Roadway Automated Driving Systems Integration

Concept of Operations for Transportation Agencies: Version 1

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7. Author(s) Deepak Gopalakrishna, Rachel Ostroff, Sarah Whitlock (ICF); Dean Deeter, Jeremy Schroeder (Athey Creek); Denny Stephens (Vital Assurance); Laurie Matkowski, Carrie Long, Ashwini Karanth, Ryan Rice (Gannet Fleming); Beverly Kuhn, Bob Brydia (Texas A&M Transportation Institute)	8. Performing Organization Report No.
9. Performing Organization Name and Address ICF Incorporated, LLC, 9300 Lee Highway, Fairfax, VA 22031 Gannett Fleming, 1801 Market Street, Suite 2600 Philadelphia, PA 19103 TTI, 3135 TAMU College Station, TX 77843-3135 Athey Creek, 2610 Lexington Terrace West Linn, OR 97068	10. Work Unit No. 11. Contract or Grant No.
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16. Abstract
This document presents the concept of operations for roadway automated driving systems (ADS) integration targeted at transportation agencies in the United States. Developed by the Federal Highway Administration, the purpose of this document is to define likely ADS uses and how they can safely, equitably, and efficiently be integrated with the overall transportation system. The document describes how ADS technology could manifest on public roads in a consistent manner and identifies the interactions between the physical, digital, and operational layers of the transportation system and ADS-equipped vehicles and the resulting needs for infrastructure owner-operators. This document is not intended to be a national vision or strategy for ADS. Rather, it is intended as a knowledge resource to support transportation agencies in considering ongoing and future research activities in this area.

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LIST OF FIGURES

LIST OF ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ADS	Automated Driving Systems
CDA	Cooperative Driving Automation
ConOps	Concept of Operations
DOT	Department of Transportation
FHWA	Federal Highway Administration
IOO	Infrastructure Owner-Operator
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation System
R&D	Research and Development
SAE	Society of Automotive Engineers
SPaT	Signal Phase and Timing
STIP	Statewide Transportation Improvement Program
TCD	Traffic Control Device
TMC	Transportation Management Center
TMS	Traffic Management System
TNC	Transportation Network Company
TSMO	Transportation Systems Management and Operations
USDOT	United States Department of Transportation
VRU	Vulnerable Road User

WHAT IS IN THIS DOCUMENT?

INTRODUCTION

This document presents the concept of operations (ConOps) aimed at helping transportation agencies integrate automated driving systems (ADS) into the transportation system. Developed by the Federal Highway Administration (FHWA), the purpose of the ConOps is to describe likely ADS use cases and how they can safely, equitably, and efficiently be integrated with the overall transportation system.

The ConOps intends to:

DESCRIBE
How ADS technology could manifest on public roads in a consistent manner.

IDENTIFY
The interactions between the physical, digital, and operational layers of the transportation system and ADS-equipped vehicles and the resulting needs for infrastructure owner-operators (IOO).

DEFINE
The capabilities that may be necessary to plan and prepare the roadway system for ADS.

AUTOMATED DRIVING SYSTEM

An ADS consists of the hardware and software that are collectively capable of performing the entire dynamic driving task on a sustained basis, regardless of whether it is limited to a specific operational design domain. This term is used specifically to describe a Level 3, 4, or 5 driving automation system in accordance with the Society of Automotive Engineers (SAE) definition standard. (SAE J3016).

This ConOps document is not intended to be a national vision or strategy for ADS. Rather, it is intended as a knowledge resource to support transportation agencies in considering ongoing and future research activities in this area.

PRIMARY AUDIENCE

INFRASTRUCTURE OWNER-OPERATORS

Help identify necessary actions for ADS integration in coordination with agency goals. Focus areas include:

- Industry engagement
- Project development
- Medium- and long-range planning

Other industry stakeholders are encouraged to use this ConOps document to better understand the IOO perspective on roadway ADS integration.

DEFINITION OF ROADWAY ADS INTEGRATION

Roadway ADS integration is defined as the set of capabilities needed to support the anticipated interactions between the existing and emerging physical and digital layers of the surface transportation system and ADS-equipped vehicles to enable safe and efficient operations with other road users in the system.

Transportation agencies are focused on readiness preparations, pilots, testing, and policy and regulatory preparations for the anticipated increase in ADS. The evolution of ADS will likely occur in phases and vary widely by application, region, and mode. This document envisions that use cases are likely to mature following the four steps outlined in figure 1.

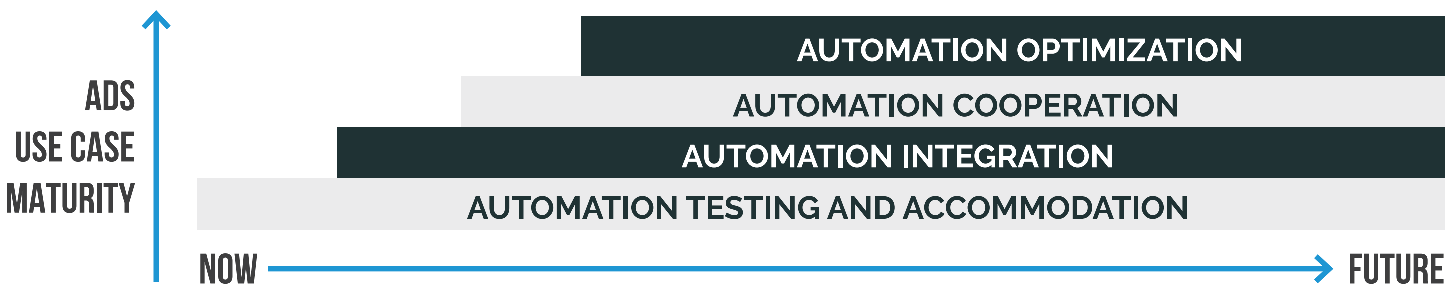


Figure 1
Evolution of Roadway ADS Integration
Source: FHWA

Roadway ADS integration is not envisioned to occur simultaneously across various ADS use cases. Each ADS use case may require a shorter or longer amount of time within each step before moving to the next. Across these steps, at any given point in time, different ADS use cases are expected to be in various states of maturity.

AUTOMATION TESTING AND ACCOMMODATION	AUTOMATION INTEGRATION	AUTOMATION COOPERATION	AUTOMATION OPTIMIZATION

Figure 2
ADS Use Case Maturity Table
Source: FHWA

The ADS use case is tested and prototyped in a controlled setting and in small-scale pilots in order to ready the technology and application for operational use.

The ADS use case is introduced into the market and grows in concentration in terms of deployment, adoption, and interaction with physical, digital, and human actors in the transportation system.

A critical mass for the use case is reached, making additional capabilities for connectivity between systems feasible and important for system-level efficiencies.

An idealized state where the ADS use case is fully optimized with other ADS and non-ADS actors and systems.

The focus of the ConOps is to define the second step-automation integration. This step is a critical milestone for transportation agencies. During this step, when interaction occurs between ADS-equipped and non ADS vehicles, it is anticipated that there will be greater emphasis on overall system efficiency. This enhanced emphasis on efficiency will occur as follows:

- The interactions[1] between the ADS use cases and the rest of the transportation system are expected to increase.
- The externalities associated with the use cases will benefit from being proactively managed by the IOOs.
- This is the first time there is a significant enough level of ADS operations to warrant modifying practices and procedures, developing new systems and tools, adapting policy and planning approaches, and changing needs for agency workforces.
- There is greater consideration of how the ADS vehicles, non-ADS vehicles, cyber-physical infrastructure, and travelers interact, complement, and aid each other to ensure safe, reliable operations for all users.

[1] The "interactions" do not necessarily describe a high penetration rate, but rather, unique scenarios that users of the transportation system may encounter with ADS.

CONOPS DEVELOPMENT PROCESS

The ConOps was developed through a consistent and continued stakeholder engagement process. The process was initiated by FHWA to create a foundational stakeholder understanding of ADS, starting with a series of national dialogues. Since then, a representative stakeholder group was created to share ideas, react to concepts, and provide feedback through interviews, workshops, and meetings.

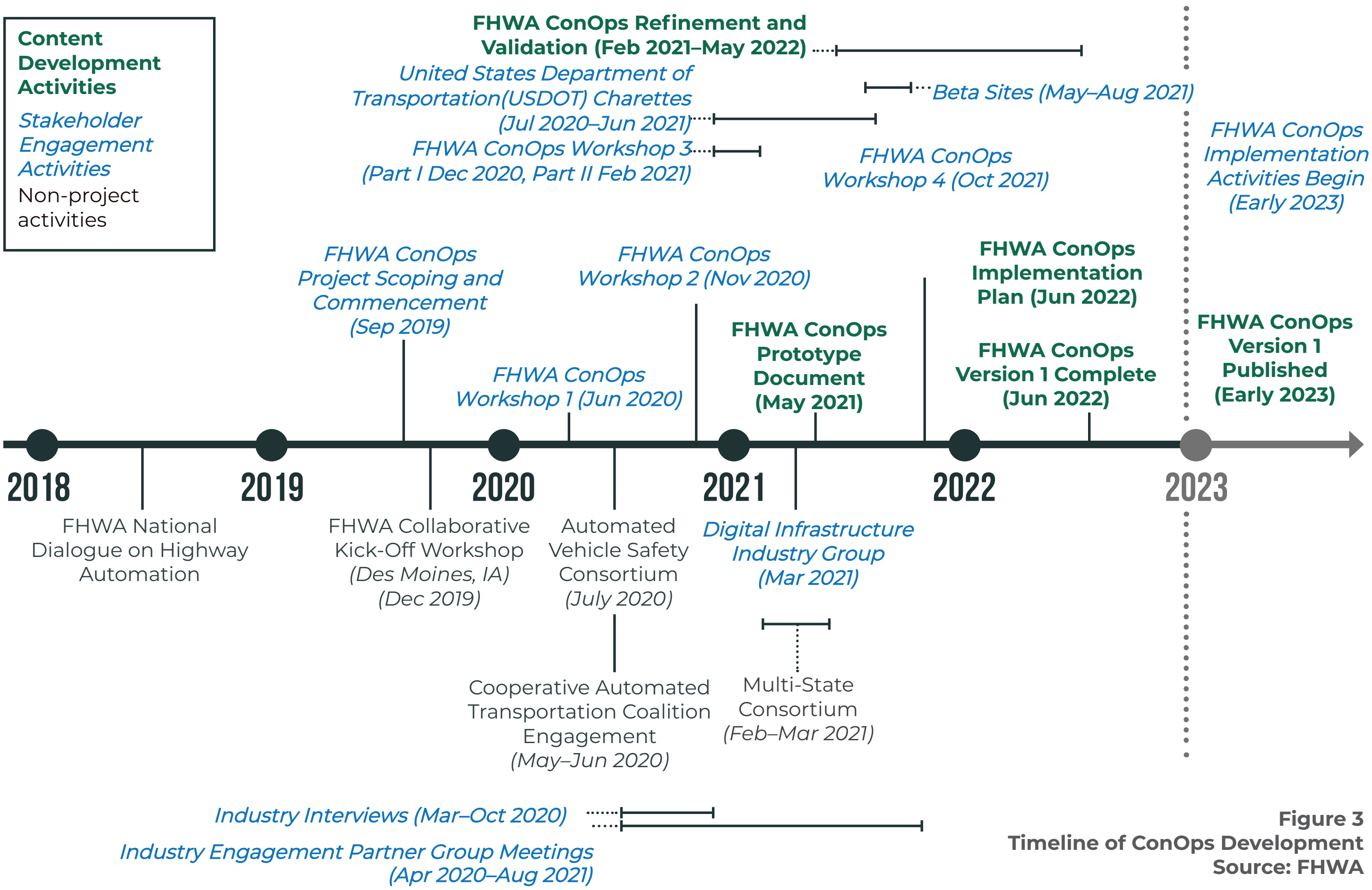


Figure 3
Timeline of ConOps Development
Source: FHWA

BUSINESS CASE

ILLUSTRATIVE SOCIETAL OUTCOMES + **TRADE-OFFS** + **SYSTEMIC VIEW** = **BUSINESS CASE**

RATIONALE FOR TRANSPORTATION AGENCY INVOLVEMENT AND RESPONSIBILITY

Private sector ADS developers are investing heavily in the technology and vehicle systems to perform automated driving tasks.

The public sector can encourage innovation while working to ensure ADS investments do not produce undesirable public outcomes. These outcomes include increased congestion, energy use, and emissions; decreased system safety; worsened accessibility; and decreased equity. Achieving innovation without producing these adverse impacts requires recognizing societal outcomes, managing trade-offs, and having a systemic view. This is done through transportation community and private sector collaboration in a series of planning, policy, infrastructure, and operations activities.

ILLUSTRATIVE SOCIETAL OUTCOMES

A SAFE SYSTEM
Integrate ADS into the transportation system to help eliminate fatal and serious injuries while mitigating new risks introduced by ADS.

EFFICIENT OPERATIONS
Create an integrated, multimodal, sustainable, and resilient environment for transportation systems management and operations (TSMO).

EQUITABLE BENEFITS AND IMPACTS
Understand and plan for the relative impacts and benefits of ADS to different communities and user groups.

