Identifying Real-World Transportation Applications Using Artificial Intelligence (AI)

Plan for Artificial Intelligence for Intelligent Transportation Systems

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16. Abstract

The purpose of this document is to present a five-year program plan for USDOT's AI for ITS Program. It is a companion document to the five-year roadmap and provides recommendations on investments and program activities to be conducted in the next five years to put the program on the path to promoting operational AI deployments by the end of the decade. The program plan is meant to be a living document to be updated periodically in concert with the roadmap.

The AI for ITS Program is a multimodal, multi-agency effort led by ITS Joint Program Office (JPO) with support from Federal Highway Administration (FHWA), Federal Transit Administration (FTA), Federal Motor Carrier Safety Administration (FMCSA), National Highway Traffic Safety Administration (NHTSA), Volpe Center, and other Federal partners.

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The authors would also like to thank the USDOT Stakeholders listed in Table 1, who participated in a 2-day virtual strategy event to provide insightful comments on the risks and rewards of investing in more than 40 potential applications of AI for five practical, real-world transportation scenarios.

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Finally, the authors would like to thank Dr. Karl Wunderlich for his feedback.

Table 1. USDOT Stakeholders

ID	EXPERT STAKEHOLDER	AFFILIATION
1	Brian Gardner	HOTM
2	Brian Philips	HRDS-2
3	Charles Fay	HRDS-2
4	Clayton Chen	HRDS
5	Dale Thompson	HRDO
6	David Kuehn	HTRM
7	David Perlman	Volpe Center
8	Dee Williams	NHTSA
9	Edward Fok	FHWA RC
10	Egan Smith	ITS JPO
11	Frederick Bowers	HOTM
12	Gene McHale	HRDO
13	Govind Vadakpat	HRDO

ID	EXPERT STAKEHOLDER	AFFILIATION
14	Gwo-Wei Torng	FTA
15	James Colyar	HOTM
16	James Pol	HRDS
17	Jay Baillargeon	FRA
18	Jeff Purdy	HOFM
19	Jeremy Raw	HOTM
20	Joe Gregory	HOTM
21	John Halkias	HOTM
22	Jon Obenberger	HRDO
23	Jonathan Walker	ITS JPO
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25	Ken Leonard	ITS JPO
26	Ken Petty	HRTM
27	Kevin Dopart	ITS JPO
28	Michael Pina	ITS JPO
29	Michael Solter	ITS JPO
30	Michelle Noch	ITS JPO
31	Mohammed Yousuf	HRDO
32	Murat Omay	FTA
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Chapter 1. Introduction

Background

Artificial Intelligence (AI) is revolutionizing every walk of life, allowing machines to learn from experience, adapt, and perform tasks that have historically required human cognition. AI was first conceptualized more than 60 years ago, and interest in AI applications has risen and fallen. Several factors have contributed to a recent resurgence in AI over the last decade, including increased computing power, mass data storage, and innovations in AI algorithmic approaches (including in machine learning (ML), a sub-field of AI).

AI has been broadly embraced, with promises of considerable benefits in productivity, efficiency, and quality of life. AI plays a significant role in the banking and finance industry for fraud detection and high frequency stock trading. AI is used in national security for cybersecurity and object/threat identification. AI is used in health care to analyze medical data to help with diagnosis and to make predictions about effective treatment options for patients. The current generation of AI sub-fields and techniques is poised for expansion into the transportation ecosystem—with potentially transformative impacts.

The United States Department of Transportation (USDOT) Intelligent Transportation Systems (ITS) Joint Program Office (JPO) and its modal partners have been leaders in tackling fundamental problems in mobility, safety, and equity leveraging emerging technologies such as connected vehicles (CV), automated vehicles (AV), shared mobility services, and accessible transportation capabilities. In the last few years, explorations into AI have grown tremendously within the USDOT (Thompson, 2019). Some of the USDOT's modal administrations, including Federal Highway Administration (FHWA), Federal Railroad Administration (FRA), and Federal Aviation Administration (FAA), have been at the forefront of adopting AI solutions for mission delivery. AI-based applications have been implemented for video analytics, anomaly detection, safety analysis, and data fusion. For example, FHWA's Exploratory Advanced Research Program funded the development of AI technologies for the collection of large amounts of traffic data, including safety data, to spot trends and identify relationships between seemingly disparate data streams, and for video analytics to help determine driver behavior in various driving scenarios (U.S. Department of Transportation, 2019). FHWA's Traffic Analysis Tools (TAT) Program is investigating the use of AI for developing prediction techniques and evaluation tools (FHWA ATDM, 2020). FHWA's Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) Program recently awarded more than $16 million in grants to develop AI powered solutions for multimodal transportation management (USDOT, 2020). FRA is developing a suite of technologies for predictive analytics and intruder detection using AI and unmanned aircraft systems (UAS) (Baillargeon, 2019). Other agencies, such as Federal Transit Administration (FTA), Federal Motor Carrier Safety Administration (FMCSA), and Pipeline an Hazardous Materials Safety Administration (PHMSA), are exploring the promise that AI has to offer in citizen-facing services (Borener, 2019).

On February 11, 2019, the Executive Order 13859 on Maintaining American Leadership in Artificial Intelligence was signed to implement a government strategy to elevate AI as one of its key priority science and technology areas (White House, 2019). The USDOT Strategic Plan (2018-2022) identifies "Innovation: Lead in the Development and Deployment of Innovative Practices and Technologies that Improve the Safety and Performance of the Nation's Transportation System" as one of the four strategic goals (U.S. Department of Transportation, 2018). In conjunction with the USDOT's strategic goals and the Executive Order, the ITS JPO established research in AI as a priority area to accelerate adoption of AI by state and local agencies for addressing transportation problems. Towards this end, USDOT has identified two key ways in which it will engage with emerging AI applications for transportation: (i) **enabling** the integration of AI into safety-critical domains, and (ii) **adopting and deploying** AI-based tools to improve the delivery of enterprise functions (U.S. Department of Transportation, 2019).

As the USDOT embarks on advancing AI in transportation, it is essential to prepare a systematic path for facilitating the next generation of transportation systems with capitalize on the transformational power of AI.

Purpose

The purpose of this program plan is to present a five-year program plan for USDOT's AI for ITS Program. It is a companion document to the five-year roadmap and provides recommendations on investments and program activities to be conducted in the next five years to put the program on the path to promote the adoption of AI in transportation. The program plan is meant to be a living document to be updated periodically in concert with the roadmap.

The AI for ITS Program is a multimodal, multi-agency effort led by ITS JPO with support from Federal Highway Administration (FHWA), Federal Transit Administration (FTA), Federal Motor Carrier Safety Administration (FMCSA), National Highway Traffic Safety Administration (NHTSA), Volpe Center, and other Federal partners.

Methodology

To shape the development of the roadmap and this program plan, **first**, a definition of AI with a focus on ITS was developed. The recommended definition aligns with the definitions of AI in the Congress S.2217 – Future of Artificial Intelligence Act of 2017 (Congress, 2017). More information is included in Chapter 2. **Second**, a review of literature was conducted to understand the landscape of how AI is being leveraged in transportation, and a report was developed to summarize existing as well as potential applications enabled by AI to address specific operational challenges and needs (Vasudevan, et al., 2020). More information is included in Chapter 2. **Third**, interviews of both federal as well as external stakeholders from the private sector and academia were conducted to identify 40 potential applications of AI for five, practical transportation scenarios (Vasudevan, et al., 2020). **Finally**, a virtual strategy event was held with ITS JPO and modal partners to gather ideas for additional applications enabled by AI, solicit input on the risks and rewards of investing in the AI-enabled applications, and prioritize the applications for potential investments. More information is included in Chapter 3 and Appendix A.

Organization

The program plan is organized as follows:

- Chapter 2 provides an overview of AI for ITS, including the definition of AI for ITS.
- Chapter 3 provides a summary of the stakeholder engagement sought to shape the development of the roadmap and program plan, including a summary of feedback received from federal stakeholders

at a virtual strategy event. A more detailed discussion of the outputs from the virtual event is documented in Appendix A.

- Chapter 4 provides the AI for ITS Program's strategic direction, including the vision, mission, goals, outcomes, and success indicators.
- Chapter 5 presents the key challenges for establishing and sustaining the federal AI for ITS Program as well as the barriers to adoption of AI-enabled solutions by agencies. This chapter also identifies the potential approaches for mitigating these challenges and barriers.
- Chapter 6 presents descriptions of potential projects that will help address the identified challenges of the AI for ITS Program.

Chapter 2. Overview of AI for ITS

This chapter provides an overview of AI for ITS, including a definition of AI, summary definitions of the 11 broad categories of AI-enabled applications for ITS, and the role of USDOT for each category.

AI for ITS Definition

The research team worked with the USDOT to recommend a definition of AI with a focus on ITS. The process included compiling a list of credible definitions of AI by conducting a comprehensive online search, crafting new definitions through internal team brainstorming sessions, comparing the 77 definitions using natural language processing (NLP), and unsupervised machine learning (clustering), and prioritizing the definitions based on four criteria, including relevance, clarity, inclusivity, and simplicity. The top two definitions were combined, based on USDOT feedback, to create the recommended definition, which is consistent with existing US government definitions of AI (Congress, 2017).

> Artificial Intelligence (AI) refers to processes that make it possible for systems to replace or augment routine human tasks or enable new capabilities that humans cannot perform. AI enables systems to: (1) sense and perceive the environment, (2) reason and analyze information, (3) learn from experience and adapt to new situations, potentially without human interaction, and (4) make decisions, communicate, and take actions.
>
> Examples of AI include machine learning, natural language processing, and object recognition. Machine learning (ML) is a broad subfield of AI in which computers learn from data, discover patterns and make decisions without human intervention. The ML field is broadly categorized into supervised, semi-supervised, unsupervised and reinforcement learning.
>
> In ITS, AI can be used to replace or augment actions of field, handheld and remote sensing devices, connected and automated vehicles, TMC operators, transit and freight operators, decision-makers, and travelers. For example, AI can be used to identify objects and images, recognize speech and audio, process large amounts of data to recognize patterns, learn from experience, and adapt to new environments to predict traffic phenomena, provide situational awareness, assist drivers with maneuvering, recognize unsafe driving conditions in real-time, identify or isolate malfunctioning or misbehaving system entities, improve cyber-security, operate infrastructure devices and vehicles, monitor pavement and support decision-making. AI can be embedded in any system entity (vehicle, mobile device, roadside infrastructure, or management center) or be distributed among many entities in the system.

This definition has three key components. First, it articulates AI's capacity to replace or augment human tasks and provides broad examples of AI. Second, it defines machine learning and mentions related concepts. Finally, it focuses on AI in ITS and provides example activities and applications in this domain. A detailed description of the approach and other definitions that were considered can be found in the USDOT *Memorandum on Documented Definition of AI with focus on ITS* (Dang, Townsend, & Vasudevan, 2019).

Figure 1 provides a list of the specific system functions, mentioned in the definition, that are enabled by AI-powered applications.

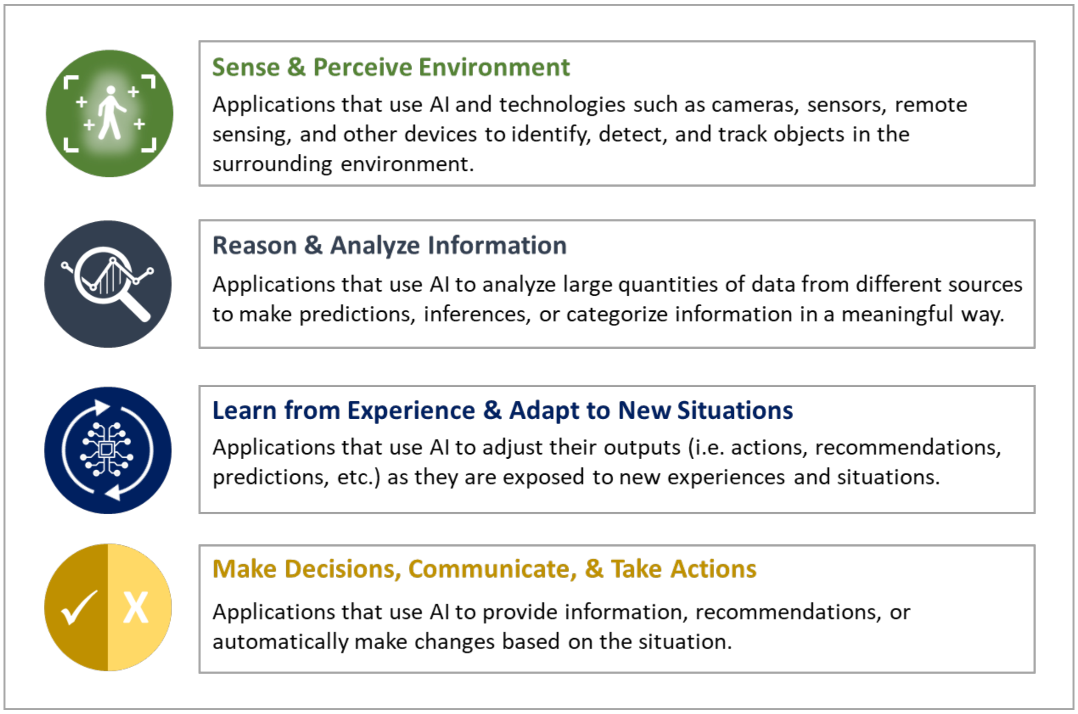

Figure 1. System Functions Enabled by AI. (Source: USDOT)

Potential Categories of AI-Enabled Applications in ITS

Eleven broad categories of AI-enabled applications were defined to help identify and categorize existing and potential ITS applications that could be enhanced with AI. These 11 categories and their definitions are documented in Table 2. The 11 categories can be mapped to the Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT) version 8.3 (U.S. Department of Transportation, 2020).

Table 2. Potential Categories of AI-Enabled Applications in ITS

ID	AI-Enabled Application Category	Definition/Scope
1	Advanced Driver Assistance Systems and Automated Driving Systems	This category includes applications that use AI to enable vehicle automation, including advanced driver assistance systems (ADAS) and Automated Driving Systems (ADS). AI may also be applicable to emerging driver warning systems and connected vehicle capabilities. CV technologies enable cars, buses, trucks, trains, roads and other infrastructure, and our smartphones and other devices to communicate through wireless communications. AI capabilities may enable more robust, reliable, and safe managing of the wireless communications spectrum. Automated Driving Systems are capable of performing the entire dynamic driving task on a sustained basis and rely on forms of AI to enable object and event detection and response capabilities. ADAS, which operate a lower level of automation, may also rely on forms of AI to enable key performance capabilities. ADAS are designed to assist the driver with monitoring, warning, braking and steering tasks. Examples of ADAS solutions are Adaptive Cruise Control (ACC), Intelligent Speed Adaptation (ISA), and integrated ACC and lane-following systems enabling Level 2 automated driving. Finally, AI can enable non-automated driver alerts and warnings. For example, AI can be used to predict the end of queue to generate an in-vehicle Queue Warning message. AI can be used to predict the possibility of a red-light violation to generate an in-vehicle Red Light Violation Warning message.
2	Cybersecurity	This category includes applications that make use of AI to provide the security of cyber technologies used in transportation for communications and control; positioning, tracking, and navigation; and operations and management. Specifically, this category includes applications that make use of AI for providing cybersecurity to vehicles, devices, and infrastructure operating in a connected or automated environment, safeguarding critical systems and sub-systems of the transportation system, enabling safe and efficient operations, and improving the system resilience, especially following a disaster. AI can be applied to ensure confidentiality, integrity, and availability of systems by: proactively identifying risks to resources supporting critical functions; preventing the damage to, unauthorized use of or exploitation of these resources and limiting the impact of cybersecurity incidents; detecting and responding to incidents that have occurred; and recovering or restoring these resources.

ID	AI-Enabled Application Category	Definition/Scope
3	Accessible Transportation	This category includes applications that make use of AI specifically for accessible transportation supporting independent travel for all travelers including people with disabilities and older adults. The accessibility of a transportation system can be described in terms of the ability of individuals to go from home to a destination without breaks in the travel chain regardless of functional ability. The travel chain can be made up of any combination of trip links including pre-trip planning, wayfinding and navigation, surface street crossing, and navigating complex indoor environments. If one link of the trip is not accessible, then access to a subsequent link is unattainable and the trip cannot be completed. Thus, the travel chain defines the scope of potential research and development in accessible transportation. The technologies, including AI, serves to reduce difficulty in traveling and tailor solutions to each individual's unique set of abilities and challenges. AI can help enhance the capability of users to reliability and safely execute independent travel for all links in the travel chain.
4	Traveler Decision Support Tools	This category includes applications that make use of AI for the provision of static, dynamic, and other information about the transportation network, such as route and mode travel times, transit status, mobility services, flight arrivals, weather conditions, pricing information, and incentive-based data. These AI-enabled applications can monitor information, process traveler requests, predict roadway or infrastructure conditions, route travel and arrival times, and help travelers of all functional abilities plan trips that are tailored to their user preferences. These AI-enabled applications help travelers make decisions regarding key elements of the trip chain, such as determining the destination, selecting and booking the mode used to travel, the route taken to the destination, the timing of the trip, and the method used to pay for the selected modes, before and during their trips. Additionally, transportation system managers and TMC operators can use the information, including traveler decisions, as input to their decision support systems. In many instances, the applications in this category are also relevant to the Accessible Transportation, Transit Operations and Management, and Transportation Systems Management and Operations categories.

ID	AI-Enabled Application Category	Definition/Scope
5	Transportation Systems Management and Operations (TSMO)	This category includes applications that make use of AI to optimize the performance of a multimodal infrastructure through implementation of real-time and dynamic systems, services and management strategies to preserve capacity, advance efficiency and productivity, and improve the security, safety, and reliability of our transportation system. AI would be applied at the system, technical, and operational levels. These applications can consider both strategic (TSMO programs and applications) and tactical decision-making (operational approaches). For example, applications could range from specific TSMO programs such as work zone management, traffic incident management, or road weather management and operational tactics could include service optimization like ramp meeting, variable speed limits, or adaptive traffic signals. TSMO includes efforts to proactively operate and improve the performance of the multimodal transportation system as a whole, by managing current and predicted travel demand. Thus, TSMO crosses political, modal, and jurisdictional boundaries.
6	Commercial Vehicle and Freight Operations	This category includes applications that make use of AI to address the management of the efficiency, safety, and operation of commercial vehicle fleets and the movement of freight. Specifically, this category includes applications that make use of AI to expedite the authorization process for freight to move across national and other jurisdictional boundaries, and expedite inter-modal transfers of freight and the operation of freight vehicles that exchange information on the motor carrier, the vehicle, the driver, and, in some cases, the cargo to enhance freight operations and management. AI can be applied for route planning and fleet management; freight drayage optimization; asset tracking; on-board cargo condition monitoring; gateway facilitation to automate operations at terminal gates, highway inspection stations, and border crossings; freight signal priority; and freight-specific traveler information. The commercial fleet and freight vehicles may or may not be equipped with CV, AV, or ADAS technology.

ID	AI-Enabled Application Category	Definition/Scope
7	Transit Operations and Management	This category includes applications that make use of AI to address the management, operations, maintenance and security of public transportation and mobility services to enable them to provide services that meet the demands of users and operate an efficient and integrated mobility system. Applications in this area include predictive tools for maintenance, incident detection, dynamic trip planning based on real time conditions and dynamic service allocation for flexible mobility services. This category also includes advanced integrated fare payment systems using AI techniques to manage demand response reservations. This category covers both systems for fixed route and demand responsive services, as well as those passenger rail systems operated by transit agencies. The transit vehicles may or may not be equipped with CV, AV, or ADAS technology.
8	Emergency Management	This category includes applications that make use of AI to address the management by public safety agencies of emergencies or incidents in the transportation network including those relating to HAZMAT materials that are transported through the transportation network. It covers public safety (police, fire, and emergency medical services) agencies using emergency management services to improve their response to emergency situations. The category also covers how emergency operations centers interact with transportation and public safety agencies to support response to disasters and for evacuations impacting the transportation network. The devices and vehicles may or may not make use of CV, AV, or ADAS technology.
9	Air Traffic Management	This category includes applications that make use of AI for safe and efficient air traffic management and operations that can be adapted for use in ITS.
10	Remote Sensing	This category includes applications that make use of AI for intelligent remote sensing such as use of drones and unmanned aerial vehicles (UAV) for traffic monitoring, pavement monitoring, bridge inspections, and aerial mapping to support transportation planning, management and operations, incident management, and transportation infrastructure maintenance and construction.

ID	AI-Enabled Application Category	Definition/Scope
11	Asset Management and Roadway Construction and Maintenance	This category includes applications that make use of AI to address the strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on engineering and economic analysis based upon quality information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the lifecycle of the assets at minimum feasible cost. This could apply to all highway/transportation physical assets including pavements, bridges, pavement markings, signs, guardrail, slopes, culverts, etc.

Potential Roles and Opportunities for USDOT Investments

This section discusses the potential roles and opportunities for USDOT to invest in AI-enabled applications under the 11 broad categories.

Advanced Driver Assistance Systems and Automated Driving Systems

This category is aligned with USDOT's Connected Vehicle and Automation Programs. The Connected Vehicle Program focuses on the adoption and deployment of CV systems by working with state and local agencies, vendors and device makers, and the public. The Automation Program focuses on research about automated road-vehicle systems and related technologies that transfer some amount of vehicle control from the driver to the vehicle (U.S. Department of Transportation, 2020).

USDOT is collaborating with public and private partners, including State and local governments, vehicle and device manufacturers, and academia, to advance connected vehicle development and implementation. The ITS JPO, is working with modal administrations within the USDOT to coordinate and foster the advancement of connected vehicle technologies. Significant progress has already been made in testing and piloting connected vehicle technologies and applications in real-world operational environments.

USDOT also plays a significant role by ensuring that automated vehicles can be safely and effectively integrated into the existing transportation system, alongside conventional vehicles, pedestrians, bicyclists, motorcyclists, and other road users. USDOT has an interest in supporting innovations that improve safety, reduce congestion, improve mobility, and increase access to economic opportunity. Finally, by partnering with industry in adopting market-driven, technology-neutral policies that encourage innovation in the transportation system, USDOT seeks to fuel economic growth and support job creation and workforce development (U.S. Department of Transportation, 2018). To accomplish these goals, USDOT works closely with stakeholders in the private and public sectors to pursue the following activities (U.S. Department of Transportation, 2018):

- Establish performance-oriented, consensus-based, and voluntary standards and guidance for vehicle and infrastructure safety, mobility, and operations.
- Conduct targeted research to support the safe integration of automation.
- Identify and remove regulatory barriers to the safe integration of automated vehicles.

