehicle Research and Test Center)
- FMCSA
- FHWA

University Collaborators

- University of Nevada – Reno (Nevada)
- UC Berkeley, PATH (California)

Transit Agencies and Operators

- Hillsborough Area Rapid Transit (Tampa, Florida)
- Lane Transit District (Eugene, Oregon)
- Kansas City Area Transportation Authority (Kansas City, Missouri/Kansas)
- Jacksonville Transportation Authority (Jacksonville, Florida)
- MetroLINK (Quad Cities, Iowa/Illinois)
- Pierce Transit (with Jerry Lutin, Consultant) (Pierce County, Washington)
- Access Services (Los Angeles, California)

Test Facilities

- Minnesota Road Research Facility – MnROAD (Otsego, Minnesota)
- American Center for Mobility (Willow Run, Michigan)
- Transportation Research Center (East Liberty, Ohio)
- Virginia Tech (VTTI)/Smart Road (Blacksburg, Virginia)
- M-City (UofM) (Ann Arbor, Michigan)
- Suntrax (Auburndale, Florida)

Original Equipment Manufacturers

- BYD
- New Flyer
- Gillig

Site Visits

- Larson Transportation Institute/Altoona Test Facility/Pennsylvania State University (Pennsylvania)
- Virginia Tech Transportation Institute/Smart Road with Blacksburg Transit (Virginia)
- Jacksonville Transportation Authority (Florida)

APPENDIX

B

Requirements Matrices by Requirement Category

This appendix contains matrices for the six requirement categories considered in this document. Within each matrix, the requirements are classified as mandatory (M), optional (O), or not applicable (N/A) for each use case within the technology package. The matrix is divided into six separate tables, one for each category (Test Facility Features, Functionality and Performance, Safety, Environmental Resilience, Human Factors, and Data Collection and Management).

Test Facility Features

Requirement	Transit Bus Advanced Driver Assistance Systems						Automated Shuttles		Maintenance/ Yard/Parking		Mobility-on-Demand Service			BRT
	Smooth Acceleration and Deceleration	Automatic Emergency Braking and Pedestrian Collision Avoidance	Curb Avoidance	Precision Docking	Narrow Lane Shoulder Operations	Platooning	Circulator Bus Service	Feeder Bus Service	Precision Movement for Fueling, Service Bays, and Bus Wash	Automated Parking and Recall	Automated First/Last-Mile	Automated ADA Paratransit	On-Demand Shared Ride	Automated Bus Rapid Transit
The test facility shall have sufficiently heavy-duty pavements and multiple wide lanes that can accommodate large, heavy-duty vehicles, such as transit buses.	M	M	M	M	M	M	O	O	M	M	O	O	O	M
The test facility shall have or be able to physically simulate highways.	O	O	N/A	N/A	O	O	N/A	O	N/A	N/A	O	O	O	O
The test facility shall have or be able to physically simulate urban roads.	O	O	O	N/A	O	O	O	O	N/A	N/A	O	O	O	O
The test facility shall have or be able to physically simulate rural roads (including dirt and gravel surfaces).	O	O	N/A	N/A	O	O	N/A	O	N/A	N/A	O	O	O	O
The test facility shall have or be able to physically simulate suburban roads.	O	O	O	N/A	O	O	O	O	N/A	N/A	O	O	O	O
The test facility shall have or be able to physically simulate residential roads.	O	O	O	N/A	N/A	O	O	O	N/A	N/A	O	O	O	O
The test facility shall have or be able to physically simulate curvy roads.	O	O	O	N/A	O	O	O	O	N/A	N/A	O	O	O	O
The test facility shall have or be able to physically simulate uphill/downhill roads.	O	O	O	N/A	O	O	O	O	N/A	N/A	O	O	O	O
The test facility shall have or be able to physically simulate bridges.	O	O	O	N/A	O	O	O	O	N/A	N/A	O	O	O	O
The test facility shall have or be able to physically simulate rail crossings.	O	O	O	N/A	O	O	O	O	N/A	N/A	O	O	O	O
The test facility shall have or be able to physically simulate roundabouts/ traffic circles.	O	O	O	N/A	N/A	O	O	O	N/A	N/A	O	O	O	O
The test facility shall have or be able to physically simulate intersections (signalized and unsignalized).	O	O	O	N/A	N/A	O	O	O	N/A	N/A	M	M	M	O