INTEROPERABLE SYSTEMS
Support interoperable systems adding convenience and reducing costs, while maintaining the same safety levels.

TRADE-OFFS

PRIORITIZE INVESTMENTS
Attempt to anticipate impacts and make decisions on investments that will result in the type of community and transportation system that is desired for the jurisdiction.

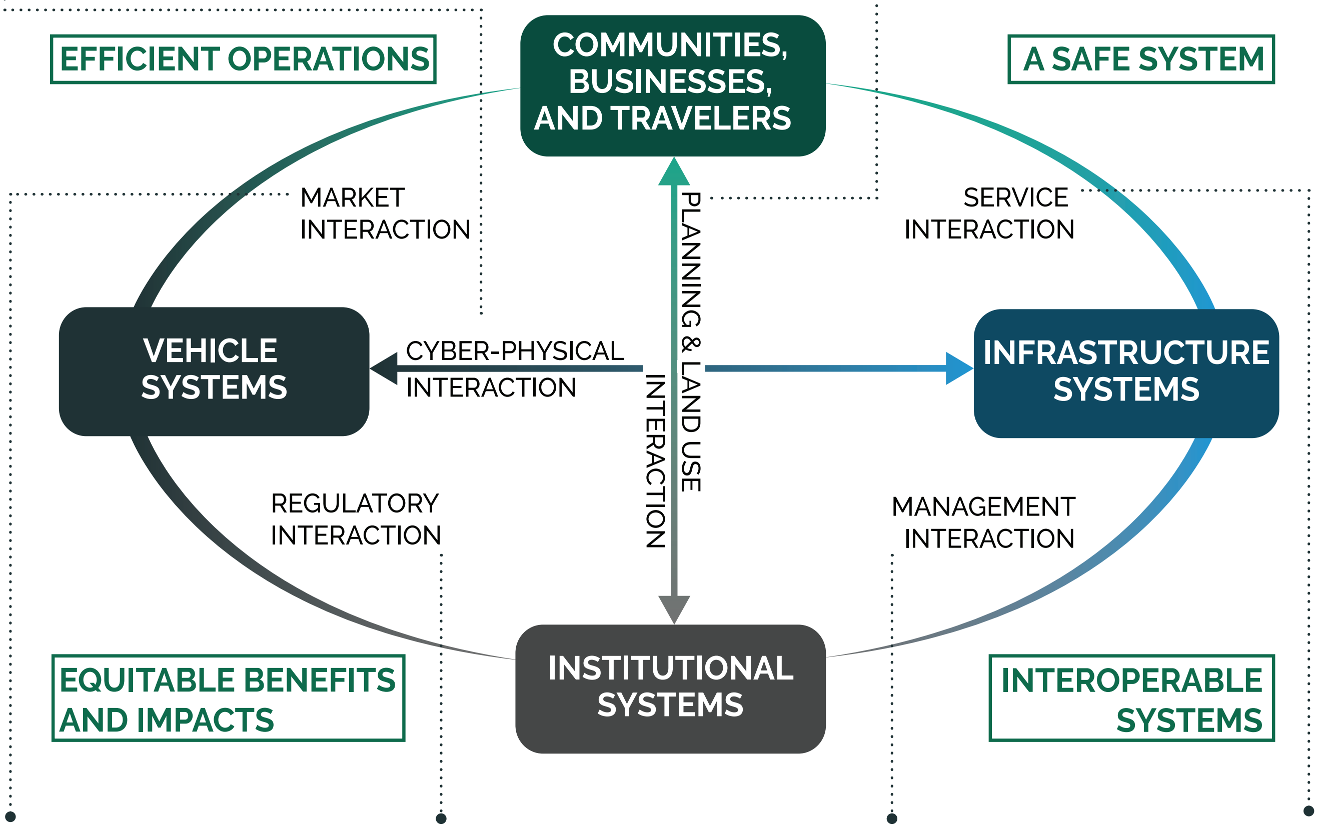
ALLOCATE FINITE RESOURCES
Manage finite resources supporting an integrated, multimodal transportation system. However, as the use cases, scenarios, and operational concept in this document illustrate, many of the investments made to support ADS integration can benefit human drivers today and ADS vehicles in the future.

SYSTEMIC VIEW

Roadway ADS integration focuses IOO and industry stakeholder attention to collaboratively look at the various interactions and tradeoffs between vehicles, infrastructure systems, institutions, and travelers while considering outcomes such as safety, efficiency, interoperability, and equity. These interactions comprise the core of roadway ADS integration.

CYBER-PHYSICAL INTERACTION: Dependencies and interactions of vehicle automation with infrastructure systems and the use of vehicle system data by infrastructure operational systems

PLANNING AND LAND USE INTERACTION: Social and economic conditions that influence longer-term, institutional change



MARKET INTERACTION: The demand for automated systems and services and the supply of products determine how quickly ADS will be deployed and adopted.

REGULATORY INTERACTION: IOO, law enforcement, and regulatory agency actions are taken to ensure safe vehicle operations.

MANAGEMENT INTERACTION: IOO actions, guided by policy, focused on designing and building infrastructure to address changing institutional demands.

SERVICE INTERACTION: Infrastructure capabilities support quality of life improvements. .

Figure 4
Systemic View Interactions Diagram
Source: FHWA

USE CASES

An ADS integration use case is a specific type of anticipated deployment of ADS technology to meet a certain business or travel need. Under this effort, eight use cases were identified by stakeholders to provide insight into the operations of ADS-equipped vehicles. These use cases are specific to freight, transit, individual, or agency uses and how they interact with other users of the transportation system.

A small number of ADS-equipped vehicles are currently operating on public roads in the United States.Most of these vehicles are involved in testing and pilot deployments, with over 100 ADS pilots happening across the country. Testing includes many modes, from passenger vehicles to shuttles, transit buses, robots, and commercial vehicles.

To support stakeholder readiness preparations in the coming years, eight stakeholder-identified ADS integration use cases are presented in the sections that follow. These use cases are organized under the categories: Freight and Package Delivery, Transit, Individual Travel and Commuting, and Agency Operations.

Each use case (outlined below) presents the intended way in which ADS could be leveraged to support a specific application.

1 FREIGHT AND PACKAGE DELIVERY

A) Automated trucking operations—long-haul freight
B) Automated trucking operations—local freight delivery
C) Automated home and package delivery

2 TRANSIT

A) Automated fixed-route transit—including low speed shuttles
B) Automated mobility on-demand transit—including low speed shuttles

3 INDIVIDUAL TRAVEL AND COMMUTING

A) Passenger vehicle automated driving system—fleets
B) Passenger vehicle automated driving system—privately owned

4 AGENCY OPERATIONS

A) Automated agency fleets

01 FREIGHT AND PACKAGE DELIVERY

The freight and package delivery use case category primarily involves the movement of goods from manufacturing centers, distribution hubs, and warehouses to the consumer at the following three scales:

A) Long-Haul Freight
B) Local Freight Delivery
C) Home and Package Delivery

A LONG-HAUL FREIGHT

Long-haul freight describes the truck transport of goods, from freight hubs such as seaports, airports, rail yards, and factories in urban areas across potentially rural areas and multiple States to distribution centers, where the freight is divided up for delivery to businesses.

Under this use case, ADS-equipped trucks perform the driving tasks, controlling steering and speed under public highway driving conditions largely from on-ramp to off-ramp ranging from free-flowing traffic to congested and stop-and-go traffic.

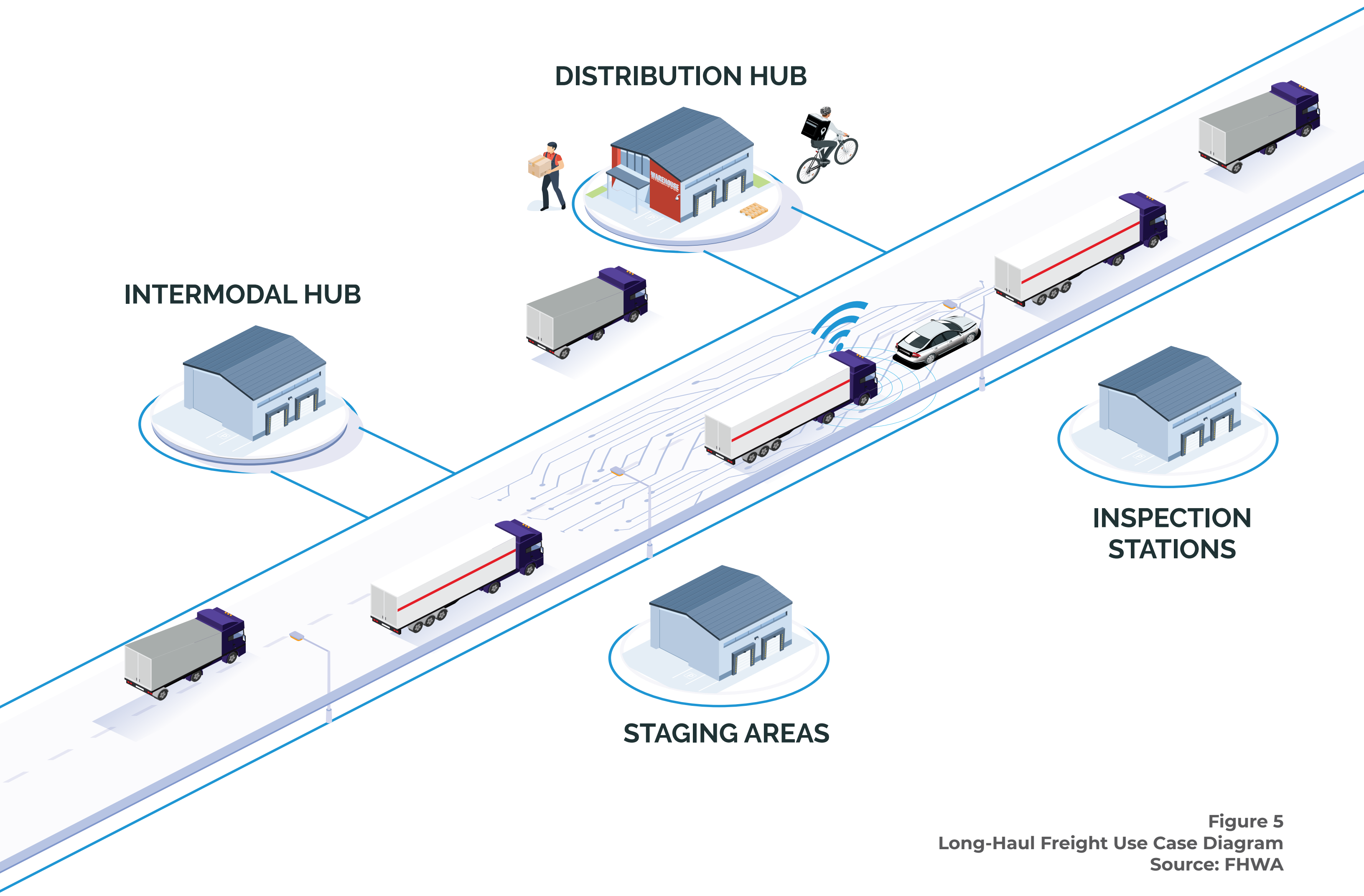


Figure 5
Long-Haul Freight Use Case Diagram
Source: FHWA

B LOCAL FREIGHT DELIVERY

Local freight delivery encompasses the conveyance of goods from distribution centers to stores, distribution centers to other centers, between intermodal points, or between industrial zones. Delivery is periodic following well-defined routes. This transport involves much shorter trips than long-haul freight movement.

While some of the travel may occur on freeways, much of the travel would occur on local roads and primary arterials. In this case, automated trucks are ultimately envisioned to perform the full range of driving tasks from the origin to the end-point delivery customer.