- Ensure national consistency for travel in interstate commerce.
- Educate the public on the capabilities and limitations of automated vehicles.

Investment in this category is an opportunity for USDOT to play a key role in enabling a more robust and reliable management of the wireless communications spectrum using AI techniques. Secondly, although development of AI-enabled applications in this category is predominantly led by the private industry, forging public-private partnerships will enable greater insights into technology performance, which can help inform future policy development.

Cybersecurity

In exploring the potential of connected vehicles and other advanced technologies, USDOT understands that cyber security has an even more important role—systems, devices, components, and communications must be protected from malicious attacks, unauthorized access, damage, or anything else that might interfere with safety functions. This category is aligned with USDOT's research programs on ensuring a secure connected transportation environment (U.S. Department of Transportation, 2020).

As noted for the category on "Advanced Driver Assistance Systems and Automated Driving Systems," by funding AI research and deployment in this category, the USDOT will have an opportunity to understand the nature of potential cyber threats, how AI can automate detection and mitigation, and use these findings to inform policy and future investment. In addition, investment in this category is an opportunity for USDOT to play a key role in ensuring safety and security of AI-enabled systems, including developing standards. The NIST National Cybersecurity Center of Excellence (NCCoE) builds cybersecurity reference solutions. USDOT could leverage their existing Practice Guides, which would not only boost intergovernmental coordination but also reduce the development effort.

Accessible Transportation

This category is aligned with USDOT's accessible transportation research supporting independent mobility options for all travelers including people with disabilities, older adults and other transportation underserved communities. USDOT conducts foundational research to support an increase in independent mobility of all travelers through the use of ITS and other advanced technologies through several multimodal research efforts, including the Accessible Transportation Technologies Research Initiative (ATTRI) and Mobility of Demand (MOD) Program. ATTRI leads the research, development, and implementation of transformative solutions, applications and systems for all people, including those with disabilities, to effectively plan and execute their travel (U.S. Department of Transportation, 2020), while the MOD program enables and leverages advancements in technology and operations to create an environment where all travelers have safe mobility options, ensuring reliable, informed, and efficient travel in a multi-modal network that prioritizes individual, on-demand mobility (U.S. DOT Intelligent Transportation Systems Joint Program Office, 2020). These and other USDOT research efforts provide information on comprehensive user needs analysis, technology scans, prototypes, and demonstrations of innovative technologies and new service models.

Building from this foundational research in concert with advancements in emerging technologies and practices, USDOT launched a new initiative, which includes several multimodal efforts, to expand access to transportation for people with disabilities, older adults, and individuals of low income. These include the Inclusive Design Challenge, the Mobility for All Pilot Program, and the Complete Trip-ITS4US Deployment Program (U.S. Department of Transportation, 2020). The Inclusive Design Challenge seeks innovative design solutions that can enable people with physical, sensory, and cognitive disabilities to use automated vehicles to access jobs, healthcare, and other critical destinations (U.S. Department of Transportation, 2020). Federal Transit Administration (FTA)’s Mobility for All Pilot Program seeks to improve mobility options through employing innovative coordination of transportation strategies and building partnerships to enhance mobility and access to vital community services for older adults, individuals with disabilities, and people of low income (Federal Transit Administration, 2020). To accelerate the piloting and testing of integrated emerging technologies to improve mobility and accessibility for all travelers in real-world situations, the ITS JPO, in coordination with the Office of the Secretary and modal partners, launched the Complete Trip-ITS4US Deployment Program (U.S. Department of Transportation, 2020). This program enables large-scale, replicable deployments of integrated innovative technologies and partnerships to address the challenges of planning and executing all segments of a trip.

As considerations for accessibility and inclusive design have not always been present in research and development of emerging technologies for transportation, USDOT has an important role in encouraging development and deployment of promising AI and other emerging technologies to improve mobility options for all travelers. Working cooperatively with USDOT’s modal partners, state and local agencies, academia and the private sector is key for developing and deploying these critical technologies. Expanding public-private partnerships and engaging diverse stakeholders will help accelerate AI advances in this area.

Traveler Decision Support Tools

The private sector leads development of applications under this category. Due to limited funding, state agencies look to the private sector to offer lower cost solutions. USDOT can play a central role in supporting public-private partnerships in the areas of data sharing, user privacy, human-machine interface, and driver distraction.

While the USDOT is unlikely to develop personal mobile traveler information applications, there is an opportunity to foster innovation in using AI to integrate multi-source, multi-sensor data which may be used by the private sector for developing traveler information applications as well as by state and local agencies to inform TSMO and regional management strategies. These data could be particularly valuable during adverse weather events and evacuations when multiple municipalities and states must coordinate responses.

Transportation Systems Management and Operations

This category is aligned with the FHWA Office of Operations Programs (U.S. Department of Transportation, Federal Highway Administration, 2020). The USDOT can play a major role in supporting state and local agencies in implementing AI solutions to address their TSMO challenges as well as in supporting public-private partnerships. AI can enhance the current capabilities of agencies to move up the active and integrated management continuum and manage their corridors and networks proactively.

FHWA’s Exploratory Advanced Research (EAR) Program has recently supported two research areas to develop technologies associated with AI and ML. One area is the collection of large amounts of traffic data, including safety data, to spot trends and identify relationships between seemingly disparate data streams. The second area is the development of video analytics research to help determine driver behavior in various driving scenarios (U.S. Department of Transportation, 2019).

Various types of AI technologies could be used to help infrastructure owner-operators (IOO) for TSMO. AI could provide significant performance benefits compared to traditional modeling approaches (Gettman, 2019). The USDOT can continue to raise awareness of AI in TSMO, foster collaboration and best practice sharing, and support new planning and programming approaches necessary to accommodate AI technologies.

Commercial Vehicle and Freight Operations

This category is aligned with the missions of the FHWA Office of Freight Management and Operations and FMCSA. FHWA Freight Management and Operations works to improve goods movement by fostering public-private partnerships. FMCSA partners with industry, safety advocates, and State and local governments to improve the safety of commercial motor vehicle (CMV) through regulation, education, enforcement, research, and technology.

The USDOT has an opportunity to foster innovation in seeking AI-enabled solutions to improve safety of commercial vehicles and promote public-private partnerships in developing solutions for improving goods movement and reliability of freight travel. Similar to the category on Traveler Decision Support Tools, USDOT can also play a role in supporting public-private partnerships in the area of data sharing.

Transit Operations and Management

This category is aligned with the FTA's Office of Research, Demonstration and Innovation focus areas (Federal Transit Administration, 2020). FTA provides financial and technical assistance to local public transit systems, including buses, subways, light rail, commuter rail, trolleys, and ferries. FTA also oversees safety measures and helps develop next-generation technology research (U.S. Department of Transportation, 2018). FTA is investing significant research resources to support the commercialization of innovative solutions in transit automation. FTA is also investing in emerging or innovative mobility services as part of the MOD Sandbox Demonstration Program. MOD allows for the use of on-demand information, real-time data, and predictive analysis to provide travelers with transportation choices that best serve their needs and circumstances (Federal Transit Administration, 2020). Thus, although the private sector leads development of applications under this category, USDOT has an opportunity to foster innovation through data sharing, AI-enabled solutions, and expanding public-private partnerships.

Emergency Management

This category is aligned with the FHWA's Emergency Transportation Operations Program (U.S. Department of Transportation, Federal Highway Administration, 2020). The USDOT can play a major role in implementing AI solutions to help state and local agencies as well as other federal authorities prepare for and respond to disasters rapidly and effectively. The USDOT could leverage AI for emergency response management to reduce transportation-related fatalities, secondary incidents, and serious injuries in evacuations, disasters, and other emergency scenarios.

Air Traffic Control and Management

The Federal Aviation Administrator (FAA) is the regulator of all the nation's civil aviation activities, including management of air traffic in U.S. airspace. The FAA conducts research on and develops systems and procedures needed for a safe and efficient system of air navigation and air traffic control.

The FAA helps develop better aircraft, engines, and equipment and test or evaluate aviation systems, devices, materials, and procedures (U.S. Department of Transportation, Federal Aviation Administration, 2018). As automation and AI continue to change the aviation landscape, the FAA may need to evolve planning, policy, data, and other practices in air traffic management.

The USDOT could play a role in supporting state and local agencies as well as public-private partnerships in adapting AI solutions developed under this category for ITS problems.

Remote Sensing

The FAA collaborates internally and maintains extensive partnerships across government, industry, and academia to develop integrated research plans that support the development of regulations, policies, procedures, guidance, and standards for drone operations. Research activities such as flight tests, modeling and simulation, technology evaluations, risk assessments, and data gathering and analysis provide the FAA with critical information in areas such as Detect and Avoid, UAS Communications, Human Factors, System Safety, and Certification, all of which enable the Agency to make informed decisions on safe drone integration (U.S. Department of Transportation, 2019). The near-term benefits of autonomous UASs for TSMO could be substantial, but depending on the development of acceptable use regulations, technical standards, and operating policies. These regulatory and policy developments will be required along with the resolution of technical challenges of autonomous flight, sense-and-avoid, intervehicle communication, and mission tasking (Gettman, 2019).

USDOT can play a major role in supporting state and local agencies as well as public-private partnerships in implementing applications enabled through data collected by drones, satellite imagery, and unmanned aerial vehicles, and processed using image recognition and other AI techniques.

Asset Management and Roadway Construction and Maintenance

This category is aligned with USDOT's programs on Asset Management and Construction Management (U.S. Department of Transportation, Federal Highway Administration, 2020). The FHWA Asset Management Team provides develops policies for physical assets, and partners with public agencies and others to achieve its goals. AI and sensor data from images and videos could make asset inspection safer and more efficient. However, new sensors present privacy concerns for roadway users. Therefore, USDOT has an opportunity to inform policies related to use of new sensors. USDOT can also play a major role in supporting state and local agencies with implementing AI solutions to address their asset management and construction problems.

Chapter 3. Summary of Stakeholder Engagement

A systematic approach was used to engage stakeholders from ITS JPO and modal partners, as well as the public and private sectors to shape the development of the roadmap and this program plan. This included conducting a review of literature to understand how AI is being leveraged today in transportation, conceptualizing how AI could potentially be used to address specific operational challenges, and gathering feedback from stakeholders through various mechanisms. This chapter summarizes the systematic approach that was used to gather input from stakeholders.

- **First,** literature and industry reviews of AI-enabled applications were conducted. A report titled, *Summary of Potential Applications of AI in Transportation*, was developed summarizing existing and potential applications enabled by AI for transportation based on the reviews. Feedback was sought on the report from experts at ITS JPO, FHWA Operations, FHWA Operations R&D, FHWA Operations Asset Management, FHWA Resource Center, and Volpe Center.
- **Second,** phone interviews of 23 expert stakeholders from USDOT, academia, and public and private sectors, were conducted to discuss their experience using AI to address transportation problems, including the AI applications employed, types of data used, benefits experienced, challenges faced, and any lessons learned.
- **Third,** using information from the literature reviews and expert phone interviews, a second report titled, *Real-World AI Scenarios in Transportation for Possible Deployment*, was developed to conceptualize and identify potential applications of AI for five practical, real-world transportation scenarios. Feedback was sought on the report from experts at ITS JPO, FHWA Operations, FHWA Operations R&D, FHWA Operations Asset Management, FHWA Office of Freight Management and Operations, FHWA Resource Center, and Volpe Center.
- **Fourth,** a virtual strategy event was held with experts from ITS JPO, FHWA Operations, FHWA Operations R&D, FHWA Safety R&D, FHWA Freight Management and Operations, FHWA Operations Asset Management, FHWA Resource Center, FMCSA, FRA, FTA, NHTSA, and Volpe Center to collect feedback on the risk, reward, and priority of 40 individual applications enabled by AI. A summary if the virtual event is provided below.
- **Finally,** a preliminary high-level roadmap and a companion high-level white paper were drafted and reviewed with the experts from ITS JPO, FHWA Operations R&D, and Volpe Center.

Summary Stakeholder Feedback at Virtual Strategy Event

A virtual strategy event was held on June 17-18, 2020 with experts from ITS JPO, FHWA Operations, FHWA Operations R&D, FHWA Safety R&D, FHWA Freight Management and Operations, FHWA Operations Asset Management, FHWA Resource Center, FMCSA, FRA, FTA, NHTSA, and Volpe Center. A total of 42 experts were invited, and 34 attended at least one session. The purpose of the event was to present 40 potential applications of AI for five practical, real-world transportation scenarios; gather feedback on the risks and rewards of potential applications of AI; and develop a prioritized list of applications for possible inclusion in the 5-year roadmap for USDOT's AI for ITS Program.

As this was a virtual event, to sustain stakeholder interest and engagement, the event was restricted to 2½ hours on the first day and 2 hours on the second day. The first day of the event included presentations of potential applications of AI for five practical, real-world transportation scenarios, including: Urban Arterial Network, Urban Multimodal Corridor, Rural Freeway Corridor, Regional Management Systems, and Underserved Communities.

- *Urban Arterial Networks* are low and medium speed mixed-use facilities that provide access to and from traffic generators and attractors, typically managed within jurisdictional boundaries by individual local agencies.
- *Urban Multimodal Corridors* are combinations of highways and arterial streets that serve as major regional travel routes, typically managed collaboratively by a group of state, regional, and local agencies.
- *Regional System Management* is the collaborative management by multiple agencies (often as a regional planning organization) to improve the performance of comprehensive, area-wide transportation systems.
- *Rural Freeway Corridors* are high-speed, limited-access divided facilities that run outside urbanized areas across multiple states and counties, typically managed by multiple agencies.
- *Underserved Communities* are those that do not have their transportation needs met by existing transportation services.

To allow stakeholders to engage in meaningful discussions and provide feedback, two sets of breakout sessions were designed for the first day. The first set had two breakout sessions running in parallel to allow for maximum participation: #2A on AI for Urban Arterial Network; #2B on AI for Rural Freeway Corridor. Following the first set of breakout sessions, a second set of breakout sessions were held. Sessions in the second set were: #3A on AI for Urban Multimodal Corridor; #3B on AI for Regional System Management; #3C on AI for Underserved Communities. At each session, stakeholders provided feedback on the applications via chat box and rated the investment risk and potential reward of each application.

On the second day, the risk-reward ratings of applications from all five breakout sessions were presented and discussed with stakeholders. Stakeholder were then invited to propose ideas for additional AI applications and concepts that had not been covered on the first day. Nine additional applications were proposed by stakeholders. Finally, stakeholders were asked to select their top six high priority applications.

Table 3 shows the individual application scores for all 49 potential applications of AI in ITS, including the nine applications proposed by stakeholders that are indicated with Roman numerals in the first column (e.g., 3A-i).

The "Reward-Risk Score" is the ratio between reward and risk. The "Prioritization Score" reflects the prioritization ratings from stakeholders. The higher the number the better it is for both Reward-Risk Score and Prioritzation Score.

Table 3. Stakeholder Assessments of AI-Enabled Applications for Transportation

App #	Application Name	Reward-Risk Score	Prioritization Score
2A-2	Real-Time Signal Optimization	1.47	35
3A-i	AI for Traffic Management Applications	1.43	35
3B-1	AI for Data Fusion in TMC	1.53	28
2B-1	AI for Crash/Emergency Detection	1.56	17
2A-6	Crash and Incident Detection	1.52	17
2A-1	Traffic Signal Plan Optimization	1.82	11
2B-3	AI for Road Weather Management	1.58	11
3A-1	Inter-Agency Coordination	1.35	11
3B-3	AI for Weather Prediction and Response	1.56	8
2A-7	Pedestrian, Cyclist, and Micro-mobility Detection	1.29	8
3B-5	AI for Work Zone Safety and Information Dissemination	1.47	7
3B-4	AI for Incident Detection and Response	1.40	7
2B-6	AI for Work Zone Management	1.38	7
2A-5	Comprehensive Traffic Modeling	1.29	7
4-v	AI to Perform Quality Checking	1.38	4
2A-10	Demand Response Transit Network Optimization	1.18	4
2A-9	Transit Signal Priority (TSP)	1.39	3
3C-7	VR for Testing	1.43	2
4-ii	Multimodal Trip Planning	1.62	0
2B-4	AI for Safe Asset Health Inspections	1.27	0
2B-8	AI for Freight Traveler Information	1.19	0
3A-3	Prediction of Multimodal Corridor Delay	1.10	11
3C-4	Environmental Mapping and Guidance	1.05	2
2B-2	AI for Wildlife Detection	0.74	2
4-iii	AI for Misbehavior Detection	1.06	0
3A-6	Integrated Payment for Urban Multimodal Corridor	0.97	0
3C-8	AI-Powered Assistive Robotics	0.94	0
3C-5	AI-Enabled Payment Assistance	0.81	0
2A-4	Misbehavior Detection System	1.17	27
3A-5	Urban Multimodal Corridor Demand Management	1.16	20
2B-9	AI for Decision Support Systems	1.23	15

App #	Application Name	Reward-Risk Score	Prioritization Score
3C-1	AI-Enabled Routing and Wayfinding Tools for Pedestrians	1.31	10
3A-2	Detection of Multimodal Failures and Incidents	1.31	9
2A-3	Traffic Signal Decision Support Subsystem	1.29	9
2A-i	AI for Unsignalized Intersections	1.13	8
4-vi	Deidentification of PII Using AI	1.20	6
3B-2	AI for Asset Condition Monitoring	1.08	6
3A-4	Personalized Dissemination of Multimodal Travel Information	1.03	6
2A-8	Safety Metrics Assessment	1.11	4
2B-5	AI for Predictive Asset Management	1.03	3
4-iv	Enhanced Pedestrian Perception and Detection	1.33	2
3C-2	Navigation applications with Augmented Reality (AR) and localized points of interest	1.19	0
3C-6	AI-Powered Safety Monitoring and Alerts	1.15	0
4-i	AI for Performance Measures	1.07	0
3C-3	AI Interpretation of User Input	1.00	0
2A-ii	AI for Loop Signature Matching?	1.40	8
3B-6	AI for Port Operations and Planning	1.10	4
2B-7	AI for Smart Truck Parking	1.21	2
2A-11	Identification of Unauthorized Bus Lane Usage	1.16	2

Summary of Breakout Session Discussions

During and at the end of each scenario breakout presentation, stakeholders shared thoughtful feedback and posed questions for group discussion. These major overarching discussion points are summarized below for each scenario breakout session.

Urban Arterial Networks (2A)

- There was discussion on how many applications presented within specific scenarios were also relevant to other scenarios (i.e., cross-cutting).
- There was discussion on the use of AI-techniques with existing and new data streams. Not all AI-based applications need new data to achieve greater benefits.
- Many of the presented applications are “siloed” and could be combined to fully leverage AI benefits.
- These applications are infrastructure centric, but vehicle perception data could allow for better decision-making processes for a typical TMC.

- For risk, a respondent considered: data availability, quality, and integration as well as the existing/legacy system.

Urban Multimodal Corridors (3A)

- There was discussion on how some of the presented applications appeared to be components of other applications. The intent was to allow implementation of individual applications as incremental steps to achieving a fully integrated system.
- There was discussion on incrementally adding AI-enabled capabilities to existing software of an agency, without losing capabilities.
- There was discussion on the role of USDOT for traveler information applications, which are typically commercial applications. An alternate viewpoint was that these applications cannot be a fully private application because agencies still have to make decisions about financially critical pricing decisions (e.g., time-of-day or congestion-based toll rates, dynamic fares, incentives, etc.).
- There was discussion on how integrated payment is not just at the level of agency agreements. It was meant to be at the operation level to include incentives, pricing, etc.
- There was discussion on how PII can be protected while maximizing the value of data for research and real time operations/personalized use. Privacy is important when providing personalized travel time information, and AI can be the answer to preserve privacy.
- One respondent mentioned that delay is an important multimodal performance metric.

Regional System Management (3B)

- High quality data are a crucial input for AI.
  - Many are turning to non-traditional sources (e.g., probe and crowdsourced).
- It may be necessary to differentiate application functions.
  - One suggestion is to separate traveler information dissemination as its own application in “Work Zone Safety and Information Dissemination.”
- There exists some overlap across scenarios, but each application has a different focus.
  - For example application 2B-4 (Safe Asset Health Inspections) and application 3B-2 (Asset Condition Monitoring) are both related to asset monitoring, but 2B-4 focuses on emergency repairs (such as bridge hazards) while 3B-2 focuses more on routine and common forms of asset fixes.
- There were discussions on connections across application areas.
  - Some applications are possible precursors to other capabilities.
  - However, teh risk-reward ratings were with respect to the specific application area at hand and not the full chain of potential AI functions.
- Stakeholders asked about the human role in managing AI decision systems.
  - Will an AI system be allowed to automatically execute decisions, or will a person-in-the-loop be needed? How will this affect the benefit from the AI system?
  - What role will the user/operator have to influence the outcome of a trained AI? What is needed?

  - The AI is unlikely and probably should not have sole decision-making power in most cases. Instead, AI will provide predictive and descriptive insights that the human will then need to assess.

Rural Freeway Corridors (2B)

- There was discussion on the need for multi-sensor (e.g., audio, video, proximity sensors) fusion for piecing together insights, and downplaying drones.
  - It was noted that due to funding constraints, it is best to use all available sources of data to enable multiple applications. A drone should be viewed as one platform that might carry multiple types of sensors, but multi-sensor fusion would extend across platforms (drones, vehicles, body cameras, etc.) to provide inputs.
- There was discussion on how the predictive element for asset maintenance would be difficult since even with expensive specialized sensors it has been hard to predict asset conditions.
- There was discussion on how AI for Decision Support Systems may encompass all the other eight applications, which was the intent to enable agencies to build incrementally.
- One stakeholder expressed uncertainty on whether "application" meant tasks, functions, operational strategies or use cases. Application in this context was meant to include all those terms.
- One stakeholder mentioned the need to include discussion on where AI could be added to existing systems to enhance capabilities. For example, there is a need to articulate where AI could be added to existing software subsystems, data subsystems, and/or computing hardware subsystems.

Underserved Communities (3C)

- There was discussion as to the USDOT role and how it is important to ensure that USDOT investments are not duplicating efforts that will be covered by market deployments.
- There was discussion on how many of these applications could be useful beyond the underserved communities scenario. Wayfinding, redirection, and security alerts are all good examples of things that would help all travelers.
- It is worth addressing: Is AI the best way to resolve these problems? In some cases, there may need to be a distinction between "is this problem accurately defined," "is the proposed application appropriate to meet the challenge," and "is it USDOT's role to invest in this application."
- One stakeholder noted that the USDOT has done extensive work on user needs, including with other federal agencies, to understand this problem from the user side.
- Many "low-tech" solutions may not be effective because of the need for extensive, precise information that agencies are in the best position to provide and maintain.