Requirement	Transit Bus Advanced Driver Assistance Systems						Automated Shuttles		Maintenance/ Yard/Parking		Mobility-on-Demand Service			BRT
	Smooth Acceleration and Deceleration	Automatic Emergency Braking and Pedestrian Collision Avoidance	Curb Avoidance	Precision Docking	Narrow Lane Shoulder Operations	Platooning	Circulator Bus Service	Feeder Bus Service	Precision Movement for Fueling, Service Bays, and Bus Wash	Automated Parking and Recall	Automated First/Last-Mile	Automated ADA Paratransit	On-Demand Shared Ride	Automated Bus Rapid Transit
The test facility shall have or be able to physically simulate curbs and boarding platforms with various geometries.	O	O	O	M	O	O	O	O	O	O	M	M	M	O
The test facility shall have or be able to physically simulate worn roads with potholes and degraded lane markings.	O	O	O	O	O	O	O	O	O	O	M	M	M	O
The test facility shall have or be able to physically simulate unusual or non-standard lane markings, including old lane markers with new lane markers painted offset, tar strips, Botts dots, bicycle lanes, construction zone barrels and cones, and emergency flares or emergency vehicles that temporarily close lanes.	O	O	O	O	O	O	O	O	O	O	M	M	M	O
The test facility shall have or be able to physically simulate a variety of road signs (including signs for bus stops, pedestrian crossings, stop signs, speed limit signs, and construction signs).	O	O	O	O	O	O	O	O	N/A	N/A	M	M	M	O
The test facility shall have or be able to physically simulate a variety of building facades, alleys, ramps, sidewalks, and roadside furniture (e.g., posts/poles, signs, benches, rails, barriers, fire hydrants, and trash cans) with either temporary or permanent features.	O	O	O	O	O	O	O	O	O	O	M	M	M	O
The test facility shall have or be able to physically simulate loading zones/ passenger pickup zones.	M	M	O	M	N/A	N/A	M	M	N/A	N/A	M	M	M	M
The test facility shall have or be able to physically simulate bus stops/ shelters.	M	M	O	M	N/A	N/A	M	M	N/A	N/A	M	M	M	M

Requirement	Transit Bus Advanced Driver Assistance Systems						Automated Shuttles		Maintenance/ Yard/Parking		Mobility-on-Demand Service			BRT
	Smooth Acceleration and Deceleration	Automatic Emergency Braking and Pedestrian Collision Avoidance	Curb Avoidance	Precision Docking	Narrow Lane Shoulder Operations	Platooning	Circulator Bus Service	Feeder Bus Service	Precision Movement for Fueling, Service Bays, and Bus Wash	Automated Parking and Recall	Automated First/Last-Mile	Automated ADA Paratransit	On-Demand Shared Ride	Automated Bus Rapid Transit
The test facility shall have or be able to physically simulate dedicated bus lanes.	O	O	O	N/A	O	O	O	O	N/A	N/A	N/A	N/A	N/A	M
The test facility shall have or be able to physically simulate a bus yard.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	M	M	N/A	N/A	N/A	N/A
The test facility shall have or be able to physically simulate a bus maintenance and service facility.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	M	O	N/A	N/A	N/A	N/A
The test facility shall have or be able to physically simulate refueling and electrical charging areas.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	M	O	N/A	N/A	N/A	N/A
The test facility shall be adequately equipped to store, maintain, refuel, and charge the transit vehicles being tested.	M	M	M	M	M	M	M	M	M	M	M	M	M	M