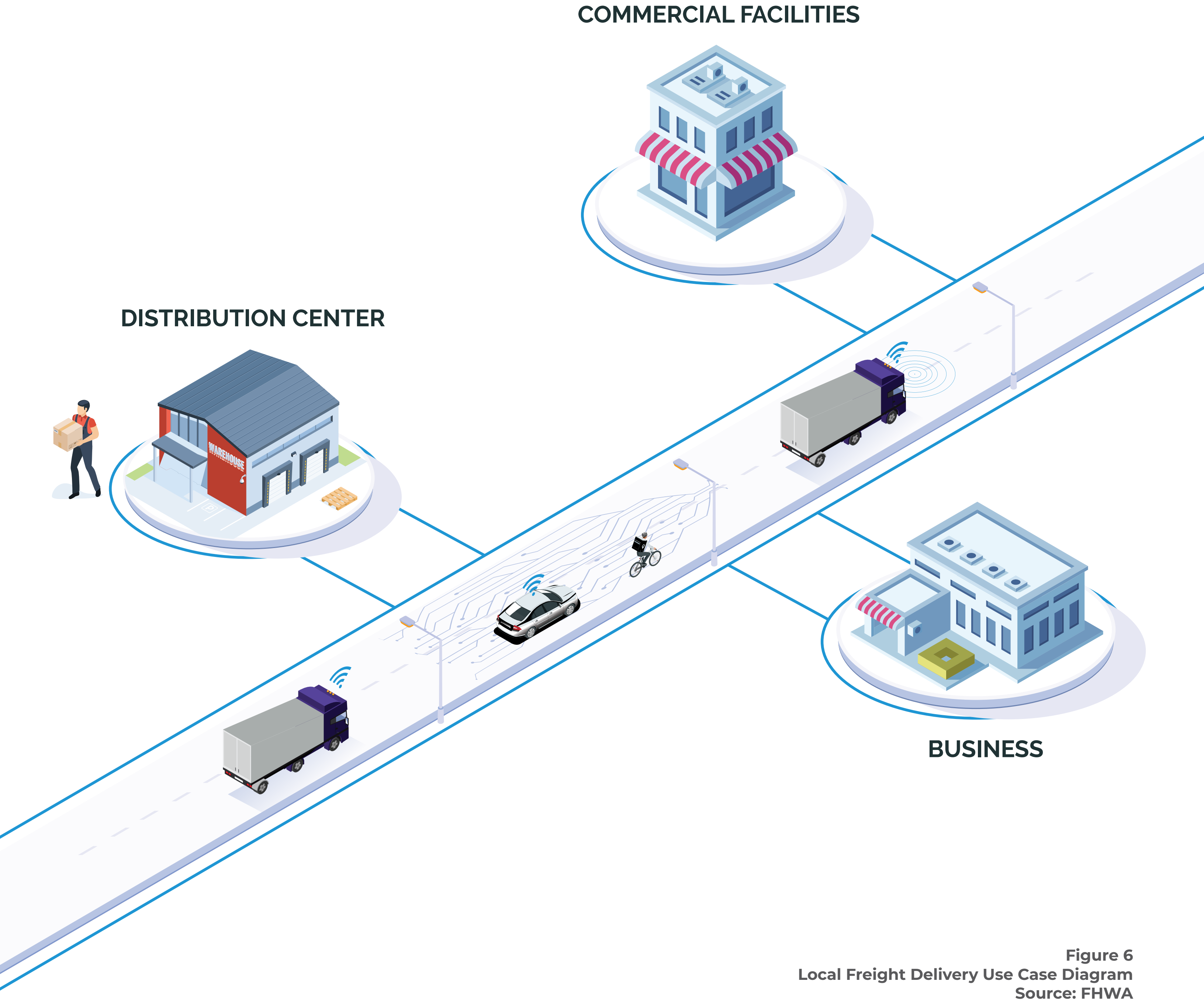


Figure 6
Local Freight Delivery Use Case Diagram
Source: FHWA

C HOME AND PACKAGE DELIVERY

Automated home package and goods delivery describes mail and package delivery by vehicles from warehouses and businesses to individual homes. The delivery vehicle serves a prescribed area for mail, food, or retail package delivery.

New business models are evolving that may not require drivers, such as customer pick-up at the curbside or the use of additional automation to deliver packages from the vehicle to the front door. Delivery vehicles include wheeled sidewalk delivery robots, legged sidewalk delivery robots, conventional design automated delivery vehicles, novel design automated delivery vehicles, and a combination of automated delivery vehicle models. The routes and schedules are variable based on the delivery locations.

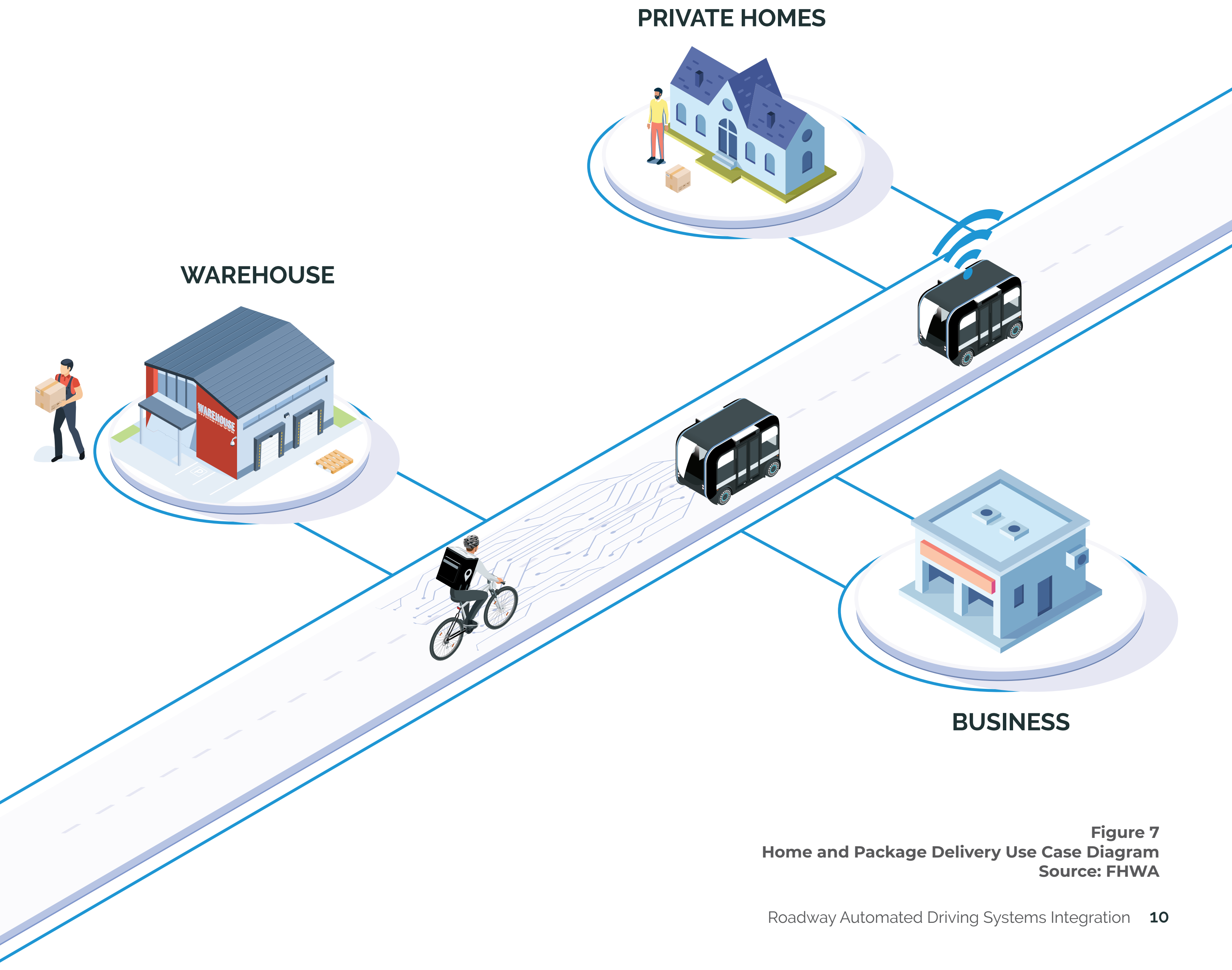


Figure 7
Home and Package Delivery Use Case Diagram
Source: FHWA

02 TRANSIT

The transit use case category primarily involves ADS aiding the movement of people through transit services that remove dependencies on single-occupant vehicles, with two specific use cases as follows:

A) Automated Fixed-Route Transit
B) Automated Mobility on Demand Transit

A AUTOMATED FIXED-ROUTE TRANSIT

Transit services have already improved with lower level automation and driver assistance in many ways. The automated fixed-route transit use case continues that progress by introducing ADS to fixed-route bus services; it emulates existing bus services but with ADS supporting some of the route operations.

This use case includes a wide variety of services, including platooned bus rapid transit models to low-speed shuttles. Other examples of this use case may be intercity express-type buses running on dedicated or semidedicated rights-of-way serving point-to-point routes.

For the foreseeable future, this use case should be seen as supplementing transit services rather than replacing existing services.

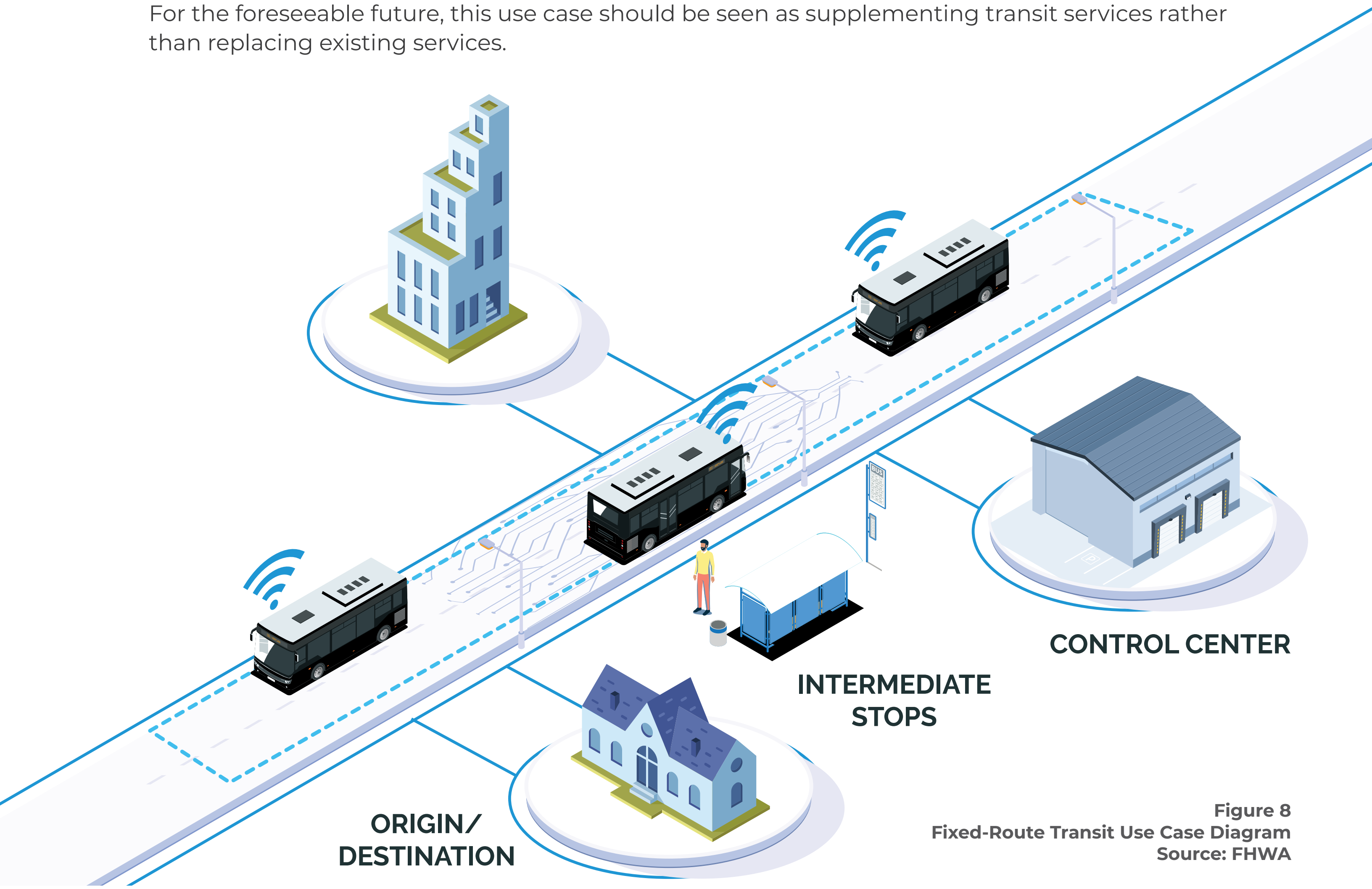


Figure 8
Fixed-Route Transit Use Case Diagram
Source: FHWA

B AUTOMATED MOBILITY ON DEMAND TRANSIT

Automated mobility on demand extends the idea of ADS operations for transit to support door-to-door shared transportation. Essential concepts for this use case are demand responsiveness, variable routing, and shared rides. Accomplishing all three concepts within a defined region is a significant step up from operating a fixed-route service and closer in technological complexity to a ride-for-hire use case. Two major markets are included in this use case. First, ridesharing services within a well-defined environment like a college campus, medical campus, or a retirement community. Second, broader paratransit services provided today in both urban and rural areas for non-emergency medical transportation and accessible services.

This use case combines transformative mobility on demand, the potential benefits of ADS, and the versatility of microtransit (e.g., flexible vehicle types, flexible routing scenarios, connection to transit services).