For additional discussion on stakeholder inputs from each session (scenario), explanations of quantitative analyses, and a table of application bundles used to inform the identification of projects in Chapter 6, please refer Appendix A.

Summary of Stakeholder Feedback Through Phone Interviews

This section summarizes the feedback from stakeholders received through phone interviews conducted in February 2020 of 23 AI experts from USDOT, academia, and public and private sectors.

- *Cybersecurity:*
  - AI is being used for misbehavior detection. Currently, a range of techniques (e.g., unsupervised learning, supervised learning, deep learning; classification, multi-class classification, ensemble learning) are being explored. As technology matures, the security solutions can be narrowed down to the most efficient and beneficial approaches for each application.
  - AI can help address staffing shortage. For example, an AI application can be trained to assist a cyberspecialist or a signal operator. However, the performance speed of an AI application must match that of the human operator; otherwise there will be reluctance in adopting AI. User acceptance is key.
  - NHTSA requires a guarantee of safety for all safety-critical systems, which in turn requires a deterministic system that will consistently produce the same result. This expectation is not feasible with AI-based systems. To date, this problem has been addressed by maintaining the expectation that these systems are “warning systems” to support a driver, rather than safety-critical solutions to circumvent the driver. Future efforts will be needed to support AI algorithm verification and explainability. Work is currently being performed to develop ways to explain and translate the functionality of AI algorithms (e.g., Explainable Artificial Intelligence, XAI, https://www.darpa.mil/program/explainable-artificial-intelligence).
  - Perception that AI is a “black box” is another major barrier to adoption of AI.
  - A key challenge in developing AI-based misbehavior detection systems remains in the compilation of sufficient quantity and quality of data. Data needs to be representative of multiple locations and situations so that security algorithms are not “over-calibrated” to specific locations (e.g., using data exclusively from the Tampa CV Pilot project could lead to an algorithm that only performs under those prevailing conditions). On the flip side, agencies will also need to deal with massive amounts of data and ensure quality.
  - Future growth in this field is not only contingent on advances in technology, but is also dependent on policy, regulation, and standardization that present institutional challenges for deployment. AI-based misbehavior detection systems may be ready in the coming years; however, there is uncertainty as to whether the prominent institutional challenges will be addressed at the same rate.
  - Another challenge of deploying AI-based solutions is the required computation power. Processing systems will need to be highly efficient before they can be deployed widely.
  - A lesson learned is related to the question of *when* to apply AI. AI systems are not the catch-all solution for every problem. Not all problems require an AI solution. Often, industry is tempted to throw AI algorithms at a problem that would be better and more efficiently addressed using conventional methods. Introduction of AI reduces result traceability; therefore, when unnecessarily converting from a conventional method to an AI method, the ability to verify a solution using traditional methods is lost.

  - A second lesson learned relates to data quality. The quality of the training data dramatically influences model performance. Development of a robust security algorithm requires a lot of rich data that isn't specific to certain areas or use cases. So far, the amount of data available in the industry is not sufficient for fully developing robust security protocols.
  - The third lesson learned relates to the nuanced skillsets required to develop and deploy these systems. Transportation engineers are typically not data scientists, and data scientists typically are not transportation engineers. This disconnect in experience and background can be a challenge for coordinating efforts and developing regulations or standards when two prominent stakeholders are not speaking the same language.
- *Accessible Transportation:*
  - ML is increasingly being used to draw inferences from larger datasets and generate or filter out information that people need.
  - ML techniques are being used to query data using speech recognition.
  - AI can be used to communicate with an individual. For example, a person with cognitive disabilities could become concerned if a bus he or she is riding in deviates from the route due to an accident. The AI application could interface with existing transit data and share reassuring words with the individual. This can have significant psycho-social benefits as it enables the individual to become more independent.
  - AI and robotics are being used to build maps, including labeling stairways and elevators. This is mostly a proof of concept.
  - AI for collision avoidance for the blind is being explored in academic papers.
  - Barriers and challenges include manual data labeling and understanding what specific problem is being solved.
  - Key to promote and foster innovation is a forward-thinking progressive outlook among decision-makers/public sector agencies.
  - A lesson learned was that even if a user is nervous about a new technology, once explained or experienced, the comfort level increases.
- *Transportation Systems Management and Operations (TSMO):*
  - AI has been used extensively for traffic signal optimization. AI is being used for image detection of pedestrians in a cross walk.
  - There is a lot of work in using ML for aggregating data.
  - AI is being used for traffic flow prediction. AI-based models are better able to handle missing data or data that are not available at regular intervals than traditional statistical methods for traffic flow prediction.
  - A key challenge is the lack of generalizability. Although there is literature on AI techniques that address the generalizability issue, those worked best only for offline conditions. For real-time implementations, the application was very slow to respond.
  - A key barrier is that even as AI is becoming more prominent in many fields of study, civil engineering degree programs have not started including basic AI concepts. This presents a challenge when the professionals working in the industry have little to no knowledge about AI and

how it could improve the state of practice. Training is needed to make engineers aware of the strengths and weaknesses of the various types of AI techniques.

- Another major barrier is related to data. We need more data to test more algorithms and better understand AI's potential. With advances in Internet of Things (IoT) and future availability of vast arrays of data, the next challenge will be instituting protocols for maintaining data security and integrity. Numerous diverse Big Data sources are needed to advance work in AI.
- Privacy is a major concern, especially when we have to track vehicles and drivers.
- Taking an application from research to deployment stage requires making the product robust. It takes time for the product to mature. Should look at what issues need to be resolved.
- A lesson learned is the need for implementing strategies or applications in concert with other synergistic strategies to maximize benefits.
- A lesson learned is to never underestimate the importance of operation and maintenance of any system and that there are adequate and trained staff and resources on board.
- Some agencies are reluctant to implement AI-enabled solutions that are either in conceptual stage or prototype development stage. While they may have interest, agencies are responsible for spending the public's money and need to exhibit some caution. Innovation requires funding, and public agencies oftentimes have a harder time providing this funding without certainty that it will work. However, a probability of success cannot be developed without first developing and testing applications. Additional sources of research funding need to be available to advance these innovative solutions beyond these local agencies.
- The biggest lesson learned is that the AI solution should never be applied blindly to any problem, no matter the size or magnitude.

- *Commercial Vehicle and Freight Operations:*
    - ML algorithms are being used to mine GPS data to collect information on parcel movement and develop better models to forecast long-haul truck movement.
    - AI is being used for enhancing freight traveler information or weather-based speed advisories.
    - Barriers and challenges to AI adoption are data accuracy, data privacy, rapidly changing landscape, and reluctance of agencies to adapt.
- *Transit Operations and Management:*
    - Majority of the AI applications that already exist or are being developed, are aimed at improving the customer experience (e.g., improving operational efficiency, dispatching on demand, chatbots, preventative asset management, preventative safety and security management using video analytics, predicting transit ridership).
    - Barriers to use of AI are the following:
        - Education and training are necessary for agencies to understand how AI differs from the other kinds of technologies they are familiar with.
        - Convincing agencies to investigate AI as a possible means to address their needs.
        - Procurement is another barrier. How do you procure AI? It is not the same as buying a bus tire or gasoline. Oftentimes it leads to using different procurement techniques. This

requires the organization to understand what AI is and how it would be helpful to the organization.

        - Data is another issue. A lot of transit agencies still struggle with becoming more data-oriented organizations. If that culture isn't already in place, it will be hard to deal with implementing AI-based solutions.
        - Risk of failure is a major barrier. A lot of agencies are afraid of doing pilots that may not work as it may make them look bad.
    - A lesson learned is that combining AI with other enabling technologies has an added benefit. AI allows streamling data analysis.
- *Remote Sensing:*
    - AI can be leveraged to optimize flight paths and reduce emissions and noise over residential area.
    - AI can be used for data fusion.
    - A major challenge with urban air mobility is related to compliance and regulations. AI could be used to identify high risk areas and possibly help with enforcement, especially since there are number of inexperienced users.
    - Ethics in AI is another major challenge. If computer only has bad options, how do we program it to make the least bad decision (e.g., avoiding a child versus an adult)?
    - Equity in AI is another major challenge. The data has underlying prejudices in it. We need to filter out biases so that historical prejudices do not get built into the code.
    - When working to address policy issues, there needs to be peer USDOT exchange to bring people with varied perspectives (e.g., policy thought leader, data science thought leader) to identify and discuss the issues.
- *Asset Management:*
    - AI is most relevant for the management of the assets, specifically with financial planning, risk analysis, lifecycle cost analysis—things that are data-sensitive.
    - There is also opportunity to use AI for predictive decision-making to determine likely failure or obsolescence (i.e., when ITS equipment might be outclassed or irrelevant).
    - Barriers and challenges to AI adoption by agencies are that the vendors are not quite on board. TSMO is focused on maximizing performance of existing systems without adding infrastructure, so maintenance of existing infrastructure is more of an afterthought. MAP21 Transportation Asset Management Plan requirements will likely accelerate that.

Chapter 4. AI for ITS Program Strategic Direction

This chapter lays out the strategic direction of the AI for ITS Program for the next five years, based on inputs from the ITS JPO and modal partners, external stakeholders, and a review of the literature conducted over the past year.

Vision

The AI for ITS Program's vision is to advance *next generation* transportation systems and services by ethically and equitably leveraging AI for safer, more accessible, and more efficient travel for all people and goods.

Mission

The AI for ITS Program identifies, develops, implements, evaluates, and coordinates technology and policy research to advance the contextualization and integration of AI into all aspects of the transportation system.

Goals

The goals of the AI for ITS Program are to:

1. Engage stakeholders to assess current capabilities, gaps and needs, ongoing research and innovations, and impacts and effectiveness of leveraging AI.
2. Foster research and innovation in AI techniques for transportation.
3. Test proof of concept (POC) to assess effectiveness of advanced research ideas in virtual or controlled environments (e.g., test tracks).
4. Conduct small-scale demonstrations of early prototypes in real-world settings.
5. Deploy high value use cases in real-world operational environments.
6. Measure impacts of the prototype demonstrations and deployments.
7. Identify policy issues and provide inputs and insights into AI-related policy development.
8. Assess needs for AI-related standards and provide inputs to standards developing organizations.
9. Facilitate collaboration among AI researchers and deployers.
10. Disseminate best practices, lessons learned, and potential benefits to accelerate adoption of AI by agencies to advance next generation transportation systems and services.

Outcomes and Success Indicators

The following are expected outcomes of the AI for ITS Program:

1. High value, advanced research in AI applications and supporting technologies not being undertaken by the private sector.
2. Comprehensive documentation of AI policy and technical issues, and mitigation approaches.
3. Successful POC tests of advanced research ideas, demonstrations of early prototypes, and deployments of high-value use cases leveraging AI.
4. Methods and tools to quantify and monetize the impacts and costs of AI-driven prototype demonstrations and deployments.
5. Clear understanding among transportation agencies regarding the policy and technical challenges, and potential benefits of leveraging AI for advancing next generation transportation systems and services.
6. Documentation of existing AI policies and evidence-based recommendations for new AI-related policies and policy extensions (e.g., adding enabling clauses to existing frameworks).
7. Recommendations for new or refined AI-related standards.
8. Cohorts of AI researchers, developers, and current and prospective deployers.
9. Guidance on AI-driven next generation ITS deployment to accelerate adoption by agencies.

Success will be measured by how effective the AI for ITS Program was in achieving these outcomes.

Roadmap Tracks

To achieve the vision, the AI for ITS Program has defined eight tracks that span across the duration of the program from FY 2021 to FY 2026. A detailed description of each track is presented in Chapter 6.

1. **Program Management:** This track is for monitoring the direction of the AI for ITS Program.
2. **Stakeholder Engagement:** This track is for engaging and assessing stakeholder needs throughout the duration of the AI for ITS Program.
3. **Enabling Technologies:** This track is for fostering development and testing of advanced AI research concepts that are not yet proven.
4. **Prototype Demonstrations:** This track is for enabling demonstrations of multiple prototypes of high-value AI applications that address specific transportation challenges.
5. **Deployments:** This track is for supporting multiple deployments, of various scales, of AI-driven next generation transportation systems.
6. **Evaluation:** This track is for measuring the impacts of prototype demonstrations and deployments.
7. **Policy & Standards:** This track is for monitoring and influencing AI-related policies and standards development.
8. **Knowledge and Technology Transfer (KTT):** This track is for facilitating the accelerated adoption of AI by public sector agencies for addressing specific transportation problems.

Chapter 5. AI for ITS Program Challenges and Needs

This chapter identifies the key challenges of the federal AI for ITS Program as well as the barriers to adoption of AI-enabled solutions by agencies. These are identified based on the literature and industry reviews and expert interviews. This chapter also identifies potential approaches (or program needs) for mitigating these challenges and barriers.

AI for ITS Program Challenges

This section identifies the challenges of establishing and sustaining a successful federal AI for ITS Program.

1. **Prioritize Investments in AI Deployments.** Smaller-scale deployments, proof of concept (POC) tests, and prototype demonstrations may involve less risk, enable USDOT to diversify investments, and have broader reach in terms of AI adoption by agencies. However, they may also be less effective in capturing the full potential of AI due to their isolated benefits. Large-scale AI deployments will help USDOT understand system of systems effects, which can yield significant benefits but are also higher risk and more complex. Given the technical uncertainties with AI and inconsistencies in the capabilities and resources of agencies, USDOT must carefully balance the investment risks and rewards of the various deployment options for an effective investment strategy. There is a need for consideration of multiple paths to eventual deployment of AI-enabled systems, depending on the maturity of the AI-enabled applications and capabilities of the agencies.
2. **Adapt to Rapidly Changing AI Environment to Minimize Investment Losses.** The field of AI is evolving rapidly due to advances in complementary fields of robotics, Internet of Things (IoT), blockchain, and quantum computing. It is essential to thus not pick winners or "prescribe" what AI techniques to invest in too early on. Failure to be careful about selection may result in investments in obsolete or less robust AI solutions. Conversely, it is also essential to not push the state-of-the art in AI too far and too fast such that the technical risks are too high. Therefore, there is a need to conduct periodic scans of complementary enabling technologies as well as advances in the AI field, assess the maturity and technical feasibility of innovative AI-enabled concepts, and assess the capabilities of agencies to implement these AI solutions.
3. **Foster Intra and Interagency Coordination, While Adapting to Program Growth.** The AI Program is a high-visibility program that has attracted significant interest within ITS JPO and modal partners. The USDOT should cultivate this interest and foster interagency coordination to promote innovation, share experiences, ensure consistency in standards and policies, and identify solutions to mitigate barriers to adoption of AI. Coordination is especially critical as the field of AI is evolving rapidly. Secondly, several USDOT programs (e.g., Automation, Data, ITS4US, ITS Architecture, Standards, and Cybersecurity [ASC]), are highly interrelated and will become increasingly linked over the next few years. Finally, the AI Program is expected to grow significantly over the next five to 10 years. The

USDOT will require clear processes established to encourage and facilitate collaboration and capitalize on synergies between projects and programs.

4. **Engage and Inform the AI for ITS Community to Enable Success.** Agencies are cautious when investing in untested or unproven technologies. Some agencies may view AI as a “black-box” and may be inherently mistrusting of AI-enabled solutions. Conversely, we may have agencies who are overly enthusiastic about the capabilities of AI and view it as a solution for all problems. Neither blind faith nor skepticism of AI is helpful. A blind believer may be disillusioned if they do not fully understand the drawbacks of AI and a skeptic will not benefit if they are not aware of the advantages of AI. In addition, interest in AI deployments may wane without a steady flow of relevant information and support. The USDOT must manage stakeholder expectations of AI and what it can do to make the management and operations of their transportation systems safer, smarter, and more secure. There is need for developing a convincing narrative to set expectations and motivate stakeholders (e.g., agencies and their partners, original equipment manufacturers [OEMs], vendors, and developers). This should include a discussion of evolutionary deployment and expected impacts, beginning with cost-effective, near-term deployments or prototype demonstrations that can evolve into complex and transformative long-term deployments.

Barriers to Adoption of AI-Enabled Solutions by Agencies

AI has many practical applications in the transportation domain. AI offers the promise to transform the transportation industry, by improving safety, mobility, accessibility, productivity, security and efficiency of transportation systems, users, or owners. However, there are significant challenges to adoption of AI. Given below are barriers commonly faced by agencies interested in implementing AI-enabled solutions to address problems seen on their transportation networks, corridors, and systems.

1. **Data:** AI techniques typically require vast amount of high-quality data. Lack of such data is a common barrier to use of AI. For example, high quality, precise weather data does not exist for urban areas. Predicting rare events such as crashes can be extremely challenging due to lack of sufficient training data. Agencies will need to continually collect high-quality data to train the AI algorithms. This can be a challenge, especially when infrastructure-based sensors are sparse or when funding is limited. With the increase in connected and automated vehicles, and probe data, the data coverage issue may decrease. But until then, since budget is typically limited, agencies may want to start small and focus on applications with the highest impact for their specific networks and operational challenges, and incrementally build capability. Those agencies with the capability and the funding may want to explore the use of AI techniques to fuse and integrate multi-source, multi-sensor data, including for real-time implementations of AI-enabled applications.

2. **Computing Power:** AI techniques are typically enabled by massive amounts of data. Agencies typically do not have access to enough data for building AI solutions. Even if big data are available, quality control becomes difficult. Additionally, many legacy systems are incapable of dealing with the large quantities of complex data, which can lead to latency, timeout, and storage issues, resulting in safety-critical decisions being voided. A possible solution is to leverage open source tools and cloud computing for data storage, management, and computing.

3. **Legacy Systems:** Incompatibility of existing hardware/systems with AI-enabled sub-systems or components is a major barrier to the use of AI. For example, AI-enabled signal optimization may be constrained by the capabilities or compatibility of signal controllers. Developing a decision support system that integrates legacy systems of multiple agencies can be technically and financially

challenging. Continued use of legacy systems will inevitably increase risks to safe and secure operations, and result in significant losses. Agencies looking to implement AI-enabled solutions must consider modernizing their legacy systems and software. There are a range of options that an agency could consider for modernization, including rehost, rearchitect, rebuild or replace, with different benefits, costs, and risks.[1]

4. **Generalizability:** While AI techniques can perform exceedingly well on certain tasks, they are less capable of generalizing to new scenarios, locations, and environments. Agencies may need to deal with scalability and transferability issues if investing in certain vendor products that are not necessarily designed to work everywhere. One promising approach, that is not yet mature, is transfer learning, which is a machine learning method where an AI model that is trained to accomplish a certain task, applies that learning to a similar but different task. Knowledge and technology transfer to share promising advances in AI could help minimize such barriers.
5. **Obsolescence:** Agencies find it undesirable to invest in long-term AI solutions due to the dynamism of the AI field. A potential approach to minimizing this barrier is through creation of peer exchanges enabling agencies to share their experiences in implementing innovative AI techniques and through periodic workforce training and knowledge and technology transfer activities.
6. **Bias:** Bias may be introduced unintentionally if the data used to train the models are distorted. AI-enabled applications are only as good or as bad as the training data. If there is bias in the data, the AI applications can also be biased leading to unethical and unfair consequences. Bias in the data may be due to flawed data sampling, in which groups are over- or underrepresented. Alternately, bias may be introduced through intentional or unintentional biases in human decisions, in framing the problem, collecting the data, and preparing the data for training the models. Guidance needs to be developed on how to recognize and minimize potential bias.
7. **Privacy:** AI is fundamentally designed to use massive amounts of data impacting the privacy of individuals through data manipulation, speech, face or image recognition, and tracking (of individuals and vehicles). Policies and guidelines on what type of user data may be tracked, when and for what purpose will need to be clearly defined.
8. **Ethics and Equity:** Ethics in transportation, which is encapsulated in the commonly known “trolley problem,” is a serious issue. For example, how should an AI-enabled application be designed to save one life over another? AI can also be misused for profiling to discriminate against individuals and populations based on unfair criteria. Equity in access to transportation systems, information, and opportunities, is another major issue, especially for underserved communities. If AI is used for workforce scheduling, it will need to be equitable. Guidelines will need to be defined for more trustworthy AI that is ethical and equitable.
9. **Liability:** Liability is unclear when a vehicle, device, equipment, or system that is powered by an AI application is involved in a crash or is hacked. Secondly, who should be held accountable for an AI-enabled application’s poor performance resulting in significant loss in productivity or even fatality, is debatable. If the AI application fails due to bias in the data, it is currently unclear whether the liable

[1] https://www.gartner.com/smarterwithgartner/7-options-to-modernize-legacy-systems/

party for the failure is the application developer or the data provider. More work is needed to establish liability for losses due to AI-enabled systems.

10. **Stakeholder Acceptance:** AI techniques are often seen as “black boxes.” Users’ inability to articulate the rationale for a decision can affect their level of trust in AI (Phillips, Hahn, Fontana, Broniatowski, & Przybocki, 2020). This mistrust or inability to explain or interpret decisions can be a major barrier to adoption of AI. For AI to be trustworthy, users should be able to understand how their data is being used, how decisions are being made, and how to interpret those decisions. Guidelines need to be developed for explainable AI systems, which is one of the key attributes of trustworthy AI (National Institute of Standards and Technology, 2019). This mistrust may be further allayed by sharing with stakeholders the benefits of using AI. These may be from proof of concept tests or real-world implementations of AI. Even when agencies are open to exploring AI solutions, they are often concerned with how quickly technology becomes obsolete leading to the perception of wasted investments. This frustration may be reduced through knowledge and technology transfer of AI-related best practices, including the need for continuous training of AI models.
11. **Talent/Workforce Availability:** There is a lack of staff trained in AI and advanced data analytics since AI is an emerging technology. Transportation systems are typically managed and operated by engineers with a traditional civil engineering background with limited awareness of AI techniques. Even as AI is becoming more prominent in many fields of study, civil engineering degree programs have not started including basic AI concepts. Data scientists and those trained to develop AI-enabled applications do not traditionally have a background in transportation management. Development of new AI systems will require workforce training for developers, operators, and engineers. Personnel will need to be trained on the safe use of UAS devices, if pursued as a solution by the agency. Decision makers will need to understand the policy and ethical issues related to AI. Training will need to be conducted periodically to keep up with the advances.
12. **Risk Aversion:** Risk aversion and budgetary constraints are primary reasons that limit an agency’s inclination to experiment or deploy un-proven AI solutions. Due to limited resources, agencies are responsible for spending public funding responsibly and tend to avoid investing in innovative solutions that have not been tried before. Secondly, agencies will need to contend with institutional challenges related to personally identifiable information (PII) issues, ethical issues, and other policy issues when implementing AI solutions. Finally, the cost of implementation of certain AI-enabled applications may prove to be significantly higher than the cost of a conventional system that provides adequate performance. This risk avoidance or concern may be reduced by establishing peer exchanges and cohorts where agencies can lean on each other and work with their peers who are implementing AI-enabled solutions. These exchanges are especially useful in facilitating adoption when there are examples of successful use cases of AI adoption and documented benefits.