Functionality and Performance

Requirement	Transit Bus Advanced Driver Assistance Systems						Automated Shuttles		Maintenance/ Yard/Parking		Mobility-on-Demand Service			BRT
	Smooth Acceleration and Deceleration	Automatic Emergency Braking and Pedestrian Collision Avoidance	Curb Avoidance	Precision Docking	Narrow Lane Shoulder Operations	Platooning	Circulator Bus Service	Feeder Bus Service	Precision Movement for Fueling, Service Bays, and Bus Wash	Automated Parking and Recall	Automated First/Last-Mile	Automated ADA Paratransit	On-Demand Shared Ride	Automated Bus Rapid Transit
The test facility shall be able to support testing of nominal bus motions, including starting, slowing and stopping (including crossing lane markers), turning (may include crossing lane markings such as double yellow line), stop and go traffic, steady speed, obeying local traffic laws and traffic control signs/devices, and signaling.	M	M	M	M	M	M	M	M	M	M	M	M	M	M
The test facility shall be able to support testing of stopping for passenger boarding and alighting, including at bus stops with various configurations (e.g., dedicated curbside bus stop, roadside bus stop with and without adjacent parking, station platforms, curb-cut and curved or otherwise anomalous bus stop geometry).	O	O	O	M	O	O	M	M	N/A	N/A	M	M	M	M
The test facility shall be able to support testing of loading/unloading and securing/unsecuring passengers with mobility devices.	O	O	O	O	N/A	N/A	O	O	N/A	N/A	O	M	O	O
The test facility shall be able to support testing of flagged service (passengers must indicate intent to board/alight for the bus to stop).	O	O	O	O	N/A	N/A	O	O	N/A	N/A	O	O	M	O
The test facility shall be able to support testing of bus yard maneuvers, including pulling in/out/docking in the bus barn, fueling station, and storage facilities.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	M	O	N/A	N/A	N/A	N/A
The test facility shall be able to support testing of navigating through the yard/barn to and through the maintenance station (e.g., lift arms and pit) and bus washing station.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	O	M	N/A	N/A	N/A	N/A
The test facility shall be able to support testing of navigating through the yard/barn to the yard exit.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	O	M	N/A	N/A	N/A	N/A

Requirement	Transit Bus Advanced Driver Assistance Systems						Automated Shuttles		Maintenance/ Yard/Parking		Mobility-on-Demand Service			BRT
	Smooth Acceleration and Deceleration	Automatic Emergency Braking and Pedestrian Collision Avoidance	Curb Avoidance	Precision Docking	Narrow Lane Shoulder Operations	Platooning	Circulator Bus Service	Feeder Bus Service	Precision Movement for Fueling, Service Bays, and Bus Wash	Automated Parking and Recall	Automated First/Last-Mile	Automated ADA Paratransit	On-Demand Shared Ride	Automated Bus Rapid Transit
The test facility shall be able to support testing of navigating with building or chain link fence in close proximity.	O	O	O	O	O	O	O	O	O	O	O	O	O	O
The test facility shall be able to conduct shock and vibration testing on electronic systems that support automation (e.g., in line with the requirements for electrical automotive components in SAE J1211).	O	O	O	O	O	O	O	O	O	O	O	O	O	O
The test facility shall be able to support testing of operation around fixed objects requiring avoidance, including different objects above, below, to the side, and ahead of the vehicle.	N/A	O	M	O	O	O	M	M	O	O	M	M	M	M
The test facility shall be able to support testing of operation around moving objects requiring avoidance, including animal mockups, bouncing balls, boxes falling out of a moving vehicle, debris, and other items.	O	M	O	O	O	O	M	M	N/A	N/A	M	M	M	O
The test facility shall be able to support testing of operation alongside either real or simulated dynamic road users (e.g., moving vehicles, bicyclists, pedestrians, and other vulnerable road users - VRUs). Elements could include human-driven vehicles, robotically controlled vehicles and pedestrian mockups (e.g., guided soft targets), and actual humans posing as VRUs.	O	M	O	O	O	O	M	M	N/A	N/A	M	M	M	O
The test facility shall be able to support testing of challenging driving situations in mixed traffic, such as left turns with heavy oncoming traffic from opposite and lateral directions.	O	O	O	O	O	O	O	O	N/A	N/A	M	M	M	O