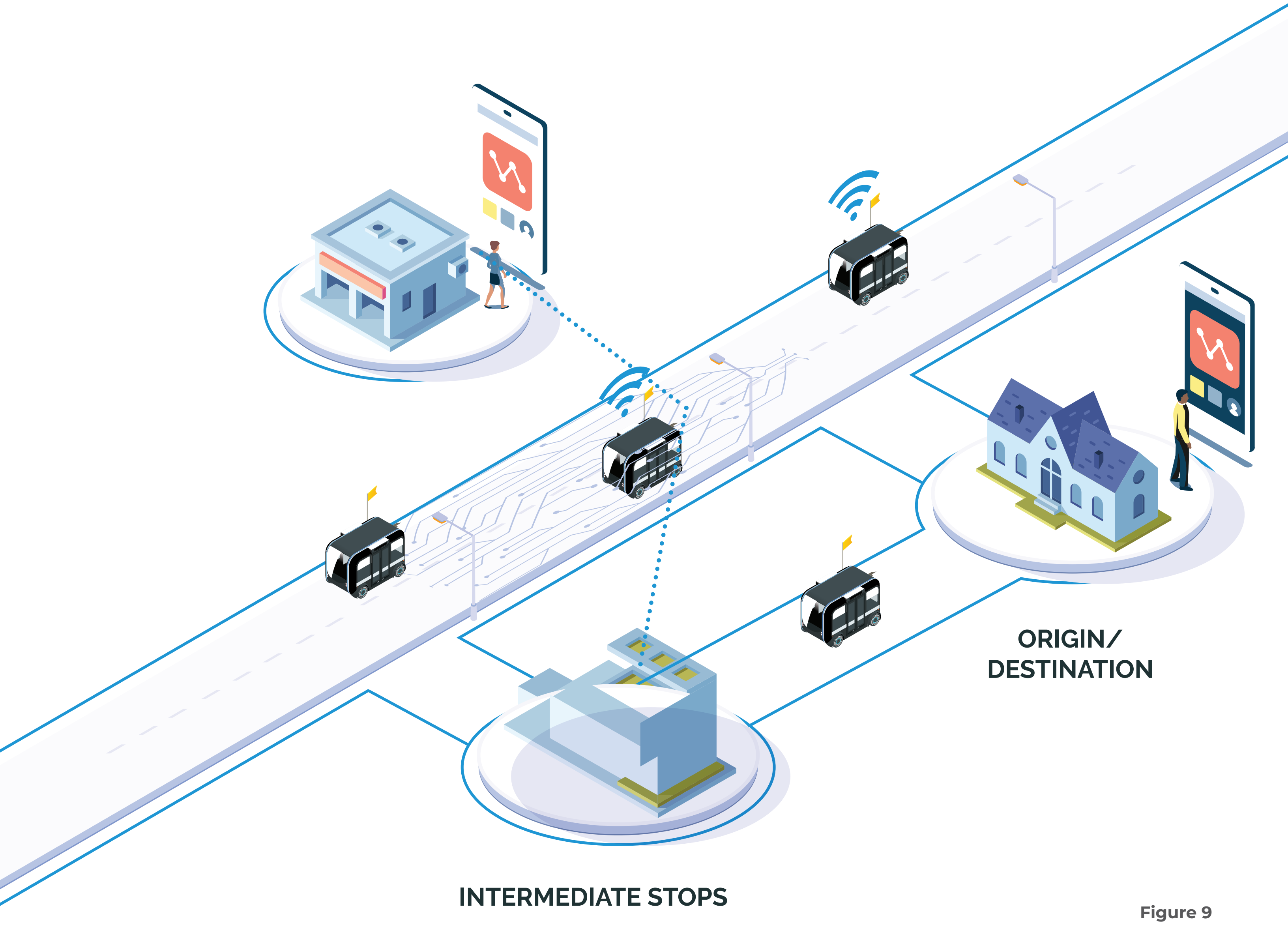


Figure 9
Mobility on Demand Transit Use Case Diagram
Source: FHWA

03 INDIVIDUAL TRAVEL AND COMMUTING

Two individual ADS integration use cases are described in this section:

A) Passenger Vehicle Automated Driving System (Fleets)
B) Passenger Vehicle Automated Driving System (Privately Owned)

A PASSENGER VEHICLE ADS (FLEETS)

Passenger vehicle ADS fleets rely on dedicated ADS vehicles that view the traveler as a passenger with no ability to control the driving task. These vehicles may be available as part of a dedicated fleet used to provide transportation network company (TNC) type mobility services but may also include other types of services focused on specific populations. The vehicle may communicate operating information over a telecommunications network to a remote location capable of operating the vehicle remotely. This use case encompasses the automation of ride-for-hire TNCs that use internet-based technology (typically a smart phone application) to link vehicle owners (providers) selling transportation with individuals who need transportation (customers). ADS-equipped vehicles may be key to TNCs' future business models.

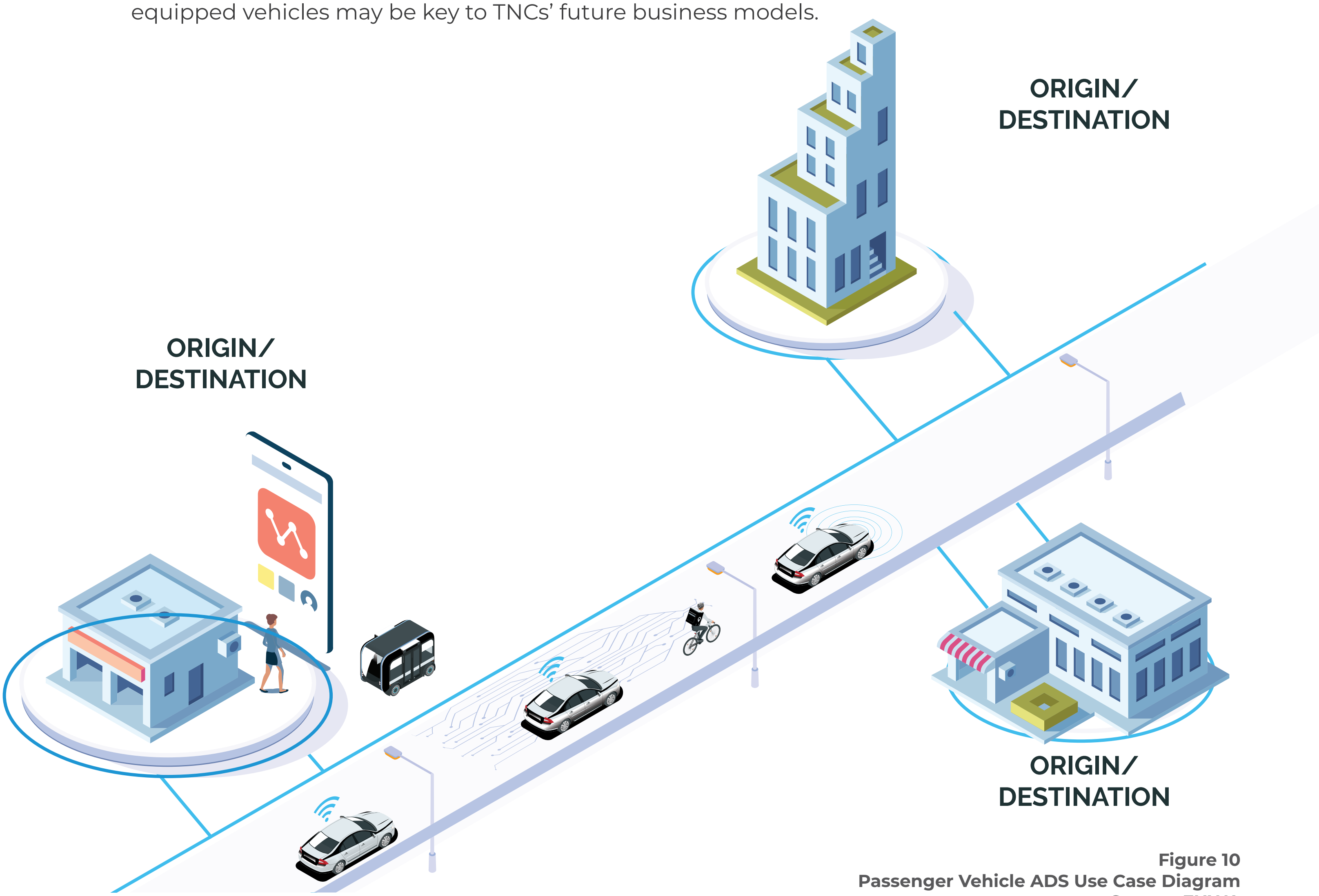


Figure 10
Passenger Vehicle ADS Use Case Diagram
Source: FHWA

B PASSENGER VEHICLE ADS (PRIVATELY OWNED)

This use case describes the use of privately owned or privately leased ADS-equipped vehicles for individual personal travel. This use case may be defined by individual car manufacturers based on their system capabilities and their preferred operational design domain. For example, the ADS functionality in a vehicle may only be available when certain geographic, infrastructure, environmental, and driver requirements are met. In other conditions, the driver reverts to lower level advanced driver assistance systems or regular driving functions. Based on current stakeholder feedback gathered for this project, this use case still includes the presence of a driver in the vehicle. Privately owned vehicles capable of zero-occupant travel are not included in the use case.

04 AGENCY OPERATIONS

One ADS integration use case is described in this section:

A) Automated Agency Fleets

A AUTOMATED AGENCY FLEETS

Installation of advanced sensors and automation of some service vehicles may provide IOOs new opportunities to improve efficiency and safety, particularly safety of their highway construction and maintenance crews. This use case describes examples of IOO fleet vehicle automation, such as snowplows, maintenance trucks, and light duty vehicles, including:

- Platooned deployment of snowplows and winter maintenance trucks
- Automation of truck-mounted safety attenuators
- Automated light duty vehicles for mapping construction and work zones

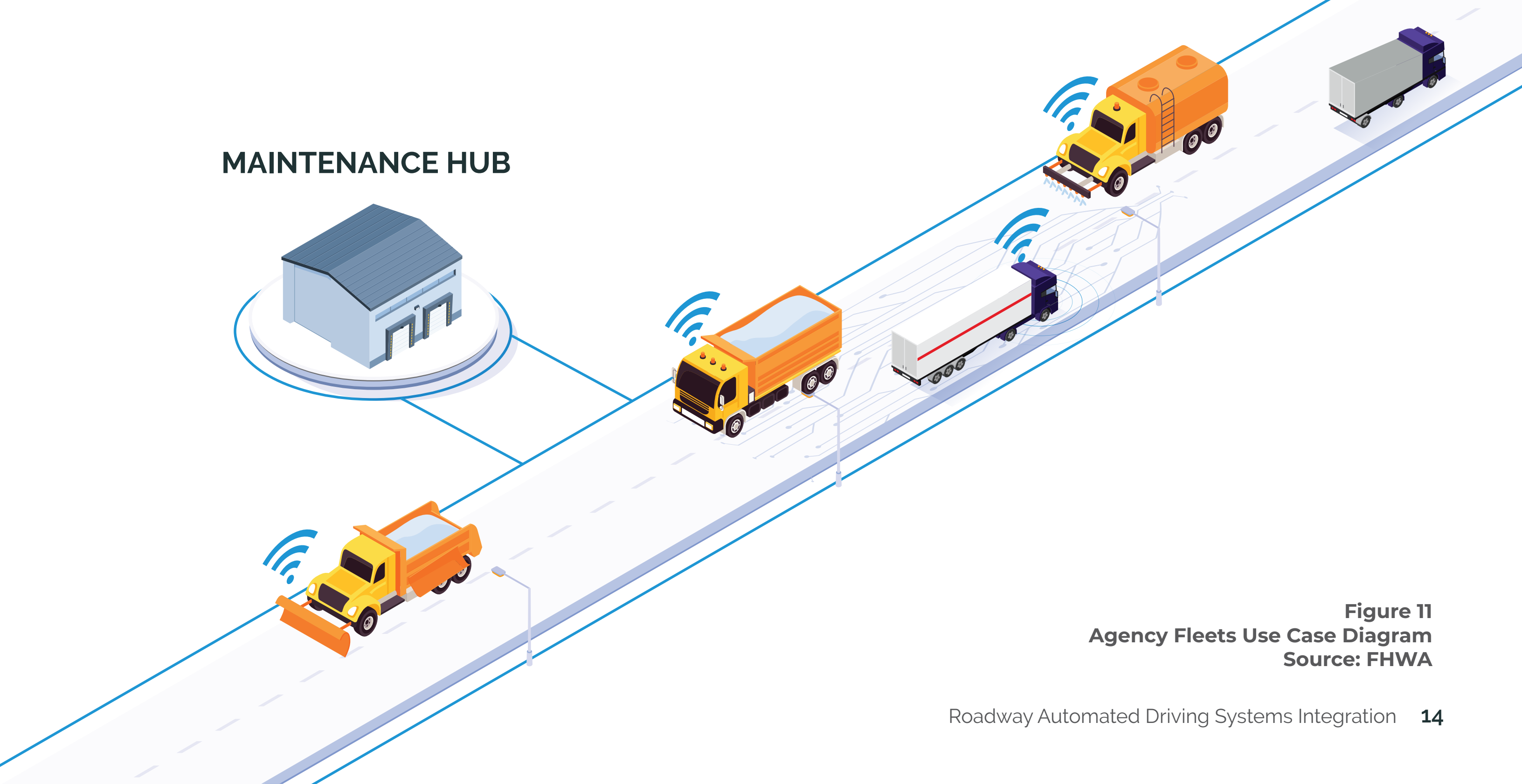


Figure 11
Agency Fleets Use Case Diagram
Source: FHWA

OPERATIONAL CONCEPT

The ConOps defines four illustrative societal outcomes for ADS integration as follows:

The ConOps describes eight stakeholder-identified ADS integration use cases (arranged in four categories) as follows:

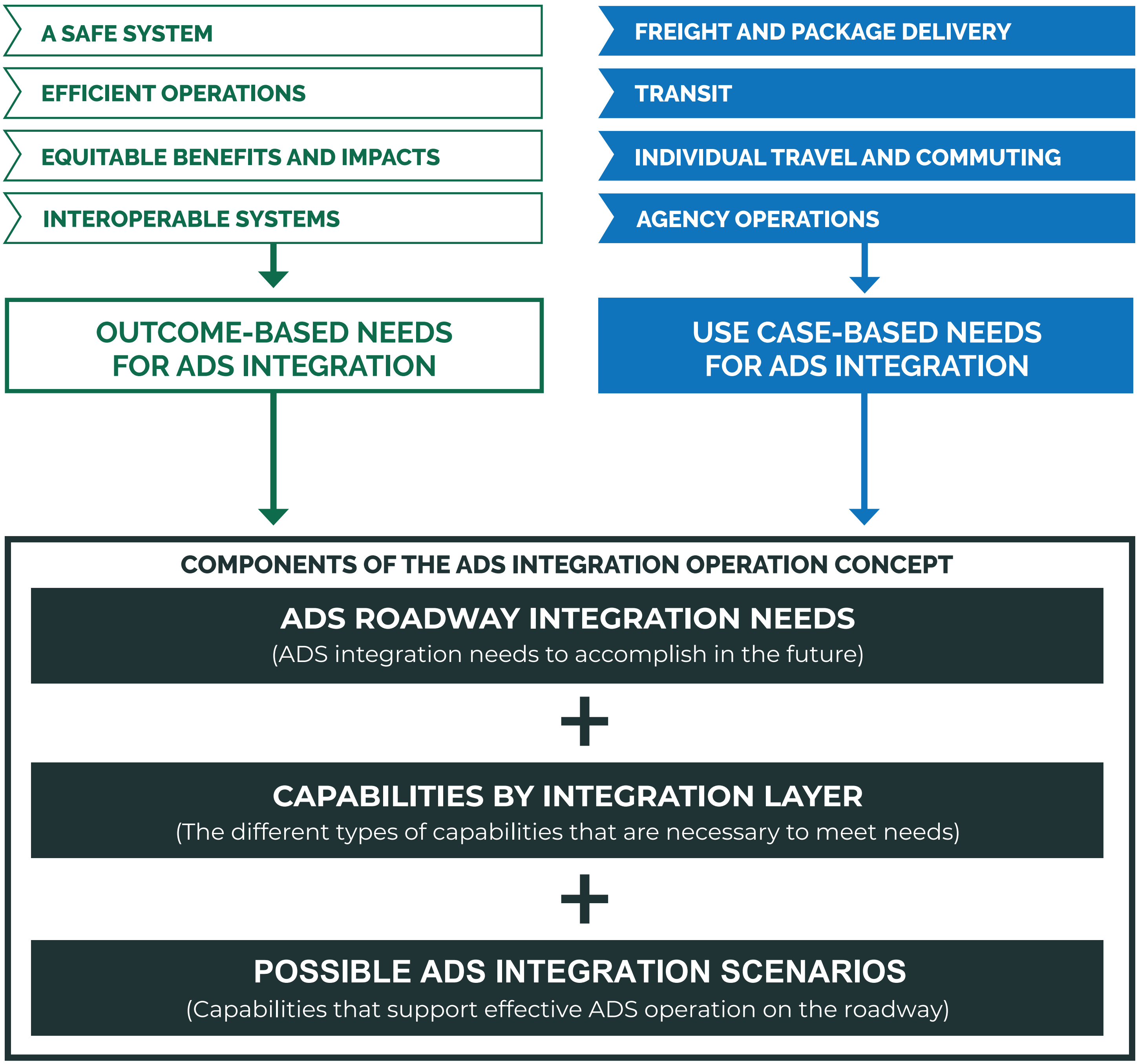


Figure 12
Operational Concept Diagram
Source: FHWA

The role of the ADS integration operational concept is to provide transportation agencies with actionable insights into practical activities they can consider **and selectively integrate entirely at their discretion.** This operational concept consists of the following:

ADS ROADWAY INTEGRATION NEEDS

ADS roadway integration needs offer issues and some candidate actions that transportation agencies may consider in anticipating the prospective impacts and possible benefits of this technology. These potential needs are derived from illustrative societal outcomes and use case-based needs.

CAPABILITIES BY INTEGRATION LAYER

Capabilities by integration layer describe what capabilities will help address the needs. ADS integration will not occur in a single, unified system. Rather, it will occur through activities at different layers of the transportation system, which are described in this document as integration layers or through cross-cutting functions. Three integration layers are defined as part of this operational concept to help organize the identified capabilities, with two cross-cutting functions, as illustrated below.

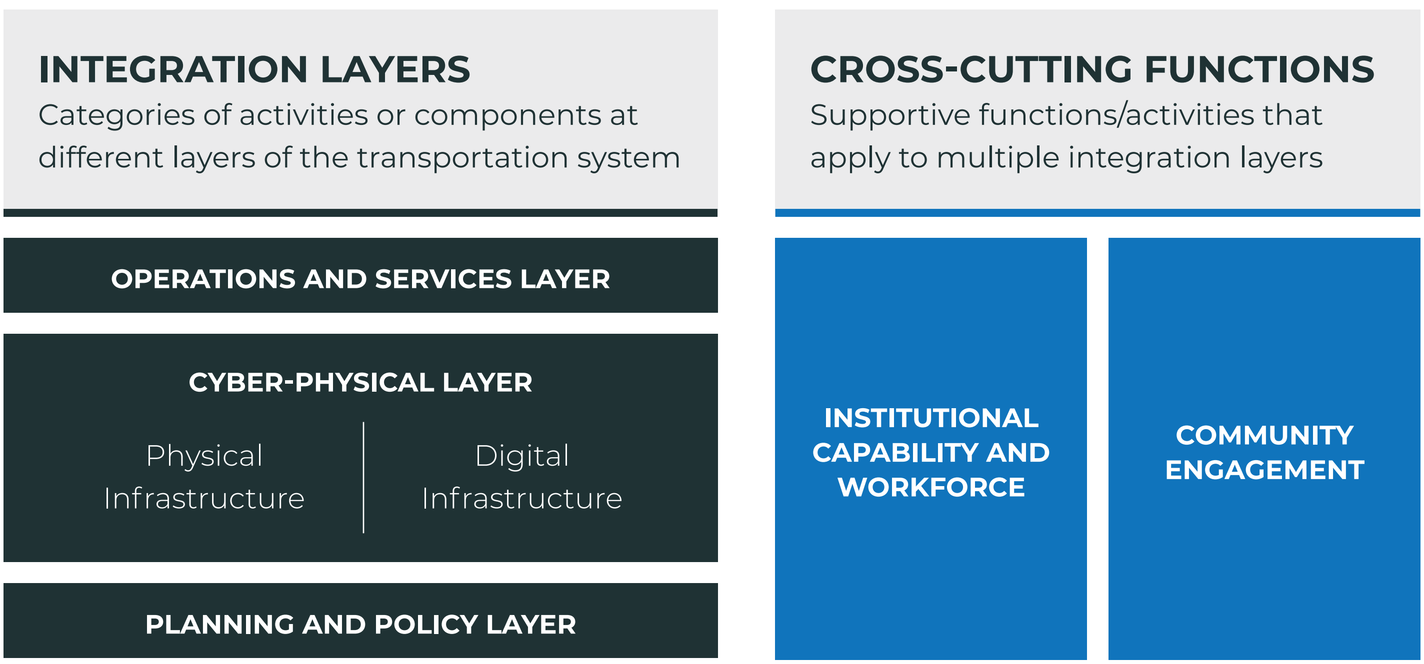


Figure 13
Integration Layers Diagram
Source: FHWA

POSSIBLE ADS INTEGRATION SCENARIOS

Scenarios connect capabilities to real-world situations to support safe, efficient, and interoperable ADS operations.

ADS INTEGRATION NEEDS

When the ADS integration operational concept was developed, a clear message from transportation agencies was the need for traceability. Traceability allows agencies to understand the basis for each capability, assess the applicability of each capability to their agency, and selectively integrate these capabilities at their discretion. Traceability is possible because of the needs-based approach used to derive the capabilities. Two key sources were used to derive the needs:

NEEDS DERIVED FROM ILLUSTRATIVE SOCIETAL OUTCOMES

By considering the illustrative societal outcomes for roadway ADS integration (i.e., safe system, efficient operations, equitable impacts, and interoperable operations), a total of 32 ADS integration needs were derived. FHWA is not stating that the items below are needed or necessary in general, rather that components of the ConOps be selectively integrate upon discretion.

NEEDS DERIVED FROM USE CASES

The use cases described earlier provide insight into the likely operations of ADS-equipped vehicles that will relate to freight, transit, individual, or agency uses. A total of 26 ADS integration needs were derived from the 8 use cases considered in this project.

NEEDS DERIVED FROM ILLUSTRATIVE SOCIETAL OUTCOMES

SS NEEDS RELATED TO A SAFE SYSTEM

SS1 Need for transportation agencies and ADS developers to work together and share their understanding (and supporting data) of the most common causes of crashes, known medical statistics, and human body tolerances, therefore enabling ADS developers to seek opportunities to design and operate ADS vehicles in ways that minimize crash risks, human injury and discomfort, and exposure of ADS vehicle occupants and other travelers (e.g., drivers of other vehicles and vulnerable road users (VRUs)) to these risks.

SS2 Need for established law enforcement and first responder training to recognize ADS-related impacts to established enforcement and traffic incident management practices, including parking, traffic enforcement, and incident response.

SS3 Need to establish data exchange agreements with ADS developers to track and share data describing crashes and near-miss collisions to assist IOOs in adjusting physical or digital infrastructure to reduce risks of future crashes.

SS4 Need for research to understand new risk factors introduced by humans interacting with ADS, including ADS vehicle operators (e.g., with regard to the human-machine interface), VRUs, or drivers of other vehicles.

SS5 Need for collaboration between IOOs and ADS developers to understand core physical and digital infrastructure elements that are essential to improve safety of ADS vehicles and can realistically be accomplished by IOOs (e.g., uniformity and consistency in traffic control devices (TCDs), lane markings).

SS6 Need for transportation agencies and ADS developers to understand and incorporate any National Highway Traffic Safety Administration safety regulations related to ADS integration.

SS7 Need for quality and consistency of the design, construction, operations, and maintenance of roadways. Variations may affect operating boundaries and performance, especially around identified corridors.

SS NEEDS RELATED TO A SAFE SYSTEM (CONTINUED)

SS8 Need to have estimates of changes in ADS vehicle use and penetration rates to prioritize infrastructure investments.

SS9 Need best practices and guiding principles for engaging the public to educate and inform them about the features and limitations of ADS.

SS10 Need to manage any emerging safety issues involving curbside and other drop-off areas, passenger loading and unloading, vehicle and passenger safety and security, and self-parking.

EO NEEDS RELATED TO EFFICIENT OPERATIONS

EO1 Need for transit and mobility providers to collaborate to define noteworthy practices and operating procedures for operations of public and private ADS vehicles to support multimodal travel.

EO2 Need for transit and mobility providers to cautiously collaborate with (or benefit from) private mobility services providers while not leaving travelers vulnerable to private sector decisions about prices, services, or service areas.

EO3 Need for IOOs to understand the effects of various penetration rates of ADS vehicles on overall network operations (e.g., how are elements such as speed, acceleration, and maneuvering different and what are the resulting impacts).

EO4 Need for IOOs and ADS developers to collaboratively determine what data will be available to IOOs that are collected from ADS vehicles and communicated in either realtime or periodically to support IOO data collection and monitoring ADS operations at Transportation Management Centers (TMCs).

EO5 Need for ADS developers to communicate to IOOs what data will benefit the ADS vehicles and expected efficiency improvements if IOOs provide the data.

EO6 Need for the TSMO community to advance transportation management concepts to leverage cooperative driving automation (CDA) capabilities (e.g., common approaches to recommending travel speeds or travel routes that will eventually be communicated to ADS vehicles through CDA) in a way that is consistent to travelers and eventually is included in the American Association of State Highway and Transportation Officials (AASHTO) *Transportation Operations Manual**.

EO7 Need national performance metrics to be defined and used consistently by transportation agencies to assess ADS impacts on systems performance.

EO8 Need best practices for workforce management to support the changing responsibilities of transportation agencies to plan, implement, and maintain the cyber-physical infrastructure and supporting legislation to support ADS vehicles.

EO9 Need industry accepted methods to incorporate ADS integration into planning for operations (e.g., planning, designing for intelligent transportation system (ITS) deployment, traffic management strategies).

EO10 Need to define and implement a nationwide approach for managing jurisdictional differences in traffic regulations and rights-of-way for ADS operations.