The key to leveraging AI for transforming the transportation industry is to recognize these potential technical, institutional and ethical challenges and barriers, find solutions to mitigate their impacts, and harness AI to solve specific problems that align with USDOT goals, rather than pursuing AI for its own sake.

Chapter 6. AI for ITS Program Description

This chapter presents the AI for ITS Program roadmap, including a detailed description of projects within each of the eight tracks that span across the duration of the program from FY 2021 to FY 2026. Each track has a specific purpose and activities designed to address the program challenges and barriers, identified in Chapter 5.

1. **Program Management:** This track is for monitoring the direction of the AI for ITS Program.
2. **Stakeholder Engagement:** This track is for engaging and assessing stakeholder needs throughout the duration of the AI for ITS Program.
3. **Enabling Technologies:** This track is for fostering development and testing of advanced AI research concepts that are not yet proven. This track covers research that may have a maturity rating of 1 to 3 on the Technology Readiness Level for Highway Research (TRL-H) scale.
4. **Prototype Demonstrations:** This track is for enabling demonstrations of multiple prototypes of high-value AI applications that address specific transportation challenges. This track covers research that may have a maturity rating of 4 to 6 on the TRL-H scale.
5. **Deployments:** This track is for supporting multiple deployments, of various scales, of AI-driven next generation transportation systems. This track covers research that may have a maturity rating of 7 or 8 on the TRL-H scale.
6. **Evaluation:** This track is for measuring the impacts of prototype demonstrations and deployments.
7. **Policy & Standards:** This track is for monitoring and influencing AI-related policies and standards development.
8. **Knowledge and Technology Transfer (KTT):** This track is for facilitating the accelerated adoption of AI by public sector agencies for addressing specific transportation problems.

Table 4 shows a mapping of the 49 potential AI-enabled applications to the roadmap tracks based on stakeholders' assessment of the potential risks and rewards of USDOT investments in the applications. Applications that were rated as high reward and low risk were assigned to the "Deployments" track. Applications suitable for "Prototype Demonstrations" either had slightly lower reward or slightly higher risk than those in "Deployments" track. Finally, applications with high reward and high risk were assigned to the "Enabling Technologies" track, since the expectation was that these applications likely required more research and development before entering the prototype phase. Appendix A provides more information on the rubric used for mapping the applications to the roadmap tracks.

Table 4. Roadmap Track Assignments of Potential AI-Enabled Applications

App #	Application Name	Reward-Risk Score	Prioritization Score	Roadmap Track
2A-2	Real-Time Signal Optimization	1.47	35	Deployment
3A-i	AI for Traffic Management Applications	1.43	35	Deployment

App #	Application Name	Reward-Risk Score	Prioritization Score	Roadmap Track
3B-1	AI for Data Fusion in TMC	1.53	28	Deployment
2B-1	AI for Crash/Emergency Detection	1.56	17	Deployment
2A-6	Crash and Incident Detection	1.52	17	Deployment
2A-1	Traffic Signal Plan Optimization	1.82	11	Deployment
2B-3	AI for Road Weather Management	1.58	11	Deployment
3A-1	Inter-Agency Coordination	1.35	11	Deployment
3B-3	AI for Weather Prediction and Response	1.56	8	Deployment
2A-7	Pedestrian, Cyclist, and Micro-mobility Detection	1.29	8	Deployment
3B-5	AI for Work Zone Safety and Information Dissemination	1.47	7	Deployment
3B-4	AI for Incident Detection and Response	1.40	7	Deployment
2B-6	AI for Work Zone Management	1.38	7	Deployment
2A-5	Comprehensive Traffic Modeling	1.29	7	Deployment
4-v	AI to Perform Quality Checking	1.38	4	Deployment
2A-10	Demand Response Transit Network Optimization	1.18	4	Deployment
2A-9	Transit Signal Priority (TSP)	1.39	3	Deployment
3C-7	VR for Testing	1.43	2	Deployment
4-ii	Multimodal Trip Planning	1.62	0	Deployment
2B-4	AI for Safe Asset Health Inspections	1.27	0	Deployment
2B-8	AI for Freight Traveler Information	1.19	0	Deployment
3A-3	Prediction of Multimodal Corridor Delay	1.10	11	Prototype *(originally fell in Enabling Technologies[2])*
3C-4	Environmental Mapping and Guidance	1.05	2	Enabling Technology
2B-2	AI for Wildlife Detection	0.74	2	Enabling Technology

[2] *Moved to Prototype track after further assessment of the potential maturity of the AI-enabled application.*

App #	Application Name	Reward-Risk Score	Prioritization Score	Roadmap Track
4-iii	AI for Misbehavior Detection	1.06	0	Prototype *(originally fell in Enabling Technology[3])*
3A-6	Integrated Payment for Urban Multimodal Corridor	0.97	0	Prototype *(originally fell in Enabling Technology[3])*
3C-8	AI-Powered Assistive Robotics	0.94	0	Enabling Technology
3C-5	AI-Enabled Payment Assistance	0.81	0	Enabling Technology
2A-4	Misbehavior Detection System	1.17	27	High-value Prototype
3A-5	Urban Multimodal Corridor Demand Management	1.16	20	High-value Prototype
2B-9	AI for Decision Support Systems	1.23	15	High-value Prototype
3C-1	AI-Enabled Routing and Wayfinding Tools for Pedestrians	1.31	10	High-value Prototype
3A-2	Detection of Multimodal Failures and Incidents	1.31	9	High-value Prototype
2A-3	Traffic Signal Decision Support Subsystem	1.29	9	High-value Prototype
2A-i	AI for Unsignalized Intersections	1.13	8	High-value Prototype
4-vi	Deidentification of PII Using AI	1.20	6	High-value Prototype
3B-2	AI for Asset Condition Monitoring	1.08	6	High-value Prototype
3A-4	Personalized Dissemination of Multimodal Travel Information	1.03	6	High-value Prototype
2A-8	Safety Metrics Assessment	1.11	4	High-value Prototype

[3] *Moved to Prototype track after further assessment of the potential maturity of the AI-enabled application*

App #	Application Name	Reward-Risk Score	Prioritization Score	Roadmap Track
2B-5	AI for Predictive Asset Management	1.03	3	High-value Prototype
4-iv	Enhanced Pedestrian Perception and Detection	1.33	2	High-value Prototype
3C-2	Navigation applications with Augmented Reality (AR) and localized points of interest	1.19	0	High-value Prototype
3C-6	AI-Powered Safety Monitoring and Alerts	1.15	0	High-value Prototype
4-i	AI for Performance Measures	1.07	0	High-value Prototype
3C-3	AI Interpretation of User Input	1.00	0	High-value Prototype
2A-ii	AI for Loop Signature Matching?	1.40	8	Moderate-value Prototype
3B-6	AI for Port Operations and Planning	1.10	4	Moderate-value Prototype
2B-7	AI for Smart Truck Parking	1.21	2	Moderate-value Prototype
2A-11	Identification of Unauthorized Bus Lane Usage	1.16	2	Moderate-value Prototype

Project Descriptions

This section provides track and project descriptions for the the AI for ITS Program Five-Year Roadmap (Version 1), shown in Figure 2.

Progressive elaboration method is used to specify initial estimates of scope and duration of the projects that are farther out and more specific details for nearer term projects. The program plan will be refined frequently as the program evolves.

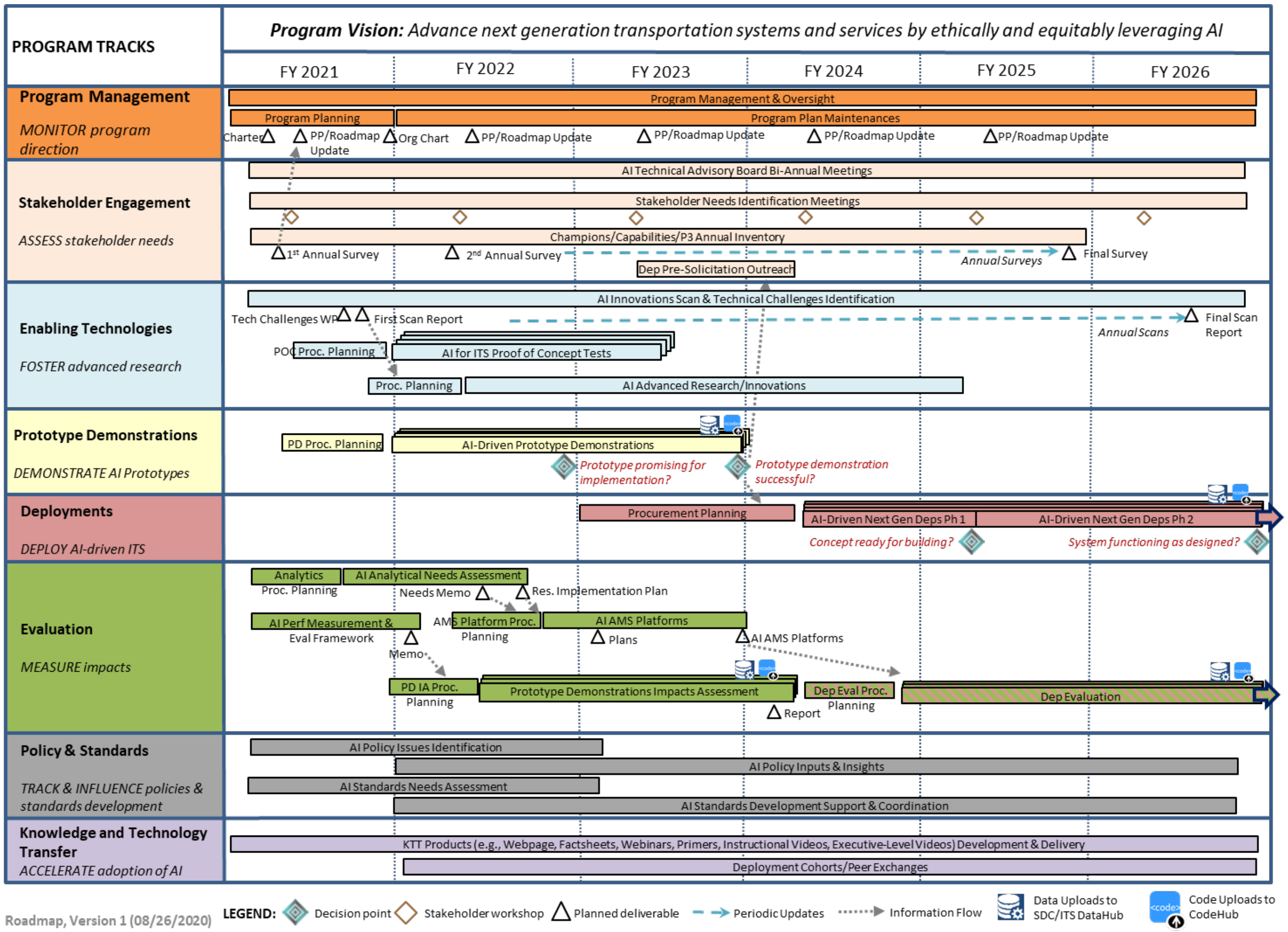

Figure 2. Artificial Intelligence (AI) for Intelligent Transportation Systems Program Five Year Roadmap, Version 1.0 (Source: USDOT)

Track 1: Program Management

This track monitors the direction of the AI for ITS Program.

Project Name: Program Management & Oversight

Start Date: 10/01/2020 *End Date*: 9/30/2026

Predecessors: None

Federal Lead:

Performing Organization:

The purpose of this project is to conduct program management and oversight throughout the duration of the program.

Key deliverables for this project include:

- Executive Briefings (Quarterly, Annual)
- Spend Plans (Annual updates)
- Implementation Plan
- Risk Management and Program Evaluation Plan

Project Name: Program Planning

Start Date: 10/01/2020 *End Date*: 9/30/2021

Predecessors: Identifying Real-World Transportation Applications Using Artificial Intelligence TSSC2 task

Federal Lead:

Performing Organization:

The purpose of this project is to refine the initial roadmap and program plan based on feedback from a broader group of federal stakeholders with a vested interest in the AI for ITS Program, develop a chart and an initial organizational chart.

Key deliverables for this project include:

- Revised Roadmap and Program Plan
- Charter
- Organizational Chart

Project Name: Program Plan Maintenance

Start Date: 10/01/2021 *End Date*: 9/30/2026

Predecessors: Program Planning

Federal Lead:

Performing Organization:

The purpose of this project is to update the roadmap, program plan, and org chart annually.

Key deliverables for this project include:

- Revised Roadmap and Program Plan (Annual Updates)
- Organizational Chart (Annual Updates)

Track 2: Stakeholder Engagement

This track engages and assesses stakeholder needs throughout the duration of the AI for ITS Program.

Project Name: AI Technical Advisory Board Bi-Annual Meetings

Start Date: 10/01/2020 *End Date*: 9/30/2026

Predecessors: None

Federal Lead:

Performing Organization:

The purpose of this project is to foster intra and inter-agency coordination and collaboration to promote innovation, share experiences, ensure consistency in standards and policies, and pool resources to identify solutions to common challenges encountered with use of AI. A technical advisory board of federal AI experts from USDOT, and other federal agencies will be created who will meet bi-annually (virtually or in-person) to identify needs; brainstorm, discuss, and identify opportunities for collaboration; form smaller working groups to tackle specific problems, including developing a series of guidelines such as Ethics Guidelines, Data Guidelines, Procurement Guidelines; report out on outputs and outcomes from the working group activities; and share best practices and lessons learned.

Key deliverables for this project include:

- Bi-Annual Meeting Agenda, Briefing Materials, and Memo on Outcomes

Project Name: Stakeholder Needs Identification Meetings

Start Date: 10/01/2020 *End Date*: 9/30/2026

Predecessors:

Federal Lead:

Performing Organization:

The purpose of this project is to conduct periodic (annual) meetings with stakeholders and the industry to assess needs and AI advances. Stakeholder needs will be inform the annual updates to the program plan and roadmap.

Key deliverables for this project include:

- Annual Meeting Agenda, Briefing Materials, and Memo on Outcomes

Project Name: Champions/Capabilities/P3 Annual Inventory

Start Date: 10/01/2020 *End Date*: 9/30/2025

Predecessors:

Federal Lead:

Performing Organization:

The purpose of this project is to identify and track champions of AI-enabled solutions for ITS problems, primarily within the public sector, to encourage participation in AI-driven prototype demonstrations, deployments, and peer exchanges. Annual surveys will be administered to public sector agencies to assess the purpose and state of their AI use and capabilities. The annual surveys will also be used to identify public-private partnerships (P3) with leading AI technology vendors with the goal to assess adoption and sustainability of AI-driven deployments. The survey findings will inform the annual updates to the program plan and roadmap.

Key deliverables for this project include:

- Survey Instrument (Initial, Revisions)
- Survey Results Briefing and Memo (Annual)

Project Name: Dep Pre-Solicitation Outreach

Start Date: 04/01/2023 *End Date*: 03/31/2024

Predecessors: AI-Driven Prototype Demonstrations

Federal Lead:

Performing Organization:

The purpose of this project is to plan, develop, organize, and conduct pre-solicitation outreach events prior to deployment procurements to ensure that the deployments are focused on specific transportation problems and not for showcasing AI techniques.

Key deliverables for this project include:

- AI-Driven Next Gen Deployment Pre-Solicitation Outreach Plan
- Briefing Materials, including Sample Deployment Scenarios

Track 3: Enabling Technologies

The goal of this track is to foster development and testing of advanced research concepts that are not yet proven. This track covers research that may have a maturity rating of 1 to 3 on the Technology Readiness Level for Highway Research (TRL-H) scale.

Project Name: AI Innovations Scan & Technical Challenges Identification

Start Date: 10/01/2020 *End Date*: 9/30/2026

Predecessors: Identifying Real-World Transportation Applications Using Artificial Intelligence TSSC2 task

Federal Lead:

Performing Organization:

There are two goals of this project. The first goal is to build on the preliminary work conducted as part of an ITS JPO funded effort and other federally funded efforts to identify AI-related technical challenges and issues as well as potential and proven strategies to mitigate them (where applicable). These challenges may be identified through a combination of approaches, including a comprehensive review of the literature on AI for ITS, and surveys and interviews of AI experts and deployers of AI-enabled solutions for ITS.

The second goal is to conduct periodic (annual) scans of current AI practices and innovations in ITS, including fundamental research being funded by FHWA R&D, FMCSA, FTA, FRA, NCHRP, TRB, EAR, and other federal partners, as well as other fields; explore advances in complementary emerging technologies, such as IoT and robotics; and recommend promising AI innovations that should be pursued for ITS for further development and test.

Key deliverables include:

- White Paper on AI Challenges Relevant to ITS and Mitigation Strategies
- Briefing on Innovations Scan in AI Methods and Complementary Emerging Technologies
- Report on Innovations Scan in AI Methods and Complementary Emerging Technologies
- Periodic (Annual) Updates to Briefing and Report on Innovations Scan in AI Methods and Complementary Emerging Technologies

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Project Name: AI Proof of Concept Test Procurement Planning

Start Date: 04/01/2021 *End Date*: 09/30/2021

Predecessors: Identifying Real-World Transportation Applications Using Artificial Intelligence TSSC2 task

Federal Lead:

Performing Organization:

This purpose of this project is to develop multiple statements of work and select contractors to develop and conduct proof of concept tests for high-value but unproven AI-enabled applications for ITS. Based on stakeholder feedback received at the virtual strategy event, the following applications may be considered for proof of concept development and test:

- AI for Wildlife Detection
- AI-Enabled User Assistance for Underserved Communities

Key deliverables will include:

- Draft Statements of Work

  Final Statements of Work

Note that additional applications may be considered for proof of concept tests as part of this track.

Project Name: AI for Wildlife Detection (2B-2)

Start Date: 10/01/2021 *End Date*: 07/31/2023

Predecessors:

Federal Lead:

Performing Organization:

The goal of this project is to: (i) develop an AI-enabled application to detect the presence of wildlife and warn drivers to minimize collisions, and (ii) conduct a proof of concept test in a virtual or controlled environment (e.g., test track). This application is relevant to rural freeway corridors. It may also be applicable to regional system management. To meet the desired goal, the specific activities may include:

- Collect data on the presence of wildlife on or near the road from multiple sources (e.g., sensor data, animal detection systems, connected and automated vehicles, high-resolution images captured by cameras mounted at wildlife crossings or drones).
- Use image recognition to analyze images captured by cameras.
- Apply ML (e.g., Random Forest) to classify if animal or non-animal.
- Warn CV/AV (if present) to alert drivers to reduce speed.
- Post speed reduction advisories on message signs.

Key deliverables include:

- Concept Paper and Briefing
- Draft Report
- Final Report
- Briefing on Application and Results
- Data Sets, Metadata and Documentation
- Source Code and Documentation

Project Name: AI-Enabled User Assistance for Underserved Communities (3C-3, 3C-8)

Start Date: 10/01/2021 *End Date*: 07/31/2023

Predecessors:

Federal Lead:

Performing Organization:

The goal of this project is to: (i) use AI to enable robotic applications to develop sophisticated approaches to administering aid, and (ii) conduct a proof of concept test in a virtual or controlled environment. This project is applicable for underserved communities in a variety of contexts. To meet the desired goal, the specific activities may include:

- Leverage AI to interpret user input, process and respond to queries, and provide dynamic and flexible support to users in unfamiliar environments.
- Use Natural Language Processing (NLP) in combination with trip itinerary information to display context-sensitive information to users.
- Consider using robots to guide travelers through dense or complex indoor spaces.

- Incorporate language and image processing to allow robotic assistants to understand and communicate in English and other languages, including potentially interpreting ASL.
- Leverage machine learning to help robots become more effective at anticipating user needs, including identifying travelers that need assistance.

Key deliverables include:

- Concept Paper and Briefing
- Draft Report
- Final Report
- Briefing on Application and Results
- Data Sets and Documentation
- Source Code and Documentation

Project Name: AI Advanced Research/Innovations Procurement Planning

Start Date: 09/01/2021 *End Date*: 04/30/2022

Predecessors: AI Innovations Scan & Technical Challenges Identification

Federal Lead:

Performing Organization:

This purpose of this project is to develop a statement of work and select a contractor to develop and test promising innovations of AI specifically for ITS that are not being addressed by the private sector.

Key deliverables may include:

- Draft Statement of Work
- Final Statement of Work

Project Name: AI Advanced Research/Innovations

Start Date: 05/01/2022 *End Date*: 03/31/2025

Predecessors: AI Advanced Research/Innovations Procurement Planning

Federal Lead:

Performing Organization:

This purpose of this project is to develop and test promising innovations of AI specifically for ITS that are not being addressed by the private sector. This project may be done in coordination with other federal partners.

Key deliverables may include:

- Concept Paper and Briefing
- Draft Report
- Final Report

- Briefing on Application and Results
- Data Sets and Documentation
- Source Code and Documentation

Track 4: Prototype Demonstrations

The goal of this track is to conduct demonstrations of multiple prototypes of high-value AI applications that address specific transportation challenges. This track covers research that may have a maturity rating of 4 to 6 on the TRL-H scale. Each project corresponds to a distinct application *area* with one or more potential AI-enabled applications. The projects may be further combined into bundles of applications that have common or consistent goals.

Project Name: AI Prototype Demonstrations Procurement Planning

Start Date: 04/01/2021 *End Date*: 09/30/2021

Predecessors: Identifying Real-World Transportation Applications Using Artificial Intelligence TSSC2 task

Federal Lead:

Performing Organization:

This purpose of this project is to develop multiple statements of work and select contractors to conduct demonstrations of multiple prototypes of high-value AI applications. Based on stakeholder feedback received at the virtual strategy event, the following applications may be considered for prototype demonstrations:

- AI-Enabled Misbehavior Detection System (2A-4, 4-iii)
- AI-Enabled Demand Management (3A-5)
- AI for ITS Decision Support (2A-3, 2B-9)
- AI for Unsignalized Intersections (2A-i)
- AI for Freight Operations and Traveler Information (2B-7, 2B-8, 3B-6)
- AI for Pedestrian and Micromobility Detection (2A-7, 4-iv)
- AI-Enabled Integrated Payment (3A-6, 3C-5)
- AI for Safety Performance Measurement (2A-8, 4-i)
- AI-Enabled Independent Travel for Underserved Communities (3C-2, 3C-4, 3C-6)
- AI for Loop Signature Matching (2A-ii)
- Deidentification of Personally Identifiable Information (PII) Using AI (4-vi)

Key deliverables will include:

- Draft Statements of Work

- Final Statements of Work

Note that additional applications or application areas may be considered for prototype demonstrations as part of this track.