Requirement	Transit Bus Advanced Driver Assistance Systems						Automated Shuttles		Maintenance/ Yard/Parking		Mobility-on-Demand Service			BRT
	Smooth Acceleration and Deceleration	Automatic Emergency Braking and Pedestrian Collision Avoidance	Curb Avoidance	Precision Docking	Narrow Lane Shoulder Operations	Platooning	Circulator Bus Service	Feeder Bus Service	Precision Movement for Fueling, Service Bays, and Bus Wash	Automated Parking and Recall	Automated First/Last-Mile	Automated ADA Paratransit	On-Demand Shared Ride	Automated Bus Rapid Transit
The test facility shall be able to support testing of intermodal trips (i.e., those where a traveler switches form one mode to another), such as bus/ rail stations, park-and-ride lots, and transit centers.	O	O	O	O	O	O	O	M	N/A	N/A	M	O	O	O
The test facility shall be able to support testing of on-demand service, including path planning, hailing (cellphone app or kiosk) and curb use for pick-ups and drop-offs.	N/A	N/A	N/A	N/A	N/A	N/A	O	O	N/A	N/A	O	M	M	N/A
The test facility shall be able to support testing of connected vehicle applications (e.g., signal phase and timing and transit signal priority) with appropriately equipped vehicles or infrastructure.	M	O	O	O	O	M	O	O	O	O	O	O	O	O
The test facility shall be able to support testing of smaller vehicles, such as cutaway vans for paratransit.	N/A	N/A	N/A	N/A	N/A	N/A	O	O	O	O	O	M	O	N/A
The test facility shall be able to support testing of 40' or smaller transit buses.	O	O	O	O	O	O	O	O	O	O	N/A	N/A	N/A	O
The test facility shall be able to support testing of 60' and 80' articulated buses.	O	O	O	O	O	O	N/A	N/A	O	O	N/A	N/A	N/A	M
The test facility shall be able to support closed-track testing.	M	M	M	M	M	M	M	M	M	M	M	M	M	M
The test facility shall be able to support open roads testing.	O	O	O	O	O	O	O	O	N/A	N/A	O	O	O	O
The test facility shall be able to support computer simulation testing (e.g., hardware-in-the-loop simulations).	O	O	O	O	O	O	O	O	O	O	O	O	O	O

Requirement	Transit Bus Advanced Driver Assistance Systems						Automated Shuttles		Maintenance/ Yard/Parking		Mobility-on-Demand Service			BRT
	Smooth Acceleration and Deceleration	Automatic Emergency Braking and Pedestrian Collision Avoidance	Curb Avoidance	Precision Docking	Narrow Lane Shoulder Operations	Platooning	Circulator Bus Service	Feeder Bus Service	Precision Movement for Fueling, Service Bays, and Bus Wash	Automated Parking and Recall	Automated First/Last-Mile	Automated ADA Paratransit	On-Demand Shared Ride	Automated Bus Rapid Transit
The test facility shall be able to support evaluation of the efficacy of different sensor systems and redundant systems to sense and interpret the vehicle's surrounding environment (e.g., simultaneous use of GPS, lidar, radar, cameras, and other technologies).	M	M	M	M	M	M	M	M	M	M	M	M	M	M
The test facility shall be able to conduct repeatable tests. This requirement may necessitate software control over the environment (e.g., traffic control signals, weather simulation, lighting conditions, etc.).	M	M	M	M	M	M	M	M	M	M	M	M	M	M
The test facility shall be able to develop and conduct pre-trip inspection (validation and diagnostic) procedures to check sensor and actuator functions to ensure they are performing to specifications and assess degradation/failures over a range of conditions.	M	M	M	M	M	M	M	M	M	M	M	M	M	M
The test facility shall make available or have a control center that can support monitoring and remote take-over of an automated vehicle.	O	O	O	O	O	O	O	O	O	O	O	O	O	O