** The first edition of the AASHTO Transportation Operations Manual is currently under production through NCHRP 03-126. Once complete, it will be a companion to the AASHTO Green Book. Its primary audience will be staff at State, regional, and local transportation agencies*

EI NEEDS RELATED TO EQUITABLE IMPACTS

EI1 Need for ADS developers to understand diverse perspectives representing equity concerns to ensure software and machine-learning systems are not biased.

EI2 Need for ADS vehicles to demonstrate benefits in order for IOOs to understand the contributions that ADS vehicles can make to improve equity by providing low-cost and/or shared transportation alternatives that benefit all users.

EI3 Need for IOOs to define and implement planning and policy actions to ensure the ADS vehicle contributions to improving equity are accomplished to the extent possible.

EI4 Need for IOOs to research and anticipate potential employment disruptions as a result of ADS implementation and promote training, equity, and inclusion, especially among low-income individuals and others with barriers to employment within the ADS sector.

EI5 Need for IOOs to understand the challenges that ADS vehicle use could pose to individuals (e.g., those who do not have smart devices, those who do not use electronic payment [such as, unbanked and underbanked individuals], those who rely on human operators for assistance when entering or exiting vehicles or loading and unloading goods) and take appropriate planning and policy actions to minimize these challenges.

EI6 Need for IOOs to influence the rollout of ADS vehicles and supporting infrastructure to encourage deployment and use of ADS in underserved and rural communities (where private investment in connectivity or other supporting elements to ADS are not as large or are more challenging due to the geographic setting and characteristics of low-volume roads) to benefit as many individuals and avoid introduction of new inequities (e.g., wealthier counties with higher tax intakes get more connectivity and the most safety benefits).

IO NEEDS RELATED TO INTEROPERABLE OPERATIONS

IO1 Need for IOOs to take appropriate actions to minimize potential negative impacts of ADS vehicles in jeopardizing use of multimodal and shared services (including traditional transit, micromobility, and active transportation).

IO2 Need for IOOs to pursue planning, policy, and infrastructure improvements that will enable ADS integration to improve multimodal operations, adding convenience and reducing costs, while maintaining the same safety levels.

IO3 Need for public transportation agencies to have the technical expertise in emerging technologies to guide their direction and key decisions about infrastructure deployments and operations of systems.

IO4 Need for a mechanism for IOOs to communicate operational strategies and dynamic traffic conditions (e.g., work zone activities, incident responses causing lane or road closures, parking and event strategies) to ADS vehicles.

IO5 Need for common understanding between IOOs and ADS providers around data sharing, data use, and data governance to receive data from ADS vehicles to support multistate/megaregion efforts.

IO6 Need a plan of action for IOOs that respects the legacy infrastructure and systems and recognizes the challenges they pose to symbiotic evolution of the use of ADS vehicles.

NEEDS DERIVED FROM USE CASES

F FREIGHT ADS INTEGRATION NEEDS

F1 Need to understand, develop, and manage an approach to transfer yards to support periodic staging and parking areas for activating/deactivating ADS and for forming platoons.

F2 Need for IOOs to communicate appropriate freight-related road network changes that may affect ADS performance (e.g., changes to road geometry, bridge clearances, temporary traffic diversions, electrical charging stations).

F3 Need to minimize non-ADS traveler confusion surrounding interactions with ADS freight vehicles, especially platooning behavior.

F4 Need to develop plan/guidelines for allowing safe ADS truck operations through specific check points (e.g., weighing stations, toll plazas).

F5 Need to train law and motor carrier enforcement on ADS-related operations and how to change enforcement practices, if necessary, especially around truck permitting, licensing, electronic screening, and inspections.

F6 Need to develop and understand changes to local infrastructure in proximity to truck facilities as the number and locations of ADS truck facilities may be different than non-ADS, which may affect local infrastructure and land use.

F7 Need to define universal policies for package delivery and access to private residence right-of-way.

T TRANSIT ADS INTEGRATION NEEDS

T1 Need to research and understand any bus facilities and curb design changes to accommodate ADS transit operations that become common to the industry.

T2 Need to understand most likely risks to VRUs because of ADS use for transit and microtransit vehicles, in order to inform street redesign and/or minimize conflicts.

T3 Need to understand cooperative bus operations models that improve transit service performance so individual agencies can make appropriate decisions on operational changes.

T4 Need for ADS bus operations to comply with Federal transit safety and workforce requirements.

T5 Need to understand and manage emerging safety issues involving bus stops, embarking and disembarking, and operator roles.

T6 Need to consider actions to encourage shared rides (i.e., explore options to ensure ADS microtransit operations have minimum occupancy requirements).

T7 Need to understand impacts of ADS microtransit on street space usage.

T8 Need to support new workforce skills to operate and maintain the ADS transit technologies and micromobility, especially for smaller transit agencies.

I INDIVIDUAL TRAVEL AND COMMUTING ADS INTEGRATION NEEDS

I1 Need to understand curb space usage and needs by TNCs operating ADS vehicles (TNC ADS) and adjust traffic operations.

I2 Need to establish a model for TNC ADS operations and interactions with non-ADS vehicles, particularly around interchanges and with pedestrians.

I3 Need to develop consistent policy, registration, taxation, regulations, and rules for reliable and safe operation and maintenance of TNC ADS vehicles and technologies.

I4 Need to accommodate elderly and disabled customers who require assistance with a wheelchair, packages, or entering and exiting the vehicle to ensure equity.

I5 Need to understand how ADS will change the number and time of trips, including TNC and private ADS vehicles, thereby changing congestion patterns and demand, and requiring changes to infrastructure maintenance practices and needs.

A AGENCY FLEET ADS INTEGRATION NEEDS

A1 Need nationally consistent procedures for IOO ADS use in specialized IOO construction and maintenance settings (adverse and winter weather, work zones, incident-related congestion).

A2 Need to support development of new IOO workforce skills to operate and maintain the agency fleet ADS vehicles and technologies.

A3 Need better understanding of capital and operations and maintenance costs for IOO fleet-related ADS purchase and deployment decisions.

A4 Need to develop public education campaigns to inform the public about how IOO fleet automation behavior may affect traffic flow and interactions with non-ADS travelers and pedestrians to minimize traveler confusion and adverse behavioral responses.

A5 Need to understand how ADS will require changes at department of transportation (DOT) facilities to accommodate new ADS vehicles and technologies.

A6 Need to understand where and how operations and maintenance practices should change to accommodate agency fleet vehicles. These changes may occur during new construction activities or during maintenance activities to better support automated fleet vehicles.

ROADWAY ADS INTEGRATION CAPABILITIES

The needs presented in the section above describe an understanding of what should be addressed to advance ADS integration to support the use cases and accomplish the illustrative societal outcomes. However, the needs alone do not provide transportation agencies with direct actionable insights into practical actions they could take today. To support these decisions, the operational concept defines a set of capabilities to support ADS integration that, if accomplished, would address the needs and increase the readiness of the transportation industry for ADS integration.

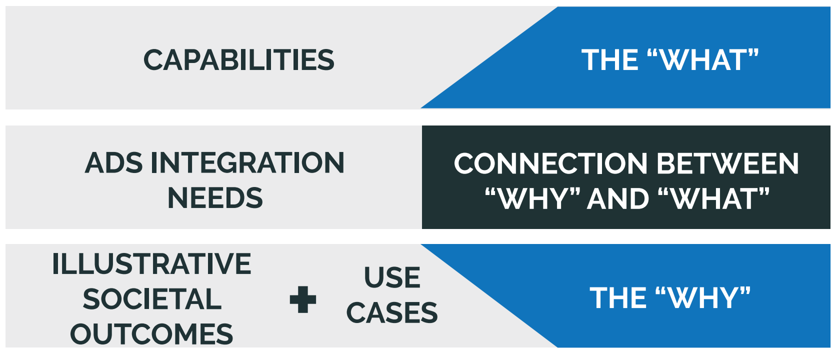


Figure 14
Capabilities Diagram
Source: FHWA

The operational concept stops short of prescribing if transportation agencies should implement these capabilities, who should implement them, or how they might be implemented. Rather, the "if," "who," and "how" will be defined by the transportation industry as their existing and effective processes evolve to support roadway automation. Each capability will require different parts of the stakeholder community to work together to advance research, pilots, standards, and deployment over the next few years.

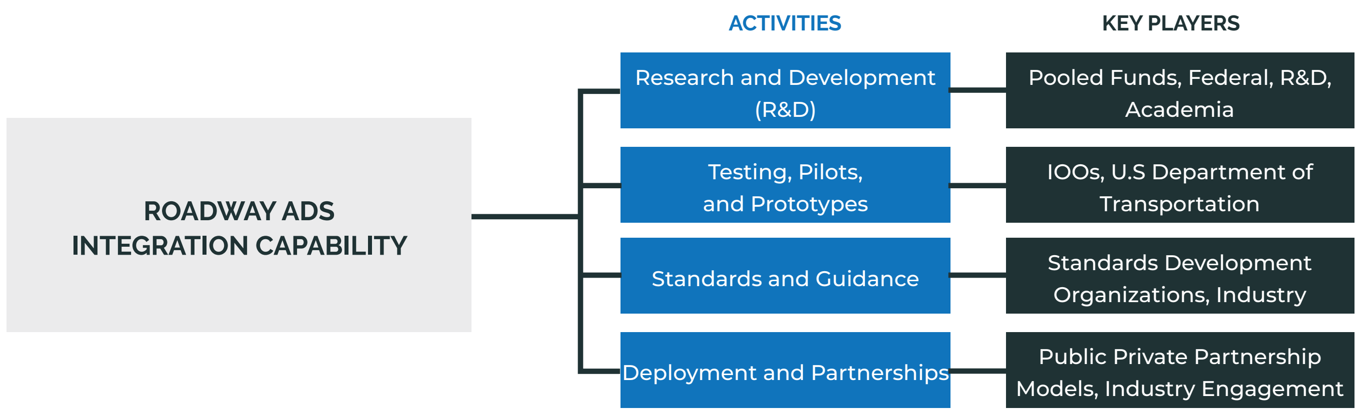


Figure 15
Integration Capability Diagram
Source: FHWA

In the following Planning and Policy Capabilities section, capabilities are described for roadway ADS integration. These capabilities will occur through activities at different layers of the transportation system, which are described in this document as integration layers, or through cross-cutting functions. In the development process, each capability was referenced (traced) back to one or more need that the capability addresses. This tracing to needs will allow the IOOs to understand the basis for each capability and also to prioritize some of the capabilities based on the use cases or illustrative societal outcomes the capability addresses.

PLANNING AND POLICY

CAPABILITIES

The organizational systems that support today's transportation planning, policymaking, and operations are rooted in more than a century of infrastructure to support human-driven vehicles. In the coming decades, the anticipated mixed use of human- and machine-driven vehicles will require a shift in these organizational aspects. FHWA envisions that transportation professionals at transportation agencies and metropolitan planning organizations will utilize existing associations and organizations to perform transportation research, education, planning, and operations.

Desired capabilities for the planning and policy integration layer include:

PP1 ADS integration decisionmaking is increasingly accommodated and supported by transportation system performance metrics and performance management.

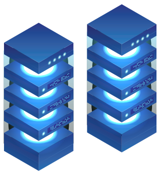
PP2 Planning processes incorporate lifecycle investment in support systems for ADS integration at all levels, from national to local, including traditional Statewide Transportation Improvement Program (STIP) decisionmaking activities.

PP3 The transportation workforce understands how to use and apply scenario planning in transportation systems management decisions.

PP4 Operations and standards for ADS implementation include accessibility and universal design, with contextual considerations from a diverse group of public and private stakeholders.

PP5 State, regional, and local planning agencies have established mechanisms to encourage equity in ADS vehicle use by influencing ADS supporting infrastructure.

PP6 Legislation and policies are compiled and readily available for ADS providers to understand different local procedures and requirements.



CYBER-PHYSICAL SYSTEMS

CAPABILITIES

The cyber-physical integration layer encompasses both physical infrastructure, such as roadway striping and signage, and digital infrastructure, including devices that transmit data.

Physical infrastructure considers changes to existing transportation infrastructure or the deployment of new equipment to accelerate and support ADS. These changes center on the quality and uniformity of TCDs, changing demands of ITS devices, multimodal impacts, and other roadside components to support digital infrastructure.

Digital infrastructure supports information exchange among roadway users and IOOs to enable ADS. Digital Infrastructure consists of information sensing, communications, processing, and storage used and located within and beyond public roads, and the organizational models, agreements, and processes that support operation of those systems.

Desired capabilities for the cyber-physical integration layer include:

CP1 Guidelines for uniformity in design and maintenance of TCDs, such as pavement markings, that support ADS operations have been developed, and many designs/facilities have been converted to match these guidelines.

CP2 Broadband growth and availability is supported along public right-of-way for transportation needs.

CP3 Flexible or changeable physical and digital infrastructure concepts around lane usage, roadside elements, and barriers are prioritized and available to support adaptive use of roadway by ADS use cases.

CP4 An established engagement mechanism is in place for IOOs to share trends in causes of crashes and for collective discussion about which can be addressed by cyber-physical infrastructure and which can be addressed by ADS development.

CP5 Alternative fuel infrastructure, that is likely the backbone for several ADS uses, is supported.