Project Name: AI-Enabled Misbehavior Detection System (2A-4, 4-iii)

Start Date: 10/01/2021 *End Date*: 09/30/2023

Predecessors:

Federal Lead:

Performing Organization:

The goal of this project is to develop an AI-enabled system to identify misbehaviors in various ITS. This project is applicable to urban arterial networks. It could also be applicable to the other four scenarios, urban multimodal corridors, regional system management, rural freeway corridors, and underserved communities. To meet the desired goal, the specific objectives are to:

- Leverage streaming analytics with deep learning neural networks tailored for time-series analysis.
- Improve traditional systems by reducing the level of effort to respond to new and novel anomalies.
- Extract patterns automatically rather than defining patterns in advance.

Key deliverables may include:

- Concept Document and Briefing
- Traditional Systems Engineering Process Documents (e.g., Concept of Operations, System Requirements Specification, System Architecture Document, System Acceptance Test Plan and Report)
- Agile Software Development Documents (e.g., Requirements, Product Backlog, User Stories)
- Prototype Demonstration Report and Briefing
- Source Code and Documentation
- Data Sets, Metadata, and Documentation
- Lessons Learned

Project Name: AI-Enabled Demand Management (3A-5)

Start Date: 10/01/2021 *End Date*: 09/30/2023

Predecessors:

Federal Lead:

Performing Organization:

The goal of this project is to proactively select and implement demand management strategies. This project is applicable to urban multimodal corridors. It could also be applicable to urban arterial networks, regional system management, and rural freeway corridors. To meet the desired goal, the specific objectives are to:

- Leverage AI-based Decision Support Systems (DSS) and machine learning techniques to proactively select and implement personal and commercial demand management strategies to reduce the impacts of planned and unplanned events.
- Determine the best demand management straetgies in response to major events.
  - Adjust tolls/fares/incentives to reduce demand for a specific mode with the overall objective of shifting demand to other modes/facilities.
  - Adjust the availability or frequency of certain modes to shift travelers from other modes.
  - Shift truck demand using strategies combining real-time information, pricing, and incentives. For example, trucks headed towards an incident area can be re-routed to rest areas or alternative routes using predictive information generated by neural networks.

Key deliverables may include:

- Concept Document and Briefing
- Traditional Systems Engineering Process Documents (e.g., Concept of Operations, System Requirements Specification, System Architecture Document, System Acceptance Test Plan and Report)
- Agile Software Development Documents (e.g., Requirements, Product Backlog, User Stories)
- Prototype Demonstration Report and Briefing
- Source Code and Documentation
- Data Sets, Metadata, and Documentation
- Memo on technical, policy and standards needs, and lessons learned and best practices

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Project Name: AI for ITS Decision Support (2A-3, 2B-9)

Start Date: 10/01/2021 *End Date*: 09/30/2023

Predecessors:

Federal Lead:

Performing Organization:

The goal of this project is to develop an AI-enabled decision support system to proactively respond to conditions and coordinate decision-making. This project is applicable to urban arterial networks. It could also be applicable to urban multimodal corridors, regional system management, and rural freeway corridors. The specific potential applications include a traffic signal decision support subsystem (2A-3) and a more general, high-level AI-enabled decision support system (2B-9).

The goal of the traffic signal decision support subsystem is to leverage AI to proactively respond to non-recurring congestion conditions. The specific objectives for the traffic signal decision support subsystem are to:

- Advance traditional decision support subsystems with AI techniques for urban arterial traffic signal control.
- Enable more intelligent and tailored responses to unpredictable events impacting all road users with AI's learning capabilities.

- Update parameters and rules based on outcomes automatically.
- Reduce the significant level of effort required to build, maintain, and expand simulation models.
- Test a wider range of potential responses through deeper exploration of the solution possibilities with smarter search methods.

The goal of the AI-enabled decision support system is to facilitate coordinated decision-making among multiple agencies and jurisdications. The specific objectives for the AI-enabled decision support system are to:

- Use machine learning techniques to fuse data from multiple sources.
- Use machine learning for rapid identification of response actions based on business rules agreed upon by agencies responsible for the rural freeway.
- Communicate in real-time necessary response plans with the various agencies for coordinated actions.
- Enable agencies to communicate with each other as well as interact with data management systems using AI-powered chatbots that use machine learning and natural language processing.

Key deliverables may include:

- Concept Document and Briefing
- Traditional Systems Engineering Process Documents (e.g., Concept of Operations, System Requirements Specification, System Architecture Document, System Acceptance Test Plan and Report)
- Agile Software Development Documents (e.g., Requirements, Product Backlog, User Stories)
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Project Name: AI for Unsignalized Intersections (2A-i)

Start Date: 10/01/2021 *End Date*: 09/30/2023

Predecessors:

Federal Lead:

Performing Organization:

The goal of this project is to develop AI-enabled tools to proactively detect wrong way driving, provide curve speed warning, and intersection movement assist warning. This project is applicable to urban arterial networks. It could also be applicable to urban multimodal corridors.

Key deliverables may include:

- Concept Document and Briefing

- Traditional Systems Engineering Process Documents (e.g., Concept of Operations, System Requirements Specification, System Architecture Document, System Acceptance Test Plan and Report)
- Agile Software Development Documents (e.g., Requirements, Product Backlog, User Stories)
- Prototype Demonstration Report and Briefing
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Project Name: AI for Freight Operations and Traveler Information (2B-7, 2B-8, 3B-6)

Start Date: 10/01/2021 *End Date*: 09/30/2023

Predecessors:

Federal Lead:

Performing Organization:

The goal of this project is to provide real-time traveler information for freight-specific needs (e.g., predict parking availability, truck arrivals at ports). This project is applicable to regional system management and rural freeway corridors. It could also be applicable to urban multimodal corridors. The specific potential applications include AI for smart truck parking (2B-7), AI for freight traveler information (2B-8), and AI for port operations and planning (3B-6).

The goal of AI for smart truck parking is to predict parking availability at truck stops to expedite search for parking. The specific objectives for AI-enabled smart truck parking are to:

- Predict availability of safe parking at public rest stops and private truck stops along the rural freeway corridor using historical and current data (e.g., sensors, video images).
- Use video analytics to detect empty spaces.
- Use machine learning to predict future parking availability based on empty and used parking spaces and truck demand.
- Disseminate parking availability information to truck drivers via in-cab systems, mobile apps, traveler information systems, and dynamic message signs.

The goal of AI for freight traveler information is to provide real-time traveler information for freight-specific needs. The specific objectives of AI for freight traveler information are to:

- Predict travel times to enable pre-trip and en route freight travel planning.
- Fuse data on wait times at intermodal facilities, traffic conditions, crashes, weather, road closures, work zones, pavement conditions, route restrictions (e.g., hazardous materials, oversize/overweight), and truck parking availability using machine learning techniques.
- Use trained machine learning models to predict route travel times and expected arrival times based on historical and real-time data.

- Disseminate real-time travel information, parking, and routing to drayage companies, drivers, and intermodal facilities.

The goal of AI for port operations and planning is to predict truck arrival and wait times, maintenance needs, and equipment utilizations to support planning efforts at ports. The specific objectives of AI for port operations and planning are to:

- Predict truck arrival windows at ports to support planning.
- Predict equipment failures of port equipment and suggest maintenance.
- Optimize cargo movement within ports.
- Reduce the amount of time trucks spend in queue.
- Increase port throughput and port equipment utilization.

Key deliverables may include:

- Concept Document and Briefing
- Traditional Systems Engineering Process Documents (e.g., Concept of Operations, System Requirements Specification, System Architecture Document, System Acceptance Test Plan and Report)
- Agile Software Development Documents (e.g., Requirements, Product Backlog, User Stories)
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Project Name: AI for Pedestrian and Micromobility Detection (2A-7, 4-iv)

Start Date: 10/01/2021 *End Date*: 09/30/2023

Predecessors:

Federal Lead:

Performing Organization:

The goal of this project is to develop an AI-enabled tool to detect and identify pedestrians, cyclists, micromobility and other modes. This project is applicable to urban arterial networks. It could also be applicable to urban multimodal corridors, and underserved communities. The specific potential applications include pedestrian, cyclist, and micro-mobility detection (2A-7) and, relatedly, enhanced pedestrian perception and detection (4-iv). To meet the desired goal, the specific objectives are to:

- Use image recognition techniques to identify pedestrians quickly and accurately.
- Leverage AI-enabled video analytics using neural networks specifically trained to recognize roadway scenes.
- Improve the ability of traffic controllers to manage pedestrian crossing times, minimum green times, priority service, and basic detection of alternate modes.

Key deliverables may include:

- Concept Document and Briefing
- Traditional Systems Engineering Process Documents (e.g., Concept of Operations, System Requirements Specification, System Architecture Document, System Acceptance Test Plan and Report)
- Agile Software Development Documents (e.g., Requirements, Product Backlog, User Stories)
- Prototype Demonstration Report and Briefing
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Project Name: AI-Enabled Integrated Payment (3A-6, 3C-5)

Start Date: 10/01/2021 *End Date*: 09/30/2023

Predecessors:

Federal Lead:

Performing Organization:

The goal of this project is to leverage AI to make integrated and secure multimodal electronic payment and enable advanced forms of identity verification. This project is applicable to urban multimodal corridors. It could also be applicable for underserved communities. The specific potential applications include integrated payment for multimodal corridor (3A-6) and AI-enabled payment assistance (3C-5).

The goal of AI for integrated payment for multimodal corridors is to integrate and make secure multimodal electronic payment for fares, tolls, road use, parking, ridesharing, and other areas requiring electronic payments. The specific objectives of integrated payment for multimodal corridors are to:

- Leverage AI to improve coordination of multimodal payments which involve many private and public transportation service providers.
- Create an AI-based payment system that can learn from past data to reduce conflicts among different payment methods and implement incentives to reduce conditions, emissions, etc.
- Ensure privacy and security of highly integrated transactions.

The goal of AI-enabled payment assistance is to enable advanced forms of identity verification. The specific objectives of AI-enabled payment assistance are to:

- Take in biometric data and use facial recognition or other methods to identify travelers quickly and accurately across modes.
- Tie traveler identities to transit accounts that may be refilled online or at designated retail points.
- Eliminate the need for owning and handling physical fare media.
- Ease payment across multiple modes.
- Use AI to learn user profiles and traveler behaviors to more easily identify suspicious activity.

Key deliverables may include:

- Concept Document and Briefing
- Traditional Systems Engineering Process Documents (e.g., Concept of Operations, System Requirements Specification, System Architecture Document, System Acceptance Test Plan and Report)
- Agile Software Development Documents (e.g., Requirements, Product Backlog, User Stories)
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Project Name: AI for Safety Performance Measurement (2A-8, 4-i)

Start Date: 10/01/2021 *End Date*: 09/30/2023

Predecessors:

Federal Lead:

Performing Organization:

The goal of this project is to track and evaluate performance metrics, tailored to individual situations and uses (e.g., predict safety metrics of ADS). This project is applicable to urban arterial networks. It could also be applicable to the other four scenarios, urban multimodal corridors, regional system management, rural freeway corridors, and underserved communities. The specific potential applications include safety metrics assessment (2A-8) and, more broadly, AI for performance measures (4-i). To meet the desired goal, the specific objectives are to:

- Predict safety and other performance metrics of Automated Driving Systems (ADS) interacting with human-driven vehicles in mixed traffic streams.
- Use AI (e.g., deep learning neural networks) to evaluate traffic network safety under different traffic conditions, including varying penetrations of connected vehicles and ADS.
- Leverage a variety of emerging data sources to create and predict performance measures.

Key deliverables may include:

- Concept Document and Briefing
- Traditional Systems Engineering Process Documents (e.g., Concept of Operations, System Requirements Specification, System Architecture Document, System Acceptance Test Plan and Report)
- Agile Software Development Documents (e.g., Requirements, Product Backlog, User Stories)
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Project Name: AI-Enabled Independent Travel for Underserved Communities (3C-2, 3C-4, 3C-6)

Start Date: 10/01/2021 *End Date*: 09/30/2023

Predecessors:

Federal Lead:

Performing Organization:

The goal of this project is to leverage AI to make independent multimodal travel more accessible. This project is applicable for underserved communities in a variety of contexts. The specific potential applications include:

- Navigation applications with augemented reality (AR) and localized points of interest (3C-2)
- Environmental mapping and guidance (3C-4)
- AI-powered safety monitoring and alerts (3C-6)

The goal of navigation applications with AR and localized points of interest is to assist travelers with navigation by using AR to display helpful information visually and intuitively. The specific objectives are to:

- Use a live AR overlay to visually display routes and points of interest.
- Use a decision algorithm to consider whether specific doors or vehicles should be visually prioritized given a traveler's needs and abilities.
- Supplement existing wayfinding applications or be included as a feature of new AI-powered route-finders.

The goal of environmental mapping and guidance is to respond dynamically to travelers' environments and provide detailed, context-sensitive directions. The specific objectives are to:

- Use SLAM and AI to build and map a traveler's immediate environment in real time.
- Provide guidance relevant to real world conditions e.g., identifying curbs, obstructions, or uneven ground.
- Respond to events, such as the presence of emergency vehicles or sidewalk obstructions, as they happen to safely reroute travelers as needed.

The goal of AI-powered safety monitoring and alerts is to ensure a robust safety net exists for travelers in case of emergency. The specific objectives are to:

- Track location and status of opted-in users to ensure that the schedule is being met and that the travelers are taking the expected route.
- Analyze unexpected behavior in the case of divergence, provide guidance to the user, and send alerts to their designated caregiver(s).
- Allos travelers to take transportation while minimizing risk and stress.

Key deliverables may include:

- Concept Document and Briefing

- Traditional Systems Engineering Process Documents (e.g., Concept of Operations, System Requirements Specification, System Architecture Document, System Acceptance Test Plan and Report)
- Agile Software Development Documents (e.g., Requirements, Product Backlog, User Stories)
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Project Name: AI for Loop Signature Matching (2A-ii)

Start Date: 10/01/2021 *End Date*: 09/30/2023

Predecessors:

Federal Lead:

Performing Organization:

The goal of this project is to use AI to enhance loop detector performance by loop signature matching to establish reliable detection across wide area. This project is applicable to urban arterial networks. It could also be applicable to urban multimodal corridors.

Key deliverables may include:

- Concept Document and Briefing
- Traditional Systems Engineering Process Documents (e.g., Concept of Operations, System Requirements Specification, System Architecture Document, System Acceptance Test Plan and Report)
- Agile Software Development Documents (e.g., Requirements, Product Backlog, User Stories)
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Project Name: Deidentification of Personally Identifiable Information (PII) Using AI (4-vi)

Start Date: 10/01/2021 *End Date*: 09/30/2023

Predecessors:

Federal Lead:

Performing Organization:

The goal of this project is to remove PII from big data sets quickly and efficienctly and generate unoriginal data for use in other AI applications. This project could be applicable to urban arterial networks, urban multimodal corridors, regional system management, and rural freeway corridors.

Key deliverables may include:

- Concept Document and Briefing
- Traditional Systems Engineering Process Documents (e.g., Concept of Operations, System Requirements Specification, System Architecture Document, System Acceptance Test Plan and Report)
- Agile Software Development Documents (e.g., Requirements, Product Backlog, User Stories)
- Prototype Demonstration Report and Briefing
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Track 5: Deployments

The goal of this track is to showcase multiple deployments of AI-driven next generation transportation systems of various scales using one or more of the applications described below. This track covers research that may have a maturity rating of 7 or 8 on the TRL-H scale. The application areas assigned to the deployment track are based largely on ratings from stakeholders at a virtual strategy event. However, many of the specific applications in each area may still need additional research, development, and testing prior to deployment, and may be considered as part of either Enabling Technologies track or Prototype Demonstrations track.

Each project corresponds to a distinct application *area* with one or more potential AI-enabled applications that could be included in a deployment.

Project Name: AI-Driven Next Gen Deployments Procurement Planning

Start Date: 10/01/2022 *End Date*: 03/31/2024

Predecessors: Identifying Real-World Transportation Applications Using Artificial Intelligence TSSC2 task

Federal Lead:

Performing Organization:

This purpose of this project is to develop multiple statements of work and select contractors to deploy AI-driven next generation transportation systems of various scales. Based on stakeholder feedback received at the virtual strategy event, the following applications may be considered for potential deployments:

- AI for Asset Management (2B-4, 2B-5, 3B-2)
- AI for Work Zone Safety (2B-6, 3B-5)
- AI for Road Weather Management (2B-3, 3B-3)
- AI for Data Fusion and Quality Checking (3B-1, 4-v)
- AI for Traffic Management Strategies (2A-5, 3A-3, 3A-i)

- AI for Traffic Signal Optimization/Planning (2A-1, 2A-2)
- AI for Transit Operations and Management (2A-9, 2A-10, 2A-11)
- AI for Crash/Incident Detection and Response (2A-6, 2B-1, 3A-2, 3B-4)
- AI for Navigation and Traveler Information (3A-4, 3C-1, 4-ii)
- AI for Inter-Agency Collaboration (3A-1)
- Virtual Reality (VR) for Testing (3C-7)

Key deliverables will include:

- Draft Statements of Work
- Final Statements of Work

Project Name: AI for Asset Management (2B-4, 2B-5, 3B-2)

Start Date: 04/01/2024 *End Date*: 09/30/2026

Predecessors:

Federal Lead:

Performing Organization:

The goal of this project is to identify and predict asset conditions with AI. This project is applicable to regional system management and rural freeway corridors. It could also be applicable to urban arterial networks and urban multimodal corridors. The specific potential applications include AI for safe asset health inspections (2B-4), AI for predictive asset management (2B-5), and AI for asset condition monitoring (3B-2).

The goal of AI-enabled safe asset health inspections is to identify emergency repair work safely and reliably by assessing conditions of highway/roadway assets. The specific objectives are to:

- Assess pavement, bridge, culvert, signs, gantries, and other highway/roadway asset conditions using data fused from multiple sources (e.g., sensors, connected vehicles, real-time aerial imagery captured by unmanned aerial systems or drones).
- Use image recognition to analyze images captured by drones equipped with high resolution cameras.
- Fuse data using machine learning techniques such as clustering, nearest neighbor, classification, anomaly detection, etc.
- Classify asset conditions rapidly (e.g., existing hazard, imminent hazard, less-time sensitive need) using classification algorithms (e.g., Decision Trees, Random Forest).
- Identify response actions using trained machine learning models (e.g., Decision Trees, Neural Networks).
- Warn connected vehicles and/or automated vehicles (if present) and maintenance personnel of the hazard.
- Disseminate information via traveler information systems, mobile apps, in-vehicle systems, and/or dynamic message signs.

The goal of AI-enabled predictive asset maintenance is to predict future maintenance needs by assessing conditions of highway/roadway assets and enable effective investment and risk analysis. The specific objectives are to:

- Assess highway/roadway assets to plan for cost-effective approaches for timely maintenance, repair, rehabilitation, and replacement.
- Fuse concurrent data from multiple sources using machine learning techniques such as clustering, nearest neighbor, classification, etc.
- Predict maintenance, repair, rehabilitation, and replacement needs using trained ML models (e.g., Decision Trees, Neural Networks) and fused data.
- Identify response actions using trained machine learning models and prioritize.
- Disseminate long-term plans via traveler information system and/or message signs.

The goal of AI-enabled asset condition monitoring is to monitor and identify asset conditions to inform infrastructure maintenance decision-making. The specific objectives are to:

- Extract asset information from sensor data and assess their conditions (e.g., pavement quality and sign status).
- Monitor pavement and detect hazards (e.g., potholes) using object recognition with a convolutional neural network (CNN).
- Alert drivers and maintenance crews to these issues before they cause damage.

Key deliverables may include:

- Concept Document and Briefing
- Traditional Systems Engineering Process Documents (e.g., Concept of Operations, System Requirements Specification, System Architecture Document, System Acceptance Test Plan and Report)
- Agile Software Development Documents (e.g., Requirements, Product Backlog, User Stories)
- Data Management Plan
- Performance Measurement Plan and Report
- Operational Readiness Plan and Report
- Source Code and Documentation
- Data Sets, Metadata, and Documentation
- Memo on technical, policy and standards needs, and lessons learned and best practices

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Project Name: AI for Work Zone Safety (2B-6, 3B-5)

Start Date: 04/01/2024 *End Date*: 09/30/2026

Predecessors:

Federal Lead:

Performing Organization:

The goal of this project is to detect, predict, and share information on work zones (e.g., delays) using AI. This project is applicable to regional system management and rural freeway corridors. It could also be applicable to urban arterial networks and urban multimodal corridors. The specific potential applications include AI for work zone management (2B-6) and AI for work zone safety and information dissemination (3B-5). These two applications are highly related but differ in their key objectives. The first application is focused primarily on assessing traffic conditions at the work zone for effective work zone management. The second application is focused primarily on identifying the geometric characteristics of the work zone and detecting physical hazards for effective work zone management.

The goal of AI-enabled work zone management is to detect and predict queues and shockwaves to harmonize speeds for reducing work zone crashes and delays. The specific objectives are to:

- Detect queues and shockwaves at work zones using data from multiple sources (e.g., sensors, weather stations, connected vehicles, real-time aerial imagery captured by unmanned aerial systems or drones).
- Fuse data using machine learning techniques such as clustering, nearest neighbor, classification, anomaly detection, etc.
- Detect queues and predict shockwave propagation speed using machine learning techniques.
- Identify effective speed advisories using trained machine learning models for detected queues and propagation speeds.
- Warn connected vehicles and/or automated vehicles (if present) of speed reductions and the presence of maintenance/construction crews.
- Disseminate information via traveler information system, mobile apps, in-vehicle systems; post speed advisories on dynamic message signs.
- Predict safety, mobility, and environmental impacts of planned work zones, for effective work zone planning.