Safety

Requirement	Transit Bus Advanced Driver Assistance Systems						Automated Shuttles		Maintenance/ Yard/Parking		Mobility-on-Demand Service			BRT
	Smooth Acceleration and Deceleration	Automatic Emergency Braking and Pedestrian Collision Avoidance	Curb Avoidance	Precision Docking	Narrow Lane Shoulder Operations	Platooning	Circulator Bus Service	Feeder Bus Service	Precision Movement for Fueling, Service Bays, and Bus Wash	Automated Parking and Recall	Automated First/Last-Mile	Automated ADA Paratransit	On-Demand Shared Ride	Automated Bus Rapid Transit
The test facility shall draft a safety plan to ensure safety of all participants and plan contingencies in the case of system failure. The safety plan shall include a hazard assessment that identifies mitigations, with reassessment of the mitigations to determine if additional actions need to be taken.	M	M	M	M	M	M	M	M	M	M	M	M	M	M
The test facility shall be able to support testing of transit vehicles in the event of a traffic control device failure.	O	O	O	O	O	O	O	O	N/A	N/A	O	O	O	O
The test facility shall be able to support testing of emergency evacuation procedures (e.g., in the event of a vehicle fire or other disaster on the bus).	O	O	O	O	O	O	O	O	N/A	N/A	O	O	O	O
The test facility shall be able to support testing of corner and edge cases as identified in simulations and real-world incidents.	O	O	O	O	O	O	O	O	N/A	N/A	O	O	O	O
The test facility shall be able to support testing of operations in the presence of and interactions with first responders (e.g., allowing a fire truck to overtake the bus or providing appropriate distance when passing a police cruiser on the side of the road).	O	O	O	O	O	O	O	O	N/A	N/A	O	O	O	O
The test facility shall be able to support crash-type testing of transit vehicles.	O	O	O	O	O	O	O	O	N/A	N/A	O	O	O	O
The test facility shall be able to support testing of transit vehicles with respect to cybersecurity.	O	O	O	O	O	O	O	O	O	O	O	O	O	O
The test facility shall be able to support testing of transit vehicles with respect to physical security (of vehicle occupants).	O	O	O	O	O	O	O	O	N/A	N/A	O	O	O	O

Environmental Resilience

Requirement	Transit Bus Advanced Driver Assistance Systems						Automated Shuttles		Maintenance/ Yard/Parking		Mobility-on-Demand Service			BRT
	Smooth Acceleration and Deceleration	Automatic Emergency Braking and Pedestrian Collision Avoidance	Curb Avoidance	Precision Docking	Narrow Lane Shoulder Operations	Platooning	Circulator Bus Service	Feeder Bus Service	Precision Movement for Fueling, Service Bays, and Bus Wash	Automated Parking and Recall	Automated First/Last-Mile	Automated ADA Paratransit	On-Demand Shared Ride	Automated Bus Rapid Transit
The test facility shall be able to support testing of operations in the presence of electromagnetic interference (EMI) as there will be many sensors and communications equipment on board.	O	O	O	O	O	O	O	O	O	O	O	O	O	O
The test facility shall be able to support testing of operations in the presence of reflective surfaces (e.g., chrome surfaces on trailers, other vehicles, or infrastructure).	O	O	O	O	O	O	O	O	O	O	O	O	O	O
The test facility shall be able to support testing of operations in the presence of various lighting conditions (e.g., solar glare, darkness, external lighting from various types of street lamps at various heights).	O	O	O	O	O	O	O	O	O	O	O	O	O	O
The test facility shall be able to support testing of operations in the transitioning between extreme lighting conditions (e.g., entering or exiting a tunnel on a bright day).	O	O	O	O	O	O	O	O	O	O	O	O	O	O
The test facility shall be able to support testing of operations in the presence of precipitation (e.g., rain, sleet, snow, and hail) to various degrees (e.g., sprinkling, drizzle, and heavy rain).	O	O	O	O	O	O	O	O	O	O	O	O	O	O
The test facility shall be able to support testing of operations in the presence of various ambient temperatures (e.g., hot and cold).	O	O	O	O	O	O	O	O	O	O	O	O	O	O
The test facility shall be able to support testing of operations in the presence of various visibility conditions (e.g., fog, smoke, and haze).	O	O	O	O	O	O	O	O	O	O	O	O	O	O
The test facility shall be able to support testing of operations in the presence of flooding (deep or shallow).	O	O	O	O	O	O	O	O	O	O	O	O	O	O