CP6 Updated Complete Streets policies and design that factor in ADS operations at the local street level are used and enhanced.

CP7 A significant proportion of traffic signal control systems and infrastructure are upgraded to include vehicle-to-everything connectivity and safely accommodate pedestrians and other VRUs.

CP8 There is an ability to harmonize around critical geospatial data assets.

CP9 Next-generation traffic management systems (TMS) at IOOs have been established for monitoring, proactive control, and decisionmaking that benefit from ADS vehicle data exchanges.

CP10 Infrastructure changes to IOO garages and facilities have been put in place or are being planned, as well as other new and supporting facilities and information.

OPERATIONS AND SERVICES

CAPABILITIES

The operations and services integration layer builds off the other layers to provide some tangible value to the travelers and users of the transportation system. The goal of the operations and service layer for ADS integration is still encapsulated by the definition of TSMO. Through this layer and associated systems, an integrated set of strategies are managed to optimize the performance (mobility and safety) of existing infrastructure.

Desired capabilities for the operations and services integration layer include:

- **OS1** Revised or restructured paratransit services offer new benefits made possible with accessible ADS vehicles, which drive models for widespread deployment.
- **OS2** IOOs are able to monitor and leverage data to manage and appropriately price demand, curb access, parking, and other potential changes introduced by ADS vehicle operations.
- **OS3** A fleet-based approach to transportation management is utilized that considers the operation of ADS and non-ADS fleets. TMCs may more readily exchange information with ADS fleets, dispatchers, and operators, as well as individual vehicles.
- **OS4** Established practices have been developed for sharing traffic-related operational strategies with ADS vehicles and receiving data from ADS vehicles.
- **OS5** Established partnerships exist with private sector mobility providers using ADS to supplement public provided transit.
- **OS6** Established performance-based procedures have been implemented for managing traffic most effectively based on ADS vehicle penetration rates and the physical infrastructure.
- **OS7** Data sharing programs or agreements are in place between public and private sectors to facilitate collaboration and the allowed use and sharing of data, including from ADS vehicles.
- **OS8** CDA has been researched and advanced by the TSMO community to deploy and implement practices, strategies, and systems that improve mobility and safety.
- **OS9** Emergency response and law enforcement have been trained and equipped to manage events involving ADS vehicles.
- **OS10** Procedures and protocols (with associated cost understanding) have been developed for ADS vehicle use in agency-performed construction and maintenance activities.
- **OS11** Agency freight management activities have adapted oversize/overweight permitting, inspection, and enforcement to include protocols for ADS vehicles.
- **OS12** Driver training/education needs have been updated to account for new human behavior, human factors, and safety risks caused by ADS integration.
- **OS13** New models for transit operations have been created to maximize benefits of ADS vehicles while maintaining compliance with Federal transit safety and workforce requirements.

CROSS-CUTTING CAPABILITIES

The cross-cutting functions layer is comprised of two major areas that affect and are needed to support each of the integration layers. The extent to which ADS integration changes the daily activities of transportation agencies remains to be seen. These changes will vary by agency. FHWA expects that agencies will define internal business processes needed to systematically implement activities to support ADS integration. Therefore, newly defined capabilities inherent to the agency (institutional capabilities) and workforce changes (potentially adding staff positions and adjusting definitions of existing positions) will likely be needed. Additionally, awareness and engagement functions refer to the need for outreach, education, and engagement with the traveling public, businesses, and the ADS industry.

INSTITUTIONAL CAPABILITY AND WORKFORCE

Desired capabilities for the institutional capability and work force area of the cross-cutting functions layer include:

CC1 Best practices across the country have been identified to inform agency professional capacity building, workforce recruitment, and training to create and retain technical expertise related to ADS infrastructure and deployments. Agencies are equipped to lead, support, and contract the decisionmaking, planning, design, implementation, operations, and maintenance of the cyber-physical infrastructure.

CC2 Guidance has been developed on topics of workforce development and management to support ADS vehicle use and micromobility.

CC3 Effects of ADS vehicles on private sector employment are understood.

COMMUNITY ENGAGEMENT

Desired capabilities for the community engagement area of the cross-cutting functions layer include:

CC4 Approaches to educate and inform travelers about ADS vehicle use, behavior, interactions, etc., have been developed and implemented across the country.

CC5 Policies and regulations are in place that consider ADS vehicle operations, as needed, that are nationally consistent to the extent possible. These policies also include resolution of conflicting legislation.

SNAPSHOT OF CAPABILITIES AT A LOCATION FOR ROADWAY ADS INTEGRATION

Readiness capabilities are identified to help transportation agencies understand, plan for, and eventually accomplish activities to address the roadway ADS integration needs. If accomplished, readiness capabilities would increase the preparedness of the transportation industry for ADS integration.

A small selection of capabilities are shown in figure 16 to illustrate how different aspects of the capabilities can combine to support roadway ADS integration in a location. Not all the capabilities listed in the roadway ADS integration section are shown.

PP1 — **ADS integration decisionmaking is increasingly accommodated and supported by transportation system performance metrics and performance management.**

PP2 — **Planning processes incorporate lifecycle investment in support systems for ADS integration at all levels, from national to local, including traditional STIP decisionmaking activities.**

CP1 — **Guidelines for uniformity in design and maintenance of TCDs, such as pavement markings, that support ADS operations have been developed, and many designs/facilities have been converted to match these guidelines.**

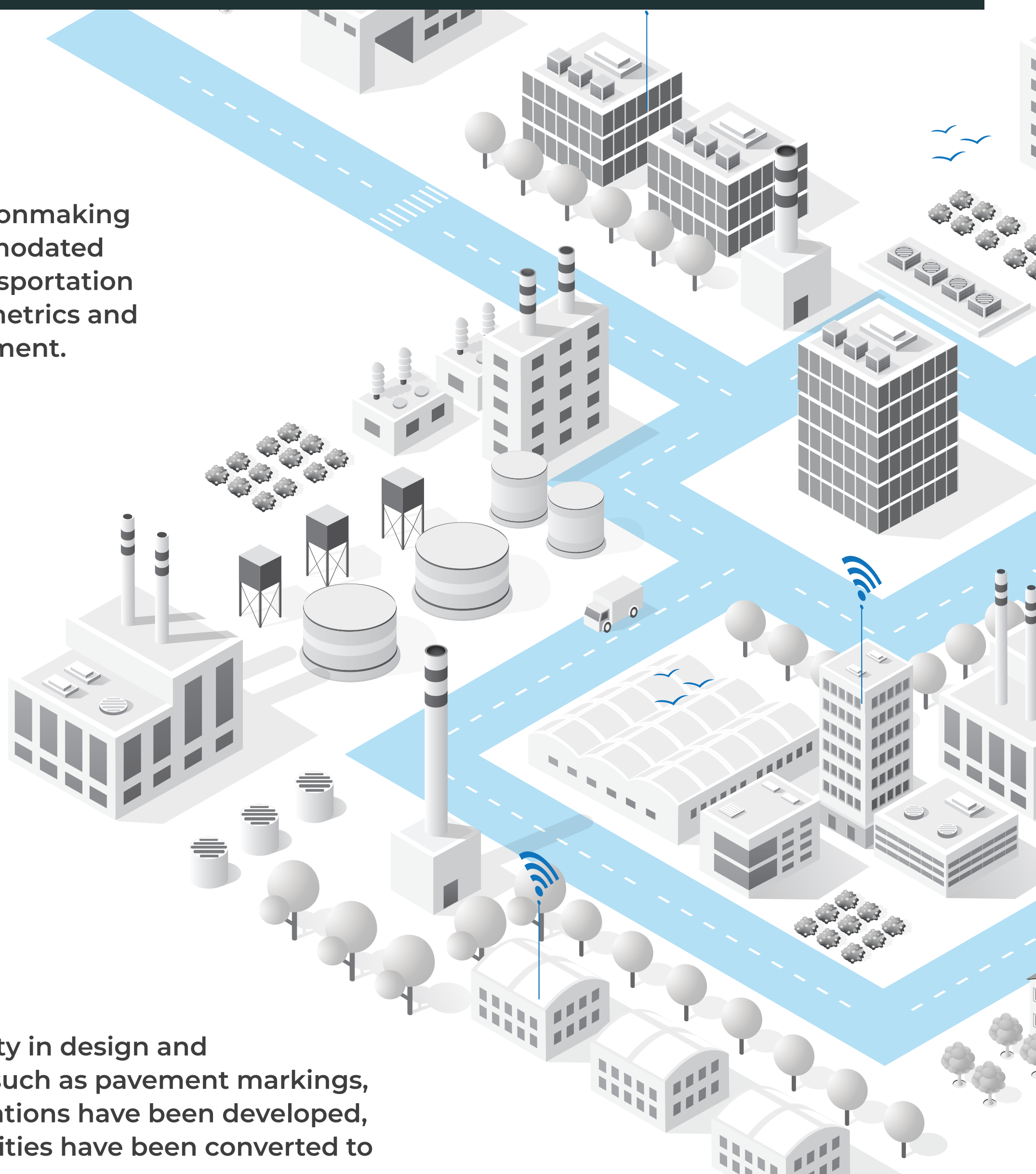
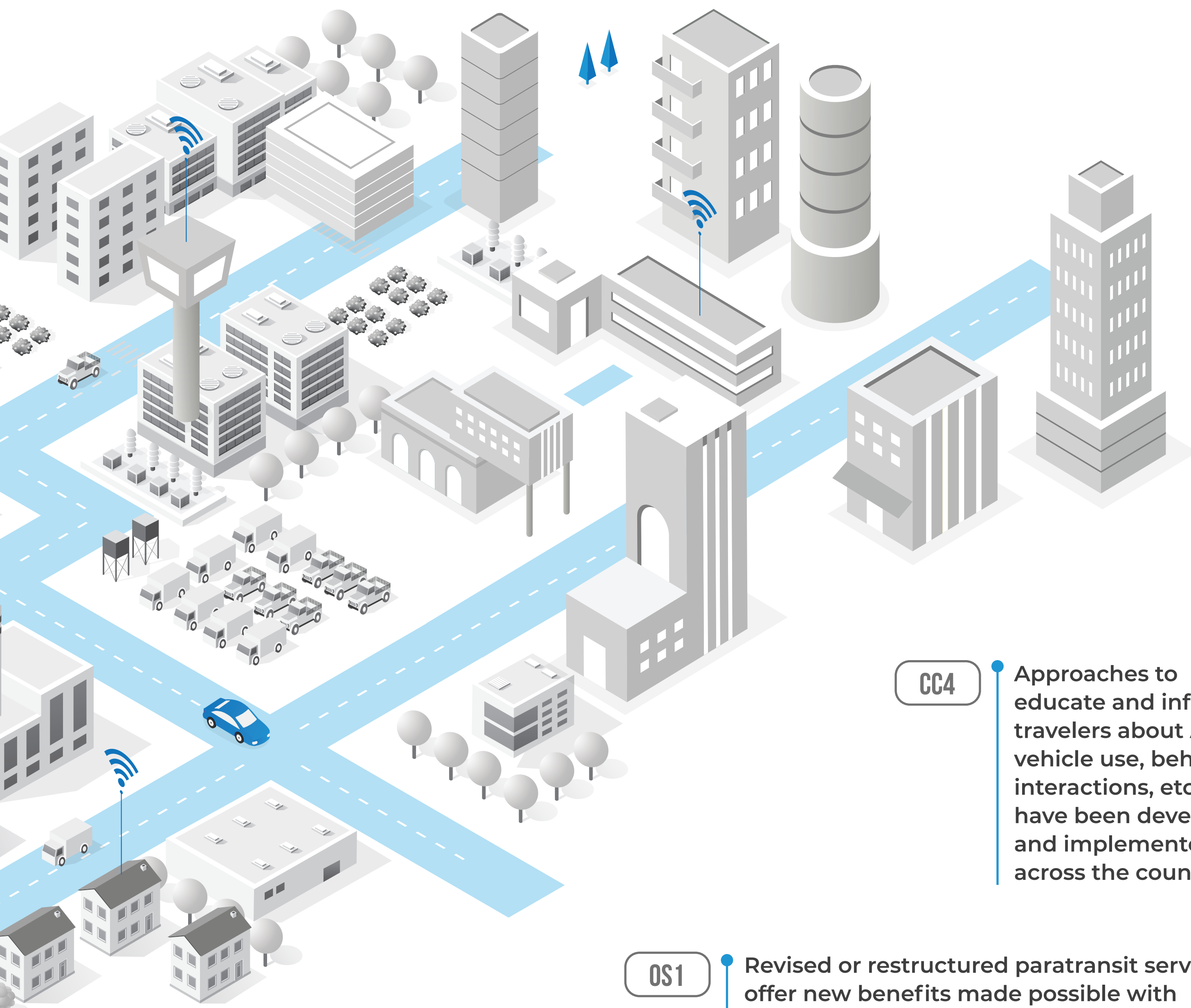


Figure 16
Snapshot of Capabilities Diagram
Source: FHWA

OS3 A fleet-based approach to transportation management is utilized that considers the operation of ADS and non-ADS fleets. TMCs may more readily exchange information with ADS fleets, dispatchers, and operators, as well as individual vehicles.