The goal of AI for work zone safety and information dissemination is to share work zone traveler information. The specific objectives are to:

- Communicate work zone locations to users through navigation applications.
- Create a schematic of a work zone configuration from drone-collected imagery or other sources.
- Detect potential hazards (e.g., fallen cones) and alert construction crews.
- Disseminate information via traveler information systems, mobile apps, in-vehicle systems; post speed advisories on dynamic message signs.

Key deliverables may include:

- Concept Document and Briefing
- Traditional Systems Engineering Process Documents (e.g., Concept of Operations, System Requirements Specification, System Architecture Document, System Acceptance Test Plan and Report)
- Agile Software Development Documents (e.g., Requirements, Product Backlog, User Stories)
- Data Management Plan

- Performance Measurement Plan and Report
- Operational Readiness Plan and Report
- Source Code and Documentation
- Data Sets, Metadata, and Documentation
- Memo on technical, policy and standards needs, and lessons learned and best practices

Project Name: AI for Road Weather Management (2B-3, 3B-3)

Start Date: 04/01/2024 *End Date*: 09/30/2026

Predecessors:

Federal Lead:

TSSC POC:

Performing Organization:

The goal of this project is to use AI detect and predict road surface conditions to inform preventative and real-time management strategies. This project is applicable to regional system management and rural freeway corridors. It could also be applicable to urban arterial networks and urban multimodal corridors. The specific potential applications include AI for road weather management (2B-3) and AI for weather prediction and response (3B-3). These two applications are highly related, with the second application as a potential specific component of the first. The second application is focused primarily on weather and road surface prediction for resource allocation while the first application includes all road weather management responses (e.g., resource allocation, information dissemination, impacts assessments, etc.).

The goal of AI-enabled road weather management is to detect and predict where weather-related road surface treatments or preventative measures are needed. The specific objectives are to:

- Detect road surface conditions from weather, sensor, connected vehicle messages, and/or images recorded by drones.
- Fuse data from multiple sources using machine learning techniques (e.g., clustering, nearest neighbor, classification).
- Use machine learning techniques (e.g., clustering, neural networks) to rapidly detect weather events (e.g., icy patches, snowdrifts, ponding, flooding).
- Identify response actions using trained machine learning models.
- Dispatch weather response teams (e.g., snowplows) and maintenance crews.
- Warn connected vehicles and/or automated vehicles (if present) of speed reductions, detours, and road closures.
- Disseminate information via traveler information system, mobile apps, in-vehicle systems; post speed advisories on dynamic message signs.
- Predict high-risk areas and impact intensities before conditions deteriorate or adverse weather strikes to allow agencies to take preventative actions.

The goal of AI-enabled weather prediction and response is to predict road surface conditions before they become dangerous and respond accordingly. The specific objectives are to:

- Predict high-risk areas before adverse weather makes them dangerous.
- Analyze data from multiple historical and real-time sources. For example, snowplows could use an AI-enabled app to determine how much salt to lay on certain stretches of the roadway given historical drift patterns and expected weather.
- Detect snow drifts and areas of flooding with machine learning classification methods.
- Notify maintenance crews where and how to concentrate preventative resources to better allocate scarce resources, reduct the frequency of road closures, and improve safety for roadway users.

Key deliverables may include:

- Concept Document and Briefing
- Traditional Systems Engineering Process Documents (e.g., Concept of Operations, System Requirements Specification, System Architecture Document, System Acceptance Test Plan and Report)
- Agile Software Development Documents (e.g., Requirements, Product Backlog, User Stories)
- Data Management Plan
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Project Name: AI for Data Fusion and Quality Checking (3B-1, 4-v)

Start Date: 04/01/2024 *End Date*: 09/30/2026

Predecessors:

Federal Lead:

TSSC POC:

Performing Organization:

The goal of this project is to fuse data from multiple sources and validate datasets. This project is applicable to regional system management. It could also be applicable to urban arterial networks, urban multimodal corridors, and rural freeway corridors. The specific potential applications include AI for data fusion in the Transportation Management Center (TMC) (3B-1) and AI to perform quality checking (4-v).

The goal of AI for data fusion at TMCs is to improve situational awareness by fusing data from multiple sources across the region. The specific objectives are to:

- Fuse data from multiple sources, time periods (historical and real-time), and of different types (e.g., videos, images, feeds, etc.) to enable proactive systemwide management.
- Use machine learning to automatically identify key pieces of information and fuse from multiple sources.

- Communicate in real-time necessary response plans with various agencies for coordinated actions.
- Reduce incident response times, improve decision-making timeliness and confidence, and improve staff's ease-of-use and situational awareness.

The goal of AI for quality checking is to use AI techniques to validate and verify datasets.

Key deliverables may include:

- Concept Document and Briefing
- Traditional Systems Engineering Process Documents (e.g., Concept of Operations, System Requirements Specification, System Architecture Document, System Acceptance Test Plan and Report)
- Agile Software Development Documents (e.g., Requirements, Product Backlog, User Stories)
- Data Management Plan
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Project Name: AI for Traffic Management Strategies (2A-5, 3A-3, 3A-i)

Start Date: 04/01/2024 *End Date*: 09/30/2026

Predecessors:

Federal Lead:

TSSC POC:

Performing Organization:

The goal of this project is to use AI to develop comprehensive traffic models, predict delays, and identify useful measures (e.g., target speeds, ramp metering rates). This project is applicable to urban arterial networks and urban multimodal corridors. It could also be applicable to regional system management and rural freeway corridors. The specific potential applications include comprehensive traffic modeling (2A-5), prediction of multimodal corridor delays (3A-3), and AI for traffic management applications (3A-i), which encompasses the first two applications. The goal of AI for traffic management applications is to proactively identify target speeds, lane assignments, ramp metering rates, etc. for improved traffic flow and throughput.

The goal of comprehensive traffic modeling is to model urban network traffic as completely as possible. The specific objectives are to:

- Use AI (e.g., neural networks) tailored for traffic network state representation to develop larger and more flexible models using vast amounts of data available by network users.

- Use these models to understand and forecast travel patterns, traffic operations, and traffic safety in large regions at a lower level of effort than is typically required to build and maintain high-resolution microsimulation models.

The goal of multimodal corridor delay prediction is to predict multimodal delays in real-time using AI techniques. The specific objectives are to:

- Leverage emerging data from different modes (e.g., third-party traffic information, traffic incident reports, connected vehicle messages, social media and mobile device data, in-vehicle camera and sensor images and videos).
- Use AI systems to fuse together data streams.
- Predict real-time online delays for multimodal trips.

Key deliverables may include:

- Concept Document and Briefing
- Traditional Systems Engineering Process Documents (e.g., Concept of Operations, System Requirements Specification, System Architecture Document, System Acceptance Test Plan and Report)
- Agile Software Development Documents (e.g., Requirements, Product Backlog, User Stories)
- Data Management Plan
- Performance Measurement Plan and Report
- Operational Readiness Plan and Report
- Source Code and Documentation
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Project Name: AI for Traffic Signal Optimization/Planning (2A-1, 2A-2)

Start Date: 04/01/2024 *End Date*: 09/30/2026

Predecessors:

Federal Lead:

TSSC POC:

Performing Organization:

The goal of this project is to optimize signal timing plans offline and in real-time. This project is applicable to urban arterial networks. It could also be applicable to urban multimodal corridors. The specific potential applications include traffic signal plan optimization (2A-1) and real-time signal optimization (2A-2). The first application uses historical data to optimize signal timing plans offline while the second application dynamically adjusts signals in real-time using historical and real-time data.

The goal of AI-enabled traffic signal plan optimization is to optimize signal timing plans offline. The specific objectives are to:

- Leverage advances in AI and machine learning to conduct signal re-timing efforts at a higher frequency using automated traffic signal performance measures (ATSPMs).
- Re-time signals more frequently than once very 3-5 years as is typical.
- Take a proactive approach to better accommodate seasonal changes in travel demand.

The goal of AI-enabled real-time signal optimization is to optimize traffic signals in real-time using AI techniques. The specific objectives are to:

- Fuse together data streams from traditional data (e.g., loop detectors and video detectors), environmental sensor systems, third-party traffic information, traffic incident reports, connected vehicle messages, and CCTV cameras.
- Learn relationships between traffic flows, bottlenecks, and environmental factors.
- Predict future conditions.
- Use continuous learning to enable a feedback loop to understand how well the previous response plan performed, use that data to inform the next response, and further improve signal optimization.

Key deliverables may include:

- Concept Document and Briefing
- Traditional Systems Engineering Process Documents (e.g., Concept of Operations, System Requirements Specification, System Architecture Document, System Acceptance Test Plan and Report)
- Agile Software Development Documents (e.g., Requirements, Product Backlog, User Stories)
- Data Management Plan
- Performance Measurement Plan and Report
- Operational Readiness Plan and Report
- Source Code and Documentation
- Data Sets, Metadata, and Documentation
- Memo on technical, policy and standards needs, and lessons learned and best practices

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Project Name: AI for Transit Operations and Management (2A-9, 2A-10, 2A-11)

Start Date: 04/01/2024 *End Date*: 09/30/2026

Predecessors:

Federal Lead:

TSSC POC:

Performing Organization:

The goal of this project is to improve transit service by using Transit Signal Priority, managing demand, and identifying unauthorized use of bus lanes. This project is applicable to urban arterial networks. It could also be applicable to urban multimodal corridors and underserved communities. The specific potential applications include Transit Signal Priority (TSP) (2A-9), demand response transit network optimization (2A-10), and identification of unauthorized bus lane usage (2A-11).

The goal of TSP is to optimize transit signal priority in real-time using AI techniques. The specific objectives are to:

- Leverage the learning capabilities of AI and machine learning to learn from past experience and improve traditional TSP algorithms and strategies.
- Improve adaptability of TSP control strategies under unique traffic and environmental conditions.

The goal of demand response transit network optimization is to improve network-wide transit service with an AI-based system that actively manages transit demand and capacity. The specific objectives are to:

- Build from transit planning efforts to match route capacities with ridership demand.
- Develop an AI-based system to identify and respond to instances where transit demand exceeds capacity. Example reponses could include adjusting transit headways or sending an additional vehicle.
- Return the outcomes of each response (i.e. in terms of its success or failure in meeting demand) to the system to further refine the underlying algorithms and improve the next response.

The goal of identification of unauthorized bus lane usage is to identify and improve enforcement of unauthorized bus lane use to improve transit schedule adherence and travel time reliability. The specific objectives are to:

- Improve effectiveness of designated bus travel lanes by enforcing compliance.
- Use AI techniques to process CCTV imagery to identify violations and enforce lane restrictions.
- Reduce unauthorized use of bus lanes.
- Improve bus operations throughout the urban arterial network.

Key deliverables may include:

- Concept Document and Briefing
- Traditional Systems Engineering Process Documents (e.g., Concept of Operations, System Requirements Specification, System Architecture Document, System Acceptance Test Plan and Report)
- Agile Software Development Documents (e.g., Requirements, Product Backlog, User Stories)
- Data Management Plan
- Performance Measurement Plan and Report
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- Memo on technical, policy and standards needs, and lessons learned and best practices

Project Name: AI for Crash/Incident Detection and Response (2A-6, 2B-1, 3A-2, 3B-4)

Start Date: 04/01/2024 *End Date*: 09/30/2026

Predecessors:

Federal Lead:

TSSC POC:

Performing Organization:

The goal of this project is to detect crashes and incidents, predict their impacts, and identify responses plans using AI. This project is applicable to urban arterial networks, urban multimodal corridors, regional system management, and rural freeway corridors. The specific potential applications include crash and incident detection (2A-6), AI for crash/emergency detection (2B-1), detection of multimodal failures and incidents (3A-2), and AI for incident detection and response (3B-4). These applications are all very similar but are applied in different contexts (e.g., urban versus rural) and in different cases (e.g., disasters versus regular incidents).

The goal of AI-enabled crash and incident detection is to detect urban network crashes and incidents. The specific objectives are to:

- Use AI to improve the detection of crashes and arterial anomalies by monitoring feeds from arterial surveillance and traffic signal operations CCTVs.
- Use video analytics and neural networks specifically trained to recognize roadway scenes to improve an agency's ability to dispatch necessary resources (e.g, emergency medical, hazmat, etc.) faster and more reliably.
- Monitor AI-enabled commercial products that are emerging and evolving, including those focused on incident management support with automated aerial drones.

The goal of AI-enabled crash/emergency detection is to rapidly detect crashes, incidents, and disasters, and identify response plans. The specific objectives are to:

- Rapidly detect crashes and emergencies (e.g., vehicle in sinkhole, hazmat spills) from sensor data, weather data, social media data, connected vehicle messages, etc.
- Use machine learning techniques such as anomaly detection, clustering, and neural networks to detect crashes and emergencies.
- Dispatch drones to confirm and capture accurate images safely and rapidly about the nature and extent of the emergency.
- Use image recognition to analyze images captured by drones.
- Identify response actions using trained machine learning models.
- Predict best routes for EMS.
- Share routes and recorded images with EMS and maintenance personnel for rapid and effective response.
- Warn connected vehicles and/or automated vehicles (if present) of the presence of the crash/emergency, EMS, and maintenance personnel.
- Disseminate information via traveler information system and/or dynamic message signs.

The goal of multimodal failure and incident detection is to detect failures and incidents in real-time. The specific objectives are to:

- Detect and identify mode specific failures/incidents using novel data sources.
- Leverage advances in AI and machine learning to acquire, process, and interpret these events based on existing and non-traditional data sources.
- Reduce failure/incident detection and verification times.

The goal of AI-enabled incident detection and response is to detect incidents, predict their impacts, and respond in real-time. The specifics objectives are to:

- Use AI to rapidly detect emergency incidents, predict their impacts, and inform EMS personnel and travelers.
- Detect emergency situations with machine learning techniques such as anomaly detection.
- Predict the best routes for EMS under different weather and traffic conditions.
- Predict visibility, rain drainage, and other environmental conditions important for traveler safety.
- Increase the number of travelers aware of road closures.
- Improve disaster and incident preparation.
- Reduce the time it takes to clear a roadway in an evacuation.
- Reduce total fuel consumption to clear a roadway.

Key deliverables may include:

- Concept Document and Briefing
- Traditional Systems Engineering Process Documents (e.g., Concept of Operations, System Requirements Specification, System Architecture Document, System Acceptance Test Plan and Report)
- Agile Software Development Documents (e.g., Requirements, Product Backlog, User Stories)
- Data Management Plan
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Project Name: AI for Navigation and Traveler Information (3A-4, 3C-1, 4-ii)

Start Date: 04/01/2024 *End Date*: 09/30/2026

Predecessors:

Federal Lead:

TSSC POC:

Performing Organization:

The goal of this project is to generate personalized real-time multimodal travel information. This project is applicable to urban multimodal corridors and underserved communities. It could also be applicable to urban arterial networks, regional system management, and rural freeway corridors. The specific potential applications include personalized dissemination of multimodal travel information (3A-4), AI-enabled routing and wayfinding tools for pedestrians (3C-1), and multimodal trip planning (4-ii).

The goal of personalized dissemination of multimodal travel information is to generate personalized real-time multimodal travel information from an AI-based Decision Support System (DSS). The specific objectives are to:

- Generate personalized travel time predictions for travelers using data from different modes and AI.
- Leverage AI to learn from individual travelers' actual experience to generate alternate multimodal schedules that will achieve connection protection given prevailing conditions.
- Create an AI-based smart recommender system that can generate multi-modal itineraries based on traveler objectives and past choices.
- Improve traveler experience and safety by providing real-time predictive and personalized travel information.
- Promote modes that will have the least impact on congestion, emissions, and energy consumption.
- Introduce maximum flexibility through the use of emerging strategies such as incentives, mode-specific pricing, etc.

The goal of AI-enabled routing and wayfinding tools for pedestrians is to make pathfinding applications more intuitive, flexible, and responsive. The specific objectives are to:

- Dynamically analyze and modify routing algorithms using deep learningbased on user's preferences.
- Build off past performance, identify successful routes, and anticipate travel conditions in real-time.
- Leverage AI systems to allow for fine-grained user profiles and optimization not possible with conventional algorithms.

The goal of AI-enabled multimodal trip planning is to use AI to determine the most effective multimodal trip, taking into account travel time, emissions, road conditions, and other factors.

Key deliverables may include:

- Concept Document and Briefing
- Traditional Systems Engineering Process Documents (e.g., Concept of Operations, System Requirements Specification, System Architecture Document, System Acceptance Test Plan and Report)
- Agile Software Development Documents (e.g., Requirements, Product Backlog, User Stories)
- Data Management Plan
- Performance Measurement Plan and Report
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- Data Sets, Metadata, and Documentation

- Memo on technical, policy and standards needs, and lessons learned and best practices

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Project Name: AI for Inter-Agency Collaboration (3A-1)

Start Date: 04/01/2024 *End Date*: 09/30/2026

Predecessors:

Federal Lead:

TSSC POC:

Performing Organization:

The goal of this project is to collaborate across agencies in real-time using DSS and Knowledge Based Expert Systems (KBES). This project is applicable to urban multimodal corridors. It could also be applicable to urban arterial networks, regional system management, and rural freeway corridors. To meet the desired goal, the specific objectives are to:

- Use a Knowledge Based Expert System (KBES) as part of a DSS to identify participating agencies and determine response strategies and resource needs. For example, the KBES could recommend deployment and allocation of incident removal response crews specific to the incident especially for hazmat or major incidents as well as the deployment of medical resources.
- Update the rule and /or improve it based on past experience.
- Reduce clearance times, delays, emissions, and energy consumption across modes.
- Reduce the risk of secondary crashes as a result of quick clearance.

Key deliverables may include:

- Concept Document and Briefing
- Traditional Systems Engineering Process Documents (e.g., Concept of Operations, System Requirements Specification, System Architecture Document, System Acceptance Test Plan and Report)
- Agile Software Development Documents (e.g., Requirements, Product Backlog, User Stories)
- Data Management Plan
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Project Name: Virtual Reality (VR) for Testing (3C-7)

Start Date: 04/01/2024 *End Date*: 09/30/2026

Predecessors:

Federal Lead:

TSSC POC:

Performing Organization:

The goal of this project is to enable development and trial of navigational apps using VR testing environments. This project is applicable to underserved communities. To meet the desired goal, the specific objectives are to:

- Reduce development costs and train users.
- Use AI functionalities such as augmented reality (AR) and virtual reality (VR) to “field-test” apps.
- Provide avenues for testing without requiring field rollouts.
- Allow users to practice taking transit and using assistive devices without the stress of real-world environments.

Key deliverables may include:

- Concept Document and Briefing
- Traditional Systems Engineering Process Documents (e.g., Concept of Operations, System Requirements Specification, System Architecture Document, System Acceptance Test Plan and Report)
- Agile Software Development Documents (e.g., Requirements, Product Backlog, User Stories)
- Data Management Plan
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Track 6: Evaluation

This track measures the impacts of prototype demonstrations and deployments.

Project Name: AI Performance Measurement and Evaluation Framework

Start Date: 01/02/2021 *End Date*: 11/30/2021

Predecessors: Identifying Real-World Transportation Applications Using Artificial Intelligence TSSC2 task

Federal Lead:

Performing Organization:

This purpose of this project is to develop a performance measurement and evaluation framework that defines the roles and responsibilities of each entity to avoid unnecessary overlap and redundancy in resources; and identifies and defines key metrics to assess performance of prototype demonstrations and deployments of AI-enabled applications.

Key deliverables will include:

- Memo on AI Performance Measurement and Evaluation Framework

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Project Name: AI Analytical Needs Assessment Procurement Planning

Start Date: 01/02/2021 *End Date*: 06/30/2021

Predecessors: Identifying Real-World Transportation Applications Using Artificial Intelligence TSSC2 task

Federal Lead:

Performing Organization:

This purpose of this project is to develop a statement of work and select a contractor to create an analytical needs assessment report to help guide the development of one or more Analysis, Modeling, and Simulation (AMS) platforms that can be used by agencies in selecting and refining which AI-enabled applications to deploy.

Key deliverables will include:

- Draft Statement of Work
- Final Statement of Work

Project Name: AI Analytical Needs Assessment

Start Date: 7/01/2021 *End Date*: 06/30/2022

Predecessors: AI Analytical Needs Assessment Procurement Planning

Federal Lead:

TSSC POC:

Performing Organization:

The purpose of this project is to create an analytical needs assessment report to help guide the development of one or more AMS platforms that can be used by agencies in selecting and refining which AI-enabled applications to deploy. Specific objectives include:

- Identify, categorize, and prioritize AI-related data and analytical needs.
- Survey current AMS tools/methods.
- Document technical capabilities and adaptability for modeling AI.
- Conduct gap analysis to identify insufficient/non-existent analytical capabilities for assessing AI-enabled applications.
- Identify future R&D.
- Develop research implementation plan.

Key deliverables include:

- AI-Analytical Needs Assessment Memo

- AI Research Implementation Plan

Project Name: AI AMS Platform Procurement Planning

Start Date: 03/01/2022 *End Date*: 07/31/2022

Predecessors: AI Analytical Needs Assessment

Federal Lead:

Performing Organization:

This purpose of this project is to develop statements of work and select contractors to develop AMS platforms that can be used by agencies in selecting and refining which AI-enabled applications to deploy.

Key deliverables will include:

- Draft Statements of Work
- Final Statements of Work

Project Name: AI AMS Platforms

Start Date: 08/01/2022 *End Date*: 09/30/2023

Predecessors: AI AMS Platform Procurement Planning

Federal Lead:

TSSC POC:

Performing Organization:

The purpose of this project is to create one or more AMS platforms that offer a cost-effective approach to identify and prioritize AI deployments. Analytical tools will play a key role in system performance management, such as estimating or predicting system-level impacts that are difficult to observe in AI field deployments.

Key deliverables include:

- AI AMS Platform Plans
- AI AMS Platforms

Project Name: AI-Driven Prototype Demonstrations Impacts Assessment Procurement Planning

Start Date: 10/01/2021 *End Date*: 04/30/2022

Predecessors: AI Performance Measurement and Evaluation Framework, AI-Driven Prototype Demonstrations

Federal Lead:

Performing Organization:

This purpose of this project is to develop statements of work and select contractors to conduct impacts assessments of AI-driven prototype demonstrations.

Key deliverables will include:

- Draft Statements of Work

- Final Statements of Work

Project Name: AI-Driven Prototype Demonstrations Impacts Assessment

Start Date: 05/01/2022 *End Date*: 04/30/2024

Predecessors: AI-Driven Prototype Demonstrations Impacts Assessment Procurement Planning

Federal Lead:

TSSC POC:

Performing Organization:

The purpose of this project is to conduct impacts impacts assessments of AI-driven prototype demonstrations. Specific activities may include:

- Develop plans to assess impacts of prototype demonstrations.
- Develop open source methods and tools methods to quantify and monetize the impacts and costs of AI-driven prototype demonstrations.
- Conduct independent assessment of the impacts of the prototype demonstrations and document impacts.
- Share data and models developed for impacts assessment in an open data and open source environment.