Requirement	Transit Bus Advanced Driver Assistance Systems						Automated Shuttles		Maintenance/ Yard/Parking		Mobility-on-Demand Service			BRT
	Smooth Acceleration and Deceleration	Automatic Emergency Braking and Pedestrian Collision Avoidance	Curb Avoidance	Precision Docking	Narrow Lane Shoulder Operations	Platooning	Circulator Bus Service	Feeder Bus Service	Precision Movement for Fueling, Service Bays, and Bus Wash	Automated Parking and Recall	Automated First/Last-Mile	Automated ADA Paratransit	On-Demand Shared Ride	Automated Bus Rapid Transit
The test facility shall be able to support testing of operations in the presence of various traction conditions (e.g., in accumulations of ice, snow, slush, and sand).	O	O	O	O	O	O	O	O	O	O	O	O	O	O
The test facility shall be able to support measurement of the impact of environmental conditions on the battery life of electric automated vehicles (e.g., how battery life is affected by extreme heat or cold).	O	O	O	O	O	O	O	O	O	O	O	O	O	O
The test facility shall be able to support testing of operations in the presence of various combinations of environmental conditions (e.g., dark and rainy, glare and snowy).	O	O	O	O	O	O	O	O	O	O	O	O	O	O
The test facility shall be able to support testing of operations in the presence of heavy wind.	O	O	O	O	O	O	O	O	O	O	O	O	O	O

Human Factors

Requirement	Transit Bus Advanced Driver Assistance Systems						Automated Shuttles		Maintenance/ Yard/Parking		Mobility-on-Demand Service			BRT
	Smooth Acceleration and Deceleration	Automatic Emergency Braking and Pedestrian Collision Avoidance	Curb Avoidance	Precision Docking	Narrow Lane Shoulder Operations	Platooning	Circulator Bus Service	Feeder Bus Service	Precision Movement for Fueling, Service Bays, and Bus Wash	Automated Parking and Recall	Automated First/Last-Mile	Automated ADA Paratransit	On-Demand Shared Ride	Automated Bus Rapid Transit
The test facility shall be able to support evaluation of how different infrastructure (e.g., station platforms) and vehicle design (e.g., communicating automated vehicle intent) influences user behavior (e.g., passengers, operators, and other road users).	O	O	O	O	O	O	O	O	O	O	O	O	O	O
The test facility shall be able to support evaluation of the vehicle's ability to provide service to users with mobility limitations or other disabilities (e.g., vision, hearing, or cognitive limitations).	O	O	O	O	O	O	O	O	N/A	N/A	O	M	O	O
The test facility shall be able to support evaluation of the effects of automated service and technologies on passengers, including standees, while the vehicle is in motion.	O	O	O	O	O	O	O	O	N/A	N/A	O	O	O	O
The test facility shall be able to support evaluation of the usability and effects of the vehicle interface on passengers (e.g., display screen, buttons, and smartphone/tablet applications).	O	O	O	O	O	O	O	O	N/A	N/A	O	O	O	O
The test facility shall be able to support human factors research on automated technologies (e.g., evaluating operators' understanding of these technologies, the effectiveness of driver state monitoring devices and methods designed to return operator's attention to driving, and the quality of the transfer of control back to the operator).	O	O	O	O	O	O	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
The test facility shall be able to support human factors research on boarding and alighting processes.	O	N/A	N/A	O	N/A	N/A	O	O	N/A	N/A	O	O	O	O