CP3 Flexible or changeable physical and digital infrastructure concepts around lane usage, roadside elements, and barriers are prioritized and available to support adaptive use of roadway by ADS use cases.



CC4 Approaches to educate and inform travelers about ADS vehicle use, behavior, interactions, etc., have been developed and implemented across the country.

OS1 Revised or restructured paratransit services offer new benefits made possible with accessible (ADS) vehicles, which drive models for widespread deployment.

CP9 Next-generation TMS at IOOs have been established for monitoring, proactive control, and decisionmaking that benefit from ADS vehicle data exchanges.

Figure 16
Snapshot of Capabilities Diagram
Source: FHWA

POSSIBLE INTEGRATION SCENARIOS

The uses of ADS-equipped vehicles will be diverse and include uses not imagined today. The local implementation of systems to accomplish the capabilities are likely to result in an endless list of possible scenarios for system and ADS-equipped vehicle interaction. ADS integration scenarios are illustrative examples to help initiate ideas around how ADS integration may proceed locally. These scenarios are are not intended to be representative or all-encompassing. Scenarios could include:

- Long-haul ADS freight vehicle arrival at destination
- Fixed-route ADS transit vehicle in metro area
- ADS vehicle for TNC ride-hailing service picking up a rider
- ADS local delivery vehicle performing a delivery
- ADS passenger vehicle encountering two freeway work zones including work zone setup
- ADS vehicle snowplow
- ADS paratransit vehicle operation in rural to urban setting

For integration scenarios to be effective, they must include enough detail about specific roles of each integration layer and expected capabilities such that key stakeholders in the local community will have a common frame of reference from which they can understand what ADS integration should be planned. In the future, these scenarios can be expanded to include more cooperative uses of ADS, such as the concepts defined in the CARMA[1] Program. The graphic below describes a possible path to developing and using ADS integration scenarios. A sample scenario definition is also provided.

1 https://highways.dot.gov/research/operations/CARMA

IDENTIFY LOCAL CAPABILITIES TO BE SUPPORTED

Based on the mapping of needs to capabilities, IOOs may identify the target capabilities for their roadway network.

IDENTIFY CANDIDATE SCENARIOS

IOOs are encouraged to develop scenarios for each use case envisioned locally. The scenarios should describe details of expected local capabilities and therefore describe how each integration layer will support ADS operations.

CONSENSUS BUILDING AROUND SCENARIOS

The initial scenarios may support local dialog among agencies to ensure consistency in understanding the planned role of capabilities to accomplish ADS integration. Collectively, participants in the process should add detail to the scenarios until the role of each capability is fully understood.

LONG-HAUL ADS FREIGHT VEHICLE ARRIVAL AT DESTINATION

Candidate features for this scenario include:

- **Use Case:** Automated trucking operations — long-haul freight
- **Conditions:** Good weather, daylight hours
- **Geographic context:** Suburban
- **Roadway Types:** Interstate, local roads
- **Capabilities utilized :** CP1, CP7, CP10 (p. 27) and PP6 (p. 26)

DESCRIPTION

In a suburban setting, an ADS-operated long-haul freight vehicle with a human operator on board is nearing the end of a 6-hour delivery run. The remainder of the route includes exiting the freeway and traveling approximately 2 miles on local roads to a local freight distribution center.

While on the freeway, the vehicle operates under ADS operation as part of a platoon of commercial vehicles, interacting with the other vehicles in the platoon to perform longitudinal and lateral control.

As the vehicle approaches the freeway exit, the vehicle departs from the platoon and exits the freeway. The vehicle proceeds under ADS operation while on the freeway, through the exit and along approximately 1 mile of local roads until the vehicle reaches the staging area. The staging area is a pre-designated location where operators engage or disengage the ADS operations and where the driver assumes manual control of the vehicle.

KEY CHALLENGES WITHOUT INTEGRATION

Without ADS-integration, challenges include:

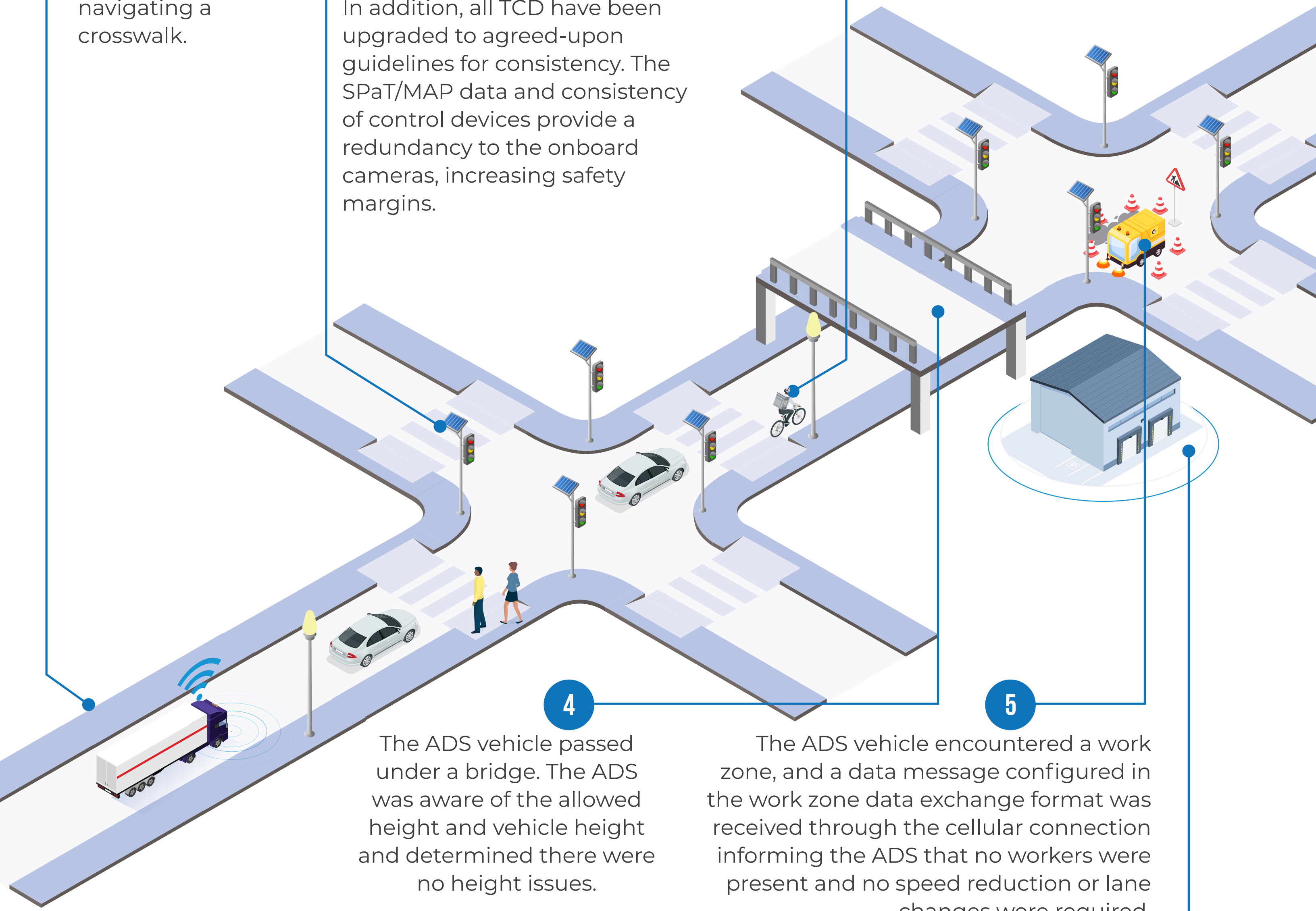
1. With no industry-wide approach to staging areas for activating/deactivating ADS, human drivers will take various approaches, not recognizing designated physical infrastructure options or limitations.
2. Without supporting connectivity to the infrastructure (e.g., work zone data, bridge height, signal phase and timing (SPaT) data), the improved safety that is afforded by redundancy may be missed at some locations.
3. Local differences in infrastructure (e.g., signage, controllers) may cause uncertainty in ADS operations.
4. It is likely that this trip would have occurred safely without ADS integration. However, assuming there are a large number (e.g., hundreds) of ADS freight vehicles arriving daily to the distribution center, even a small percentage of trips that do not occur safely will add up.

DURING THE ADS-OPERATED PORTION OF THE DRIVE ON THE LOCAL ROAD:

1 The ADS vehicle encountered other non-ADS-equipped vehicles at a traffic light, as well as pedestrians navigating a crosswalk.

2 The vehicle proceeded through two traffic signal-controlled intersections. As this corridor is frequented by ADS freight vehicles, SPaT/MAP data for both intersections were available. In addition, all TCD have been upgraded to agreed-upon guidelines for consistency. The SPaT/MAP data and consistency of control devices provide a redundancy to the onboard cameras, increasing safety margins.

3 The ADS vehicle encountered a bicyclist riding on the shoulder. The ADS detected the bicyclist and determined the ADS vehicle could safely proceed in its travel lane.



4 The ADS vehicle passed under a bridge. The ADS was aware of the allowed height and vehicle height and determined there were no height issues.

5 The ADS vehicle encountered a work zone, and a data message configured in the work zone data exchange format was received through the cellular connection informing the ADS that no workers were present and no speed reduction or lane changes were required.

STAGING AREAS

The staging area is not a dedicated area but rather a stretch of road commonly used for drivers to reassume control on the shoulder. The driver assumed control and the ADS portion of this trip was concluded. The driver proceeded to the freight distribution center.

Figure 17
Candidate Scenario Diagram
Source: FHWA

LONG-HAUL ADS FREIGHT VEHICLE ARRIVAL AT DESTINATION

A SAFE SYSTEM

Key safe system outcomes with ADS integration include:

1. The driver was familiar with the procedure the ADS vehicle would follow when exiting the platoon and performed his/her role in the process that was required.
2. The physical roadway (striping, signal control, signs) along the mile drive from the freeway to the staging area was at an acceptable level of consistency and maintained properly to support on-board sensors and cameras. Therefore, they were recognized adequately by the vehicle, and no navigation issues were encountered.
3. The ADS vehicle received notice of the work zone start and end locations, as well as the status of worker presence and any lane closures.
4. The ADS vehicle had, through the digital infrastructure, information about the bridge it traveled under and allowed height.

EFFICIENT OPERATIONS

Key efficient operations outcomes with ADS integration include:

1. Cyber-physical infrastructure enabled ADS operation until just prior to the freight distribution center, increasing mobility of all vehicles on the freeway and surface road.
2. The ADS driver was familiar with the process of assuming control in the staging area as he/she regularly perform similar actions.

INTEROPERABLE SYSTEMS

Key interoperable systems outcomes with ADS integration include:

1. The ADS vehicle successfully navigated local roads efficiently, causing minimal impacts and allowed efficient operations of the freight distribution center.
2. While the ADS vehicle had traveled through multiple States on this trip, local laws and policies for each State were accessible and included in the ADS control decisions.

EQUITABLE BENEFITS AND IMPACTS

Key equity and impact outcomes with ADS integration include:

1. The ADS vehicle operates in mixed traffic for the entirety of the trip, leveraging infrastructure that is available for all travelers.

NEXT STEPS

The ConOps document is intended to work together with other resources and activities to ultimately achieve the safest and most effective use of ADS-equipped vehicles. This document describes an illustrative "what" and "why" for roadway ADS integration. The "what" is described in the desired capabilities for each layer (i.e., cyber-physical, operations, planning/policy). The "why" is described in the needs derived from the use cases and outcomes and is validated in the scenario descriptions.

Ongoing local, State, Federal, and national collaborative activity around roadway automation integration will collectively determine how to implement the capabilities defined in this version and future versions of the ConOps. Collaborative partners include the existing and ever-evolving transportation community of research, standards-setting, policy-developing, and infrastructure and systems operating organizations.

Finally, stakeholder input will drive overall ADS vehicle deployment and use. While preparing for ADS integration, public sector transportation agencies and supporting associations can perform many activities to "ready" the transportation network for ADS integration using the capabilities described in this document. However, the development, deployment, and use of ADS vehicles by the private companies and individuals will be conducted by the industry and travelers.

FHWA will continue to assist stakeholders in utilizing the ConOps and evaluating its utility. FHWA's intention is to refine and supplement the ConOps, as necessary, to provide a knowledge resource for State and local IOO agencies to ready their organizations, physical assets, and policies for roadway ADS integration.

ACKNOWLEDGMENTS

The contents of this document have been developed based on extensive stakeholder input over the last 2 years. The authors greatly appreciate the time and expertise provided by the various State DOTs, metropolitan planning agencies, ADS developers, and other industry associations that participated in workshops, interviews, and other stakeholder meetings for this effort.

Roadway Automated Driving Systems Integration

Concept of Operations for Transportation Agencies
Version 1

U.S. Department of Transportation
Federal Highway Administration

U .S. Department of Transportation
Federal Highway Administration
Office of Operations
1200 New Jersey Avenue, SE
Washington, DC 20590

Toll-Free "Help Line" 866-367-7487
https://ops.fhwa.dot.gov