Key deliverables include:

- AI-Driven Prototype Demonstrations Impacts Assessment Plans
- AI-Driven Prototype Demonstrations Impacts Assessment Reports and Briefings
- Source Code and Documentation
- Data Sets, Metadata, and Documentation
- Memo on technical, policy and standards needs, and lessons learned and best practices

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Project Name: AI-Driven Next Generation Deployments Evaluation Procurement Planning

Start Date: 05/01/2024 *End Date*: 08/30/2024

Predecessors: AI Performance Measurement and Evaluation Framework, AI-Driven Next Generation Deployments

Federal Lead:

Performing Organization:

This purpose of this project is to develop statements of work and select contractors to conduct independent evaluations of AI-driven next generation deployments.

Key deliverables will include:

- Draft Statements of Work
- Final Statements of Work

Project Name: AI-Driven Next Generation Deployments Evaluation

Start Date: 09/01/2024 *End Date*: 09/30/2026

Predecessors: AI-Driven Next Generation Deployments Evaluation Procurement Planning

Federal Lead:

TSSC POC:

Performing Organization:

The purpose of this project is to conduct independent evaluations of AI-driven next generation deployments. Specific activities may include:

- Develop plans to evaluate deployments.
- Develop open source methods and tools methods to quantify and monetize the impacts and costs of AI-driven deployments.
- Conduct independent evaluations of the deployments and document impacts.
- Share data and models developed for evaluation in an open data and open source environment.

Key deliverables include:

- AI-Driven Next Generation Deployments Evaluation Plans
- AI-Driven Next Generation Deployments Evaluation Reports and Briefings
- Source Code and Documentation
- Data Sets, Metadata, and Documentation
- Memo on technical, policy and standards needs, and lessons learned and best practices

Track 7: Policy & Standards

This track monitors and influences AI-related policies and standards development. It contains two sub-tracks: the policy sub-track and the standards sub-track. The policy sub-track includes the following activities:

- Track AI-related policy development by the Office of Secretary (OST) and other federal partners.
- Identify AI policy issues, including need for refinement or development of new AI ethics principles, data governance and data sharing policies.
- Share policy-related lessons learned and other challenges from deployment efforts.
- Identify existing policy frameworks that could incorporate AI.
- Inform and influence policy development activities.

The standards sub-track will be coordinated with the ITS JPO Standards Program. The standards sub-track includes the following activities:

- Assess the need for refined or new standards.

- Enhance or develop new standards to ensure that data can be easily accessed and shared for execution of AI-applications.

Track 8: Knowledge and Technology Transfer

This track facilitates the accelerated adoption of AI by public sector agencies for addressing specific transportation problems.

- Develop wide-ranging KTT products (e.g., program webpage, factsheets, webinars, primers, instructional videos, executive level videos, deployment guidance) to increase awareness and understanding of AI concepts and technologies for transportation problems.
- Educate and train agencies to deploy AI-driven systems and services.
- Share technical challenges, and potential benefits of leveraging AI for advancing next generation transportation systems and services.
- Share policy issues, policy changes and how they will enable AI implementation.
- Establish and provide technical assistance and peer exchange opportunities to cohorts of AI researchers, developers, and current and prospective deployers to facilitate adoption of AI for transportation problems.

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Appendix A. Summary of Stakeholder Feedback from Strategy Session

A virtual strategy event was held on June 17-18, 2020 with experts from ITS JPO, FHWA Operations, FHWA Operations R&D, FHWA Safety R&D, FHWA Freight Management and Operations, FHWA Operations Asset Management, FHWA Resource Center, FMCSA, FRA, FTA, NHTSA, and Volpe Center. A total of 42 experts were invited, and 34 attended at least one session. The purpose of the event was to present 40 potential applications of AI for five practical, real-world transportation scenarios; gather feedback on the risks and rewards of potential applications of AI; and develop a prioritized list of applications for possible inclusion in the 5-year roadmap for USDOT's AI for ITS Program. Figure 3 shows the number of invitees by department, including those who were invited but did not attend.

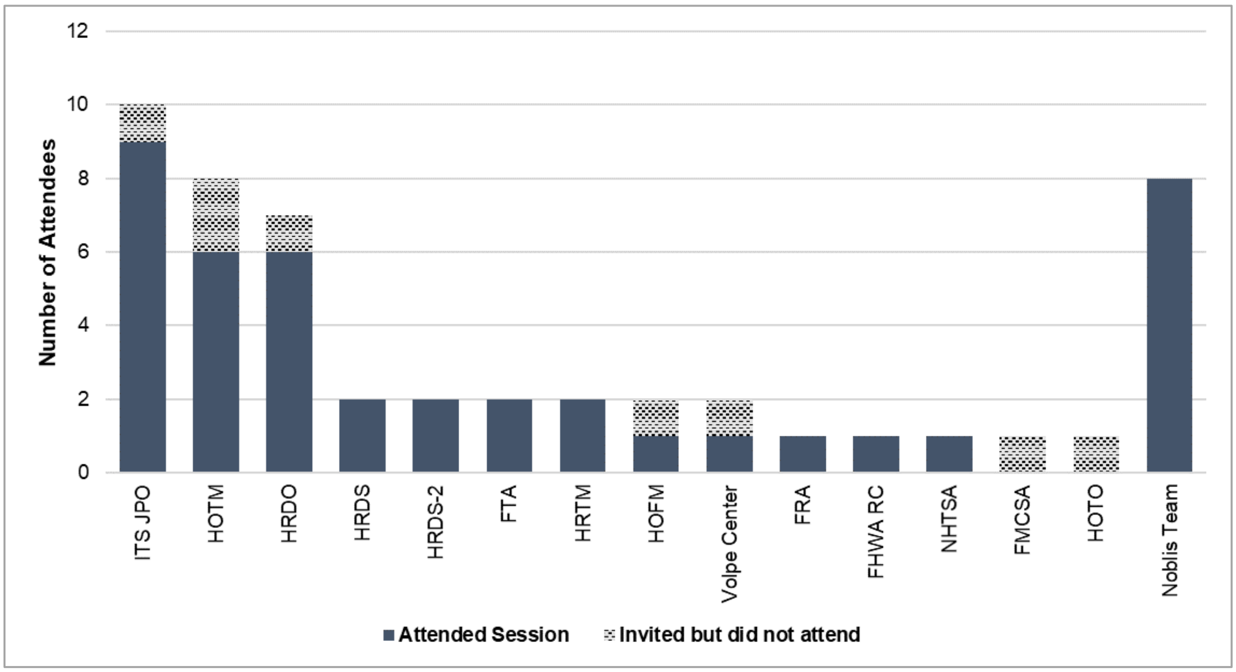

Figure 3. Strategy Session Attendance by Department (Source: USDOT)

As this was a virtual event, to sustain stakeholder interest and engagement, the event was restricted to 2½ hours on the first day and 2 hours on the second day. The first day of the event included presentations of potential applications of AI for five practical, real-world transportation scenarios, including: Urban Arterial Network, Urban Multimodal Corridor, Rural Freeway Corridor, Regional Management Systems, and Underserved Communities.

- *Urban Arterial Networks* are low and medium speed mixed-use facilities that provide access to and from traffic generators and attractors, typically managed within jurisdictional boundaries by individual local agencies.
- *Urban Multimodal Corridors* are combinations of highways and arterial streets that serve as major regional travel routes, typically managed collaboratively by a group of state, regional, and local agencies.
- *Regional System Management* is the collaborative management by multiple agencies (often as a regional planning organization) to improve the performance of comprehensive, area-wide transportation systems.
- *Rural Freeway Corridors* are high-speed, limited-access divided facilities that run outside urbanized areas across multiple states and counties, typically managed by multiple agencies.
- *Underserved Communities* are those that do not have their transportation needs met by existing transportation services.

To allow stakeholders to engage in meaningful discussions and provide feedback, two sets of breakout sessions were designed for the first day. The first set had two breakout sessions running in parallel to allow for maximum participation: #2A on AI for Urban Arterial Network; #2B on AI for Rural Freeway Corridor. Following the first set of breakout sessions, a second set of breakout sessions were held. Sessions in the second set were: #3A on AI for Urban Multimodal Corridor; #3B on AI for Regional System Management; #3C on AI for Underserved Communities. Figure 4 shows the participants per session.

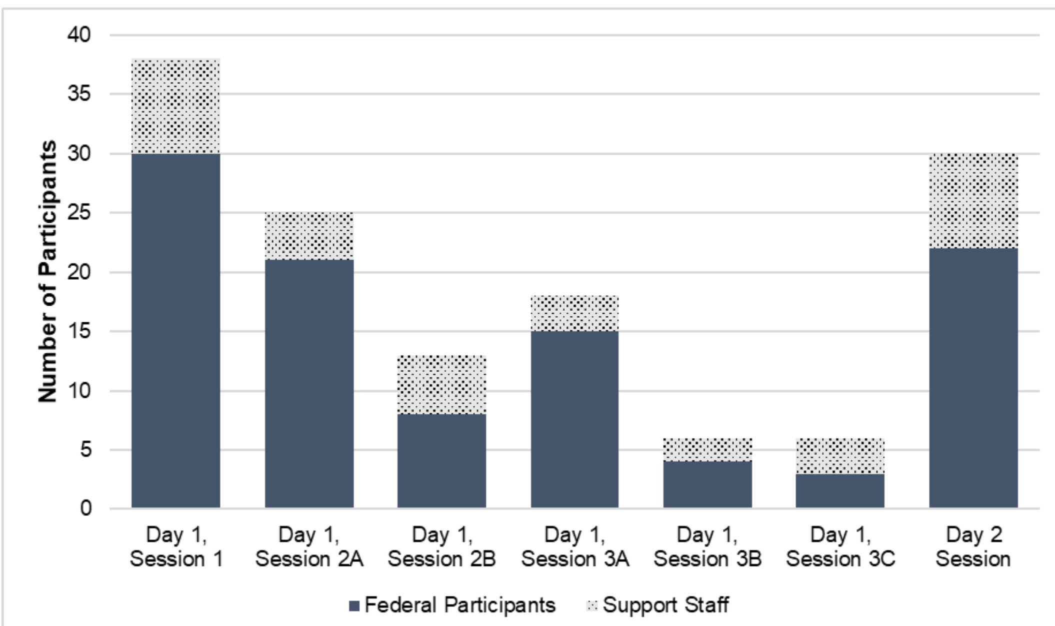

Figure 4. Participation by Session (Source: USDOT)

At each session, stakeholders provided feedback on the AI-enabled applications via chat box and rated the investment risk and potential reward of each application. Risk and reward were both ranked on a scale of 1 to 5, where 1 represented "Very Low" risk or reward and 5 represented "Very High" risk or reward. Following the conclusion of the strategy event, the support team also supplied their own ratings, to ensure that the findings were based on as wide a range of input as possible. These inputs were then used to calculate the Reward-Risk proportion, which may be used to judge the tradeoff between risk and reward. On this scale, a Reward-Risk proportion of 2 would represent an application's perceived reward receiving an average rating twice as high as its risk, while a proportion of 1 would indicate that they received equivalent ratings for both reward and risk.

On the second day, the reward-risk ratings of applications from all five breakout sessions were presented and discussed with stakeholders. Stakeholder were then invited to propose ideas for additional AI applications and concepts that had not been covered on the first day. Nine additional applications were proposed by stakeholders. Applications that were suggested by participants were given IDs with Roman numerals (e.g., 4-i and 4-ii) to distinguish them. The results of the reward and risk ratings were also used to categorize the applications on quad-charts. This format may be seen in Figure 5.

The quad-chart helps to easily distinguish the results into four different buckets. Applications with low risk and high reward may be considered "pearls," given that they require minimal work to obtain better-than-average reward. Applications with high risk and high reward are considered "oysters," as they require some initial investment but will ultimately pay off much like pearls. Applications with low risk and low reward are considered "bread and butter" applications, which would give moderate rewards in exchange for minimal work. Finally, applications with high risk and low reward are "white elephants," requiring a great deal of effort for very little benefit. While "pearls" are the most appealing applications to pursue, in general "bread and butter" and "oyster" applications should also be considered to ensure a balance in return-on-investment and to ensure that deployments may be achieved at a steady pace. "White elephants" should be avoided where possible.

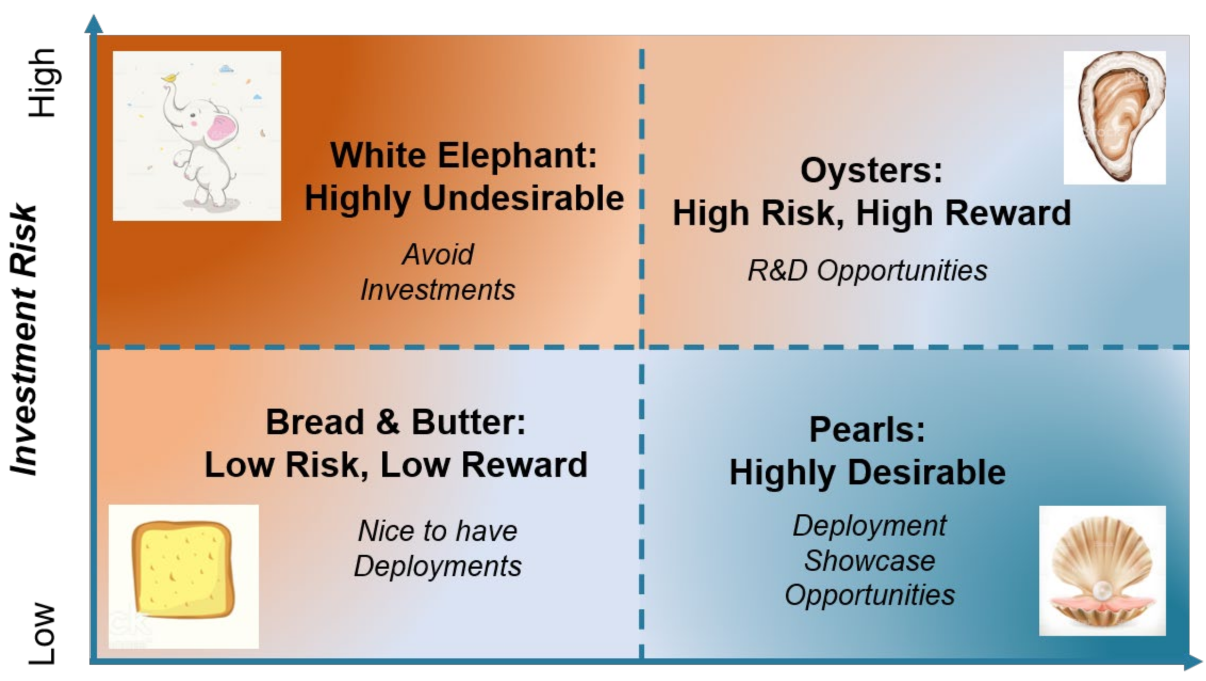

Figure 5. Potential Reward-Investment Risk Chart (Source: USDOT)

Reward and Risk Quad-Charts

The applications' reward and risk ratings may be seen in Figure 6 through Figure 11. The ratings are divided by breakout session.

Figure 6 shows the quad-chart for Session 2A, Urban Arterial Networks. Here it may be noted that the majority of applications were considered "pearls," with some exceptions. In particular, Application 2A-6, Crash and Incident Detection, was considered to have the highest overall reward but less-than-average risk. The high number of pearls allows for the selection process to be particularly discerning, as almost all applications were seen as being cost-effective by participants.

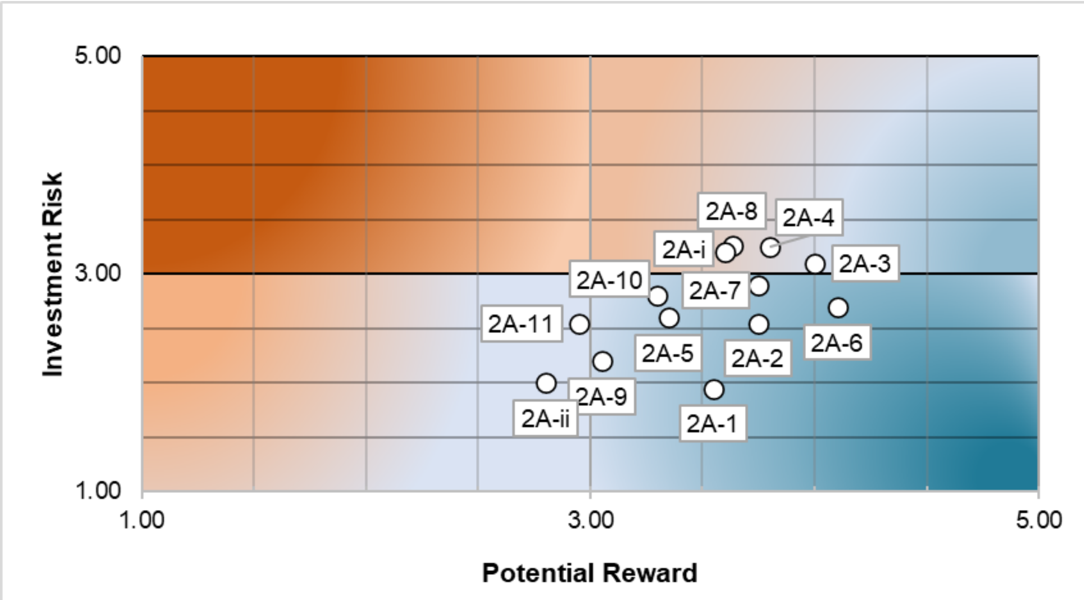

Figure 6. Reward vs Risk for Session 2A (Source: USDOT)

Figure 7 shows the quad-chart for Session 2B, Rural Freeway Corridors. While the majority of applications are also considered to be pearls for this breakout session as well, they are almost all much closer to the boundary between pearls and oysters, having middling risk. In this case, Application 2B-1 was seen as having the highest reward—much like the very similar application in Session 2A. This indicates that the application may have strong relevance in multiple scenarios.

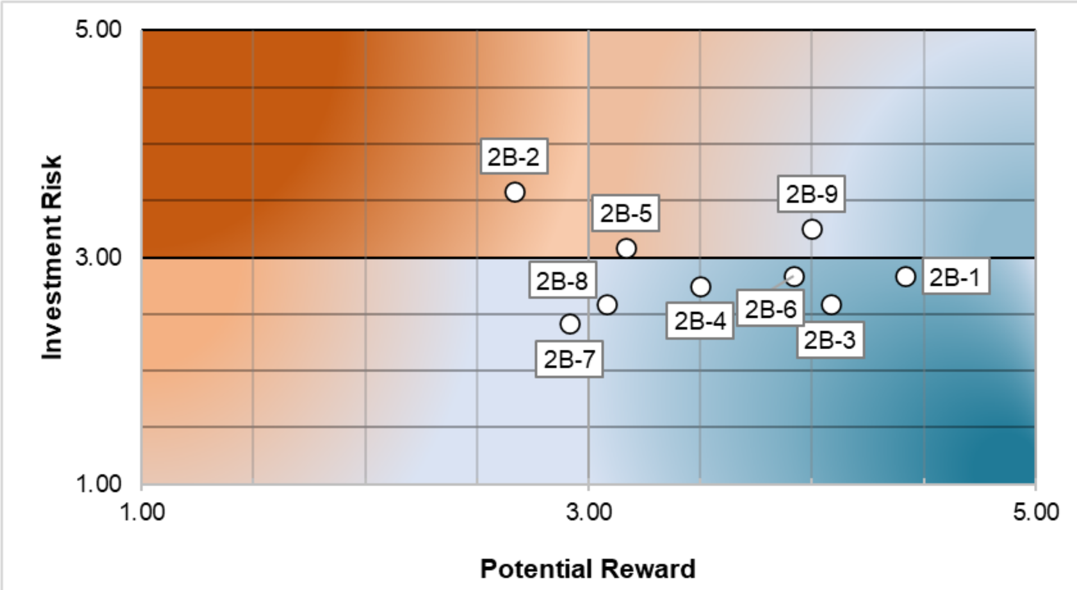

Figure 7. Reward vs Risk for Session 2B (Source: USDOT)

The quad chart in Figure 8 shows the reward-risk ratings for Session 3A, Urban Multimodal Corridors. In contrast to the previous sessions, the majority of applications here were categorized as oysters. This was largely due to having higher than average risk ratings. In this session, the pearl with the highest reward was 3A-i, a participant-suggested application proposing AI for Traffic Management Applications. This application was proposed prior to the virtual event.

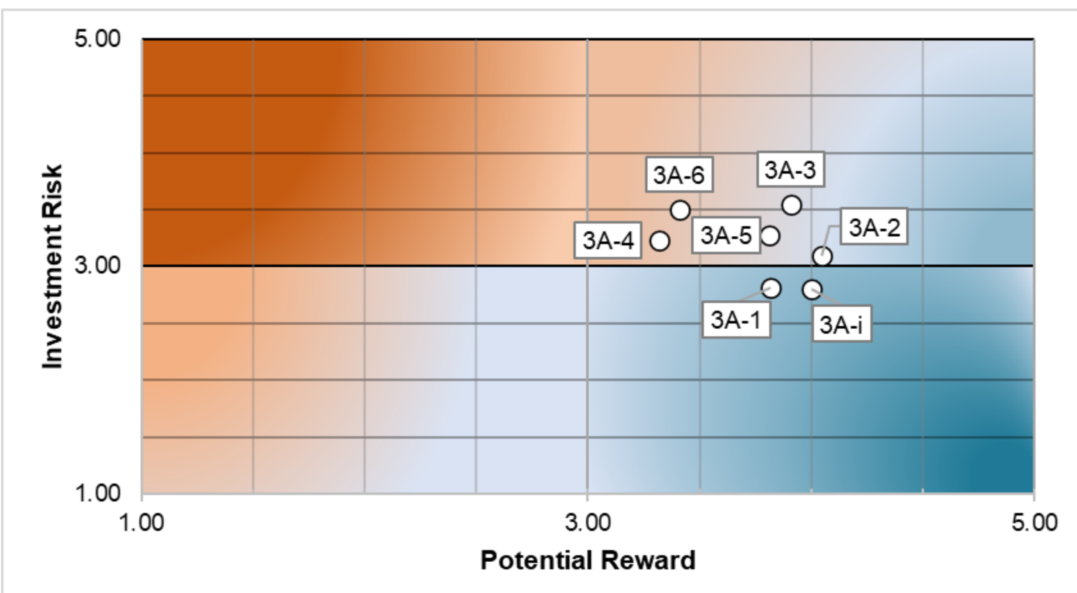

Figure 8. Reward vs Risk for Session 3A (Source: USDOT)

Figure 9 displays the reward-risk quad-chart for Session 3B, Regional Systems Management. This session features a couple of applications that straddle the border between being oysters and pearls, though the majority are considered pearls. Application 3B-1, AI for Data Fusion, was seen as having the highest reward and relatively manageable risk.