Requirement	Transit Bus Advanced Driver Assistance Systems						Automated Shuttles		Maintenance/ Yard/Parking		Mobility-on-Demand Service			BRT
	Smooth Acceleration and Deceleration	Automatic Emergency Braking and Pedestrian Collision Avoidance	Curb Avoidance	Precision Docking	Narrow Lane Shoulder Operations	Platooning	Circulator Bus Service	Feeder Bus Service	Precision Movement for Fueling, Service Bays, and Bus Wash	Automated Parking and Recall	Automated First/Last-Mile	Automated ADA Paratransit	On-Demand Shared Ride	Automated Bus Rapid Transit
The test facility shall be able to support testing of recognizing passenger intent (e.g., intent to board or alight) at bus stop locations (both inside and outside the bus).	O	O	N/A	O	N/A	N/A	O	O	N/A	N/A	O	O	O	O
The test facility shall be able to support evaluation of how pedestrians and other road users perceive an automated vehicle and how they react to it.	O	O	O	O	O	O	O	O	N/A	N/A	O	O	O	O
The test facility shall be able to support collection of information from pre- and post-ride user surveys (e.g., rider comfort, user acceptance, and other perceptions).	O	O	O	O	O	O	O	O	N/A	N/A	O	O	O	O
The test facility shall comply with requirements for human subject testing (e.g., Institutional Review Board process).	M	M	M	M	M	M	M	M	M	M	M	M	M	M

Data Collection and Management

Requirement	Transit Bus Advanced Driver Assistance Systems						Automated Shuttles		Maintenance/ Yard/Parking		Mobility-on-Demand Service			BRT
	Smooth Acceleration and Deceleration	Automatic Emergency Braking and Pedestrian Collision Avoidance	Curb Avoidance	Precision Docking	Narrow Lane Shoulder Operations	Platooning	Circulator Bus Service	Feeder Bus Service	Precision Movement for Fueling, Service Bays, and Bus Wash	Automated Parking and Recall	Automated First/Last-Mile	Automated ADA Paratransit	On-Demand Shared Ride	Automated Bus Rapid Transit
The test facility shall be able to support collection of data from testing in various environmental conditions (e.g., rain, snow), with sensors that can operate in those conditions.	O	O	O	O	O	O	O	O	O	O	O	O	O	O
The test facility shall be able to support transmission of data (either wirelessly or through wired connections) collected from devices in vehicles and infrastructure and store it for future research use.	M	M	M	M	M	M	M	M	M	M	M	M	M	M
The test facility shall be able to support wireless transmission of data collected from devices in vehicles and infrastructure for use in real-time applications.	O	O	O	O	O	O	O	O	O	O	O	O	O	O
The test facility shall be able to support remote, real-time monitoring (e.g., visual supervision) of the vehicle and its occupants.	O	O	O	O	O	O	O	O	O	O	O	O	O	O
The test facility shall be able to support collection of information on the technical accuracy and performance of the systems (e.g., false alarms, emergency interventions, and frequency of failure).	M	M	M	M	M	M	M	M	M	M	M	M	M	M
The test facility shall be able to remotely monitor the functionality of the entire system, including the status of vehicles, the infrastructure, and all relevant sensors.	O	O	O	O	O	O	O	O	O	O	O	O	O	O
The test facility shall be able to calibrate the test equipment to ensure that it is able to take accurate measurements of test vehicles, environment, and other relevant factors.	M	M	M	M	M	M	M	M	M	M	M	M	M	M

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The test facility shall be able to provide or create regularly-updated high-definition maps of the site that automated test vehicles can use during operation.	O	O	O	O	O	O	O	O	O	O	O	O	O	O
The test facility shall be able to support collection of information on operations (e.g., wait times, communications, vehicle availability, serviceability, and energy use and charging).	M	M	M	M	M	M	M	M	M	M	M	M	M	M
The test facility shall have protocols for developing an effective test plan. Specific use cases could inform the performance requirements, which, in turn, could inform metrics for testing and the test plan.	M	M	M	M	M	M	M	M	M	M	M	M	M	M
The test facility shall have protocols for developing an effective plan for data collection, storage, and use (or reuse).	M	M	M	M	M	M	M	M	M	M	M	M	M	M

U.S. Department of Transportation

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