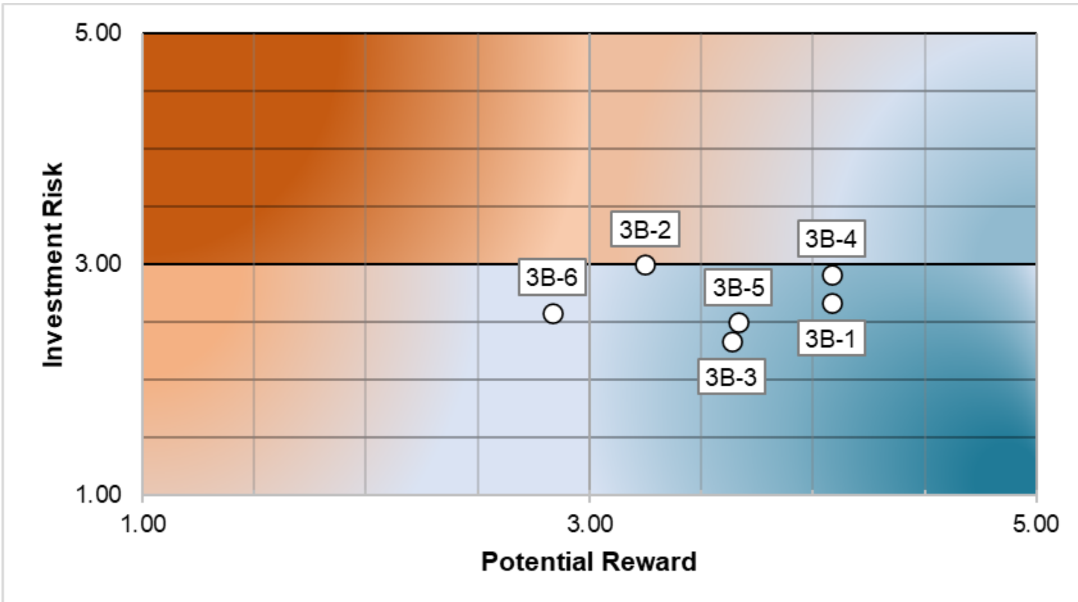

Figure 9. Reward vs Risk for Session 3B (Source: USDOT)

The quad-chart for Session 3C, AI for Underserved Communities, is shown in Figure 10. In this scenario, the majority of applications were considered to have high risk, with only one pearl in the group—3C-7, VR for Testing. However, the overall reward ratings were higher than average, indicating that the applications have high potential despite the inherent risks.

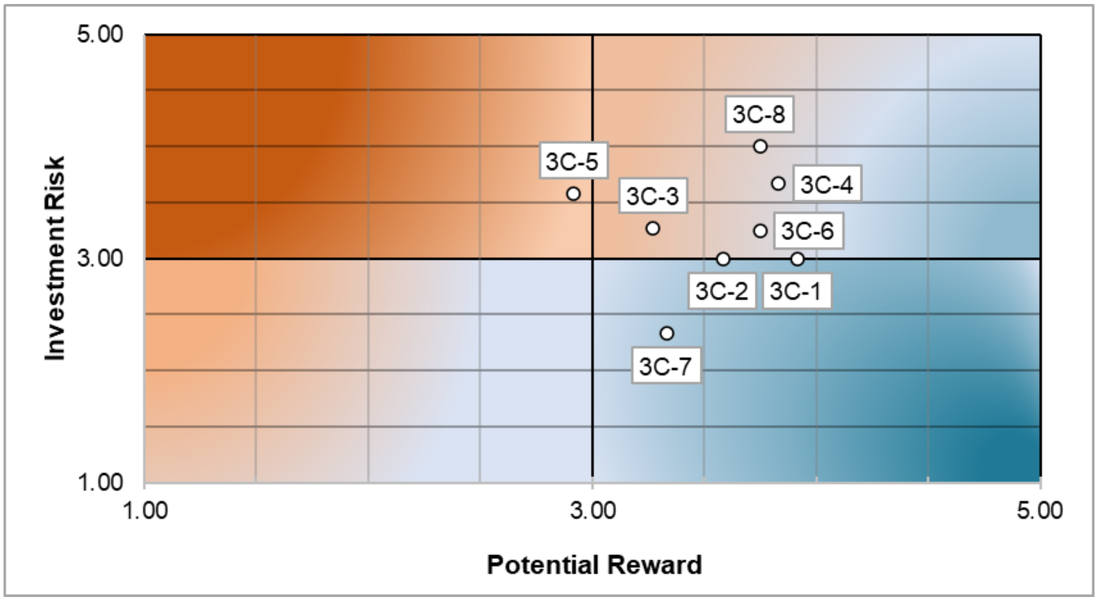

Figure 10. Reward vs Risk for Session 3C (Source: USDOT)

Finally, Figure 11 shows the quad-chart for applications that were proposed by stakeholders on the second day of the strategy session during Session 4. The majority of them were categorized along the oyster-pearl border, indicating moderate risk. Application 4-ii, Multimodal Trip Planning, was seen as having the highest reward among the group, and comments noted that it was similar to the existing application 3C-1, AI-Enabled Routing Tools, which also performed well in the reward-risk assessment.

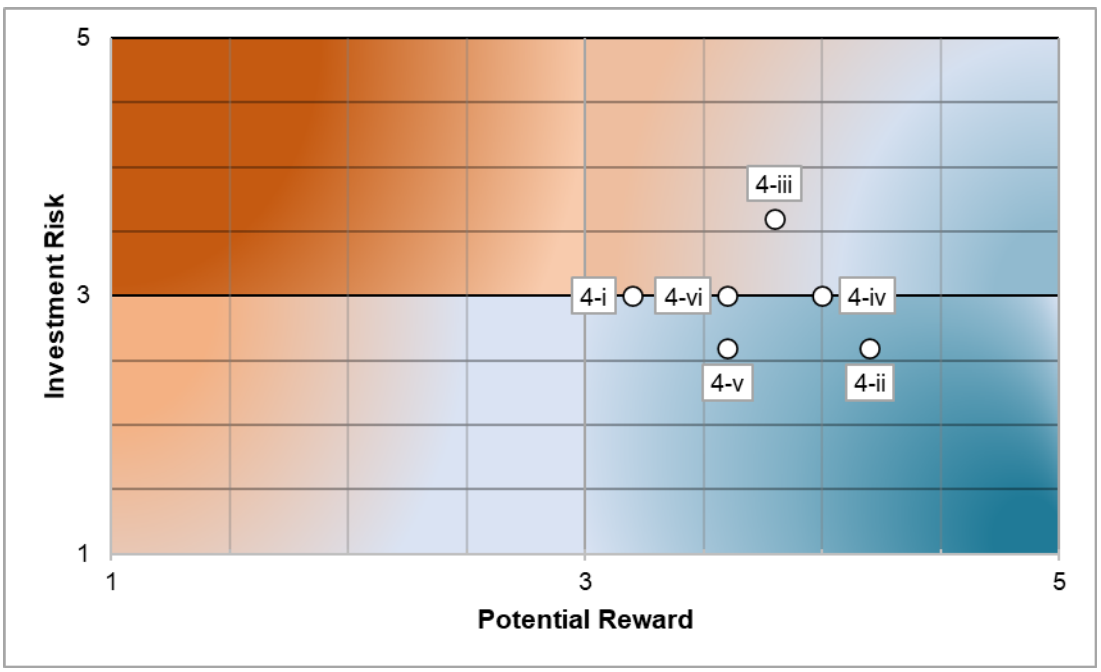

Figure 11. Reward vs Risk of Applications Proposed by Stakeholders on Day 2 (Source: USDOT)

As part of Session 4, the stakeholders picked their top six high priority applications. The selection process involved choosing one "Gold" application, worth 6 points; two "Silver" applications, each worth 3 points; and three "Bronze" applications, each worth 2 points. This permitted respondents to indicate which applications they viewed as critical priorities and which they thought were important but not as immediately pressing. Figure 12 shows the applications that were examined and compares their prioritization scores to their reward-risk proportion. Applications placed on the right side of the graph were considered to be a priority by many respondents, while those that are placed in the upper part of the graph were considered to have a reward that significantly outweighed their risks.

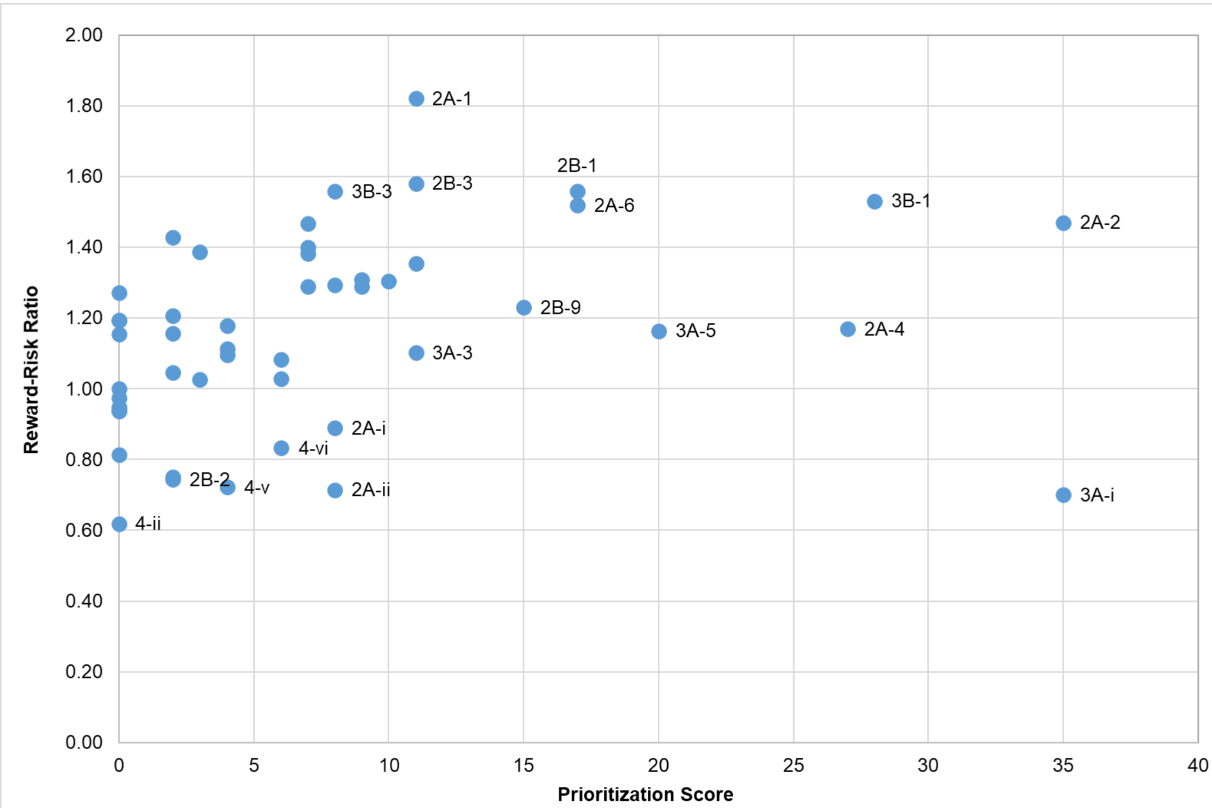

Figure 12. Prioritization Scores compared to Reward-Risk Scores (Source: USDOT)

Mapping Applications to Roadmap Tracks

To convert the stakeholder feedback for each application into roadmap tracks, the team mapped areas of the reward-risk quad-chart to the tracks. Applications in the lower right quadrant corresponding to high reward and low risk (the "Pearls") were assigned to the "Deployments" track. Applications suitable for "Prototype Demonstrations" either had slightly lower reward or slightly higher risk than those in "Deployments". Finally, applications with high reward and high risk were assigned to the "Enabling Technologies" track, since they likely require more research and development before entering the prototype phase. The rubric for mapping applications to roadmap tracks is shown in Table 5. These numeric designations correspond to the illustration in Figure 13.

Table 5. Rubric for Assigning Individual Applications to Roadmap Tracks

Roadmap Track	Min Reward	Max Reward (<=)	Min Risk (>=)	Max Risk (<=)
Deployments	(>) 3	5	1	3
Moderate-Value Prototype Demonstrations	(>=) 2.5	3	1	3.5
High-Value Prototype Demonstrations	(>) 3	5	3	3.5
Enabling Technologies	(>=) 3	5	3.5	5
Enabling Technologies	(>=) 2.5	3	3.5	4

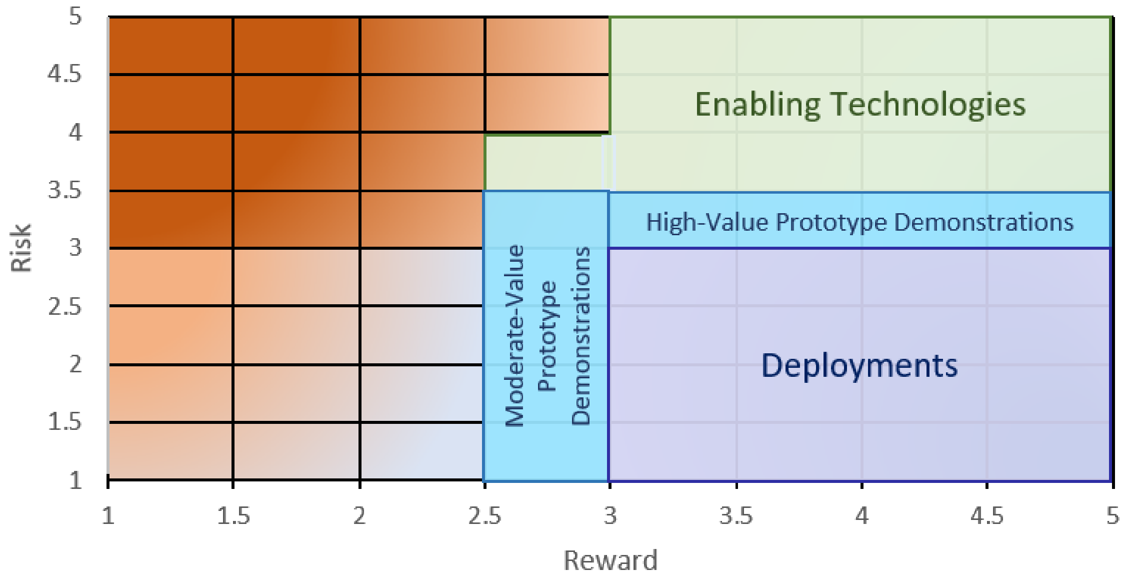

Figure 13. Mapping Roadmap Tracks to Quad Chart (Source: USDOT)

As many of the individual applications share similar objectives, the AI for ITS team bundled related applications into application *areas*. These application areas were used to inform projects in the Prototype Demonstrations and Deployments tracks. Table 6 shows the application areas and their assigned tracks based on the average reward-risk scores across each individual application in the application area using the same rubric as shown in Figure 13 and Table 5.

Table 6. Combining Applications with Similar Objectives

ID	Application Area	Objective	Relevant Scenarios	Avg. Risk	Avg. Reward	Prioritization	Assigned Track
2A-4 **4-iii**	AI-Enabled Misbehavior Detection System	Identify misbehaviors in various ITS	**Urban Arterial Network,** Urban Multimodal Corridor, Regional System Mgmt, Rural Freeway Corridor, Underserved Communities	3.4	3.8	26	Prototype Demonstration
2B-4 **2B-5** **3B-2**	AI for Asset Management	Identify and predict asset conditions	Urban Arterial Network, Urban Multimodal Corridor, **Regional System Mgmt, Rural Freeway Corridor**	2.9	3.3	9	Deployment
3A-5	AI-Enabled Demand Management	Proactively select and implement demand management strategies	Urban Arterial Network, **Urban Multimodal Corridor**, Regional System Mgmt, Rural Freeway Corridor	3.3	3.8	20	Prototype Demonstration
2B-6 **3B-5**	AI for Work Zone Safety	Detect, predict, and share information on work zone issues (e.g., delays)	Urban Arterial Network, Urban Multimodal Corridor, **Regional System Mgmt, Rural Freeway Corridor**	2.7	3.8	14	Deployment
2B-3 **3B-3**	AI for Road Weather Management	Detect and predict road surface conditions to inform preventative and real-time strategies	Urban Arterial Network, Urban Multimodal Corridor, **Regional System Mgmt, Rural Freeway Corridor**	2.5	3.9	19	Deployment

ID	Application Area	Objective	Relevant Scenarios	Avg. Risk	Avg. Reward	Prioritization	Assigned Track
2A-3 2B-9	AI for ITS Decision Support	Proactively respond to conditions and coordinate decision-making	**Urban Arterial Network,** Urban Multimodal Corridor, Regional System Mgmt, **Rural Freeway Corridor**	3.2	4	24	Prototype Demonstration
3B-1 4-v	AI for Data Fusion and Quality Checking	Fuse data from multiple sources and validate datasets	Urban Arterial Network, Urban Multimodal Corridor, **Regional System Mgmt**, Rural Freeway Corridor	2.6	3.8	32	Deployment
3A-i 2A-5 3A-3	AI for Traffic Management Strategies	Develop comprehensive traffic models, predict delays, and identify useful measures (e.g., target speeds, ramp metering rates)	**Urban Arterial Network**, **Urban Multimodal Corridor**, Regional System Mgmt, Rural Freeway Corridor	3	3.8	53	Deployment
2A-1 2A-2	AI for Traffic Signal Optimization/ Planning	Optimize signal timing plans offline and in real-time	**Urban Arterial Network,** Urban Multimodal Corridor	2.3	3.7	46	Deployment

ID	Application Area	Objective	Relevant Scenarios	Avg. Risk	Avg. Reward	Prioritization	Assigned Track
2A-i	AI for Unsignalized Intersections	Proactively detect wrong way driving, provide curve speed warning and intersection movement assist warning	**Urban Arterial Network,** Urban Multimodal Corridor	3.2	3.6	8	Prototype Demonstration
2B-7 **2B-8** **3B-6**	AI for Freight Operations and Traveler Information	Provide real-time traveler information for freight-specific needs (e.g., predict parking availability, truck arrivals at ports)	Urban Multimodal Corridor, **Regional System Mgmt, Rural Freeway Corridor**	2.5	2.9	6	Prototype Demonstration
2A-9 **2A-10** **2A-11**	AI for Transit Operations and Management	Improve transit service by using Transit Signal Priority, managing demand, and identifying unauthorized use of bus lanes	**Urban Arterial Network,** Urban Multimodal Corridor, Underserved Communities	2.5	3.1	9	Deployment

ID	Application Area	Objective	Relevant Scenarios	Avg. Risk	Avg. Reward	Prioritization	Assigned Track
2A-7 4-iv	AI for Pedestrian and Micromobility Detection	Detect and identify pedestrians, cyclists, micromobility and other modes	**Urban Arterial Network,** Urban Multimodal Corridor, Underserved Communities	3	3.9	10	Prototype Demonstration
2A-6 2B-1 3A-2 3B-4	AI for Crash/ Incident Detection and Response	Detect crashes and incidents, predict their impacts, and identify response plans	**Urban Arterial Network, Urban Multimodal Corridor, Regional System Mgmt, Rural Freeway Corridor**	2.9	4.2	50	Deployment
3C-1 3A-4 4-ii	AI for Navigation and Traveler Information	Generate personalized real-time multimodal travel information	Urban Arterial Network, **Urban Multimodal Corridor,** Regional System Mgmt, Rural Freeway Corridor, **Underserved Communities**	2.9	3.8	16	Deployment
3A-6 3C-5	AI-Enabled Integrated Payment	Make integrated and secure multimodal electronic payment and enable advanced forms of identity verification	**Urban Multimodal Corridor,** Underserved Communities	3.5	3.2	0	Prototype Demonstration

ID	Application Area	Objective	Relevant Scenarios	Avg. Risk	Avg. Reward	Prioritization	Assigned Track
3A-1	AI for Inter-Agency Collaboration	Collaborate across agencies in real-time using DSS and Knowledge Based Expert System (KBES)	Urban Arterial Network, **Urban Multimodal Corridor,** Regional System Mgmt, Rural Freeway Corridor	2.8	3.8	11	Deployment
2A-8 **4-i**	AI for Safety Performance Measurement	Track and evaluate performance metrics, tailored to individual situations and uses (e.g., predict safety metrics of ADS)	**Urban Arterial Network,** Urban Multimodal Corridor, Regional System Mgmt, Rural Freeway Corridor, Underserved Communities	3.1	3.4	4	Prototype Demonstration
3C-2 **3C-4** **3C-6**	AI-Enabled Independent Travel for Underserved Communities	Make independent multimodal travel more accessible	**Underserved Communities**	3.4	3.4	2	Prototype Demonstration
3C-7	Virtual Reality (VR) for Testing	Enable development and trial of navigational apps using VR testing environment	**Underserved Communities**	2.3	3.3	2	Deployment

ID	Application Area	Objective	Relevant Scenarios	Avg. Risk	Avg. Reward	Prioritization	Assigned Track
3C-3 3C-8	AI-Enabled User Assistance for Underserved Communities	Communicate with and assist multimodal travelers	**Underserved Communities**	3.6	3.5	0	Enabling Technology
2B-2	AI for Wildlife Detection	Detect the presence of wildlife and warn drivers to minimize collisions	Regional System Mgmt, **Rural Freeway Corridor**	3.6	2.7	2	Enabling Technology
2A-ii	AI for Loop Signature Matching	Enhance loop detector performance by loop signature matching to establish reliable detection across wide area	**Urban Arterial Network,** Urban Multimodal Corridor	2	2.8	8	Prototype Demonstration
4-vi	Deidentification of PII Using AI	Remove PII from big data sets quickly and efficienctly and generate unoriginal data for use in other AI applications	Urban Arterial Network, Urban Multimodal Corridor, Regional System Mgmt, Rural Freeway Corridor	3	3.6	6	Prototype Demonstration

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