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

Summary of Potential Application of AI in Transportation

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16. Abstract

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. The US government elevated AI as one of its key priority science and technology areas. In response, 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.

The purpose of this report is to identify broad categories of AI-enabled applications that can be applied to address specific transportation problems and needs and summarize existing and potential applications enabled by AI under each category based on a review of literature.

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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-enabled 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 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 United States Department of Transportation (USDOT) (Thompson D. , 2019). Some of the USDOT's modal administrations, including the Federal Highways 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 the Federal Transit Administration (FTA), the Federal Motor Carrier Safety Administration (FMCSA), and the Pipeline and 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-enabled 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).

Purpose

The purpose of this report is to identify broad categories of AI-enabled applications that can be applied to address specific transportation problems and needs, and to provide a high-level summary of existing and potential AI-enabled applications under each category based on a review of literature.

Please note that the report represents a snapshot in time and does not include an exhaustive list of ITS applications that can be enhanced by AI.

Organization

The report is organized as follows:

- Chapter 2 identifies and defines 11 broad categories of AI-enabled applications that can be applied to address specific transportation problems and needs.
- Chapter 3 provides summary descriptions of the AI-enabled applications corresponding to the 11 categories. Each section, corresponding to a category, includes summary descriptions of existing and potential AI-enabled applications covered under the category, and the potential role of USDOT for investing in AI-enabled applications under the category. This chapter also summarizes the risks and barriers to use of AI that are common across all categories.
- Chapter 4 presents the conclusion and next steps.

Chapter 2. Overview of AI-Enabled Application Categories

This chapter provides a summary of broad categories of AI-enabled applications that can be applied to address specific transportation problems and needs.

As a first step in the identification of potential AI-enabled application categories with relevance to ITS, the research team worked with the USDOT to recommend a definition of AI with a focus on ITS. The recommended definition aligns with the definitions of AI in the Congress S.2217 – Future of Artificial Intelligence Act of 2017 (Congress, 2017), which include the following:

- Any artificial systems that perform tasks under varying and unpredictable circumstances, without significant human oversight, or that can learn from their experience and improve their performance. Such systems may be developed in computer software, physical hardware, or other contexts not yet contemplated. They may solve tasks requiring human-like perception, cognition, planning, learning, communication, or physical action. In general, the more human-like the system within the context of its tasks, the more it can be said to use artificial intelligence.
- Systems that think like humans, such as cognitive architectures and neural networks.
- Systems that act like humans, such as systems that can pass the Turing test or other comparable test via natural language processing, knowledge representation, automated reasoning, and learning.
- A set of techniques, including machine learning, that seek to approximate some cognitive task.
- Systems that act rationally, such as intelligent software agents and embodied robots that achieve goals via perception, planning, reasoning, learning, communicating, decision making, and acting.

The recommended definition, as stated below, contextualizes AI for use in ITS, and is consistent with existing US government definitions of AI.

> 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, *et al.* 2019).

Potential Categories of AI-Enabled Applications in ITS

The research team identified 11 categories of AI-enabled applications that can be mapped to the Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT) version 8.3 (U.S. Department of Transportation, 2020) . A table that maps the AI-enabled application categories to the existing ITS taxonomy can be found in Appendix A. The 11 AI-enabled application categories and their definitions are given in Table 1. The definitions are adapted from the Service Area descriptions included in ARC-IT.

The next chapter presents summary descriptions of existing and potential applications of AI under these 11 categories.

Table 1. 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.

ID	AI-Enabled Application Category	Definition/Scope
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.
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.

ID	AI-Enabled Application Category	Definition/Scope
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.

Chapter 3. Summary Descriptions of AI-Enabled Applications

This chapter provides summary descriptions of current and potential AI-enabled applications corresponding to the 11 categories defined in Chapter 2. Each section corresponds to an AI category and includes summary information of AI-enabled applications identified from an ITS-focused literature search. The discussions presented in this chapter represents a snapshot in time and does not constitute an exhaustive list of ITS-related applications enhanced by AI. Instead, this report provides a high-level overview of how AI is currently being used or could potentially be used in the future to enhance existing transportation systems or introduce new capabilities.

In addition to summarizing applications in that category, each section discusses, the potential role of USDOT for investing in AI-enabled applications in that category.

The summary descriptions of the existing and potential applications of AI are provided in a tabular format and document the following:

- ID: Unique identifier that references the category and number of the application
- Application: Name of the existing or potential AI-enabled application
- Objective: Identifies the objective of the AI-enabled application
- Description: Provides a summary description, including references (where applicable)
- AI Techniques: Provides a list of the AI techniques that are or may be used by the AI-enabled application (see Figure 1 for definitions of a few common AI sub-fields and techniques)
- System Functions: Provides a list of the specific functions enabled by each potential AI-enabled application under this category (see Figure 2).
- Maturity: Identifies the maturity of the AI-enabled application. Four maturity levels have been defined including:
    - Concept: Application is at a conceptual stage.
    - R&D: Application is in the research and development stage.
    - Prototype/MVP: Application has been tested and is now a prototype or a Minimum Viable Product (MVP).
    - Production: Application is in production and has been implemented in the field.

The descriptions are based on a review of the literature. This chapter also presents risks and barriers to use of AI that are common across all categories.

Machine Learning

It is a broad AI sub-field 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 algorithms.

Artificial Neural Networks

Inspired by biological neural networks, artificial neural network (ANN) is a group of interconnected artificial neurons (nodes) that uses mathematical models to learn patterns and predict. This is a class of ML algorithms.

Deep Learning

Deep Learning (DL) is another class of ML that imitates the workings of the human brain in processing data and creating patterns for use in decision making. It is based on ANN. The "deep" refers to the use of large number of layers of neurons to learn unsupervised from vast amounts of data that is unstructured and unlabeled.

Object and Face Recognition

Object recognition is an AI technique for identifying specific objects in images or videos. Similarly, face recognition is a technique for automatically identifying or verifying a person from images or videos.

Natural Language Processing

Natural language processing (NLP) is an AI technique for parsing, processing and analyzing natural human language. It is the first step toward speech recognition, natural language understanding (NLU) and comprehensive translation.

Computer Vision and Imagery Analysis

This technique seeks to automate human visual tasks by analyzing images and videos. Computers are trained to interpret, understand, and even recreate the visual world.

Figure 1. Examples of AI Sub-Fields and Techniques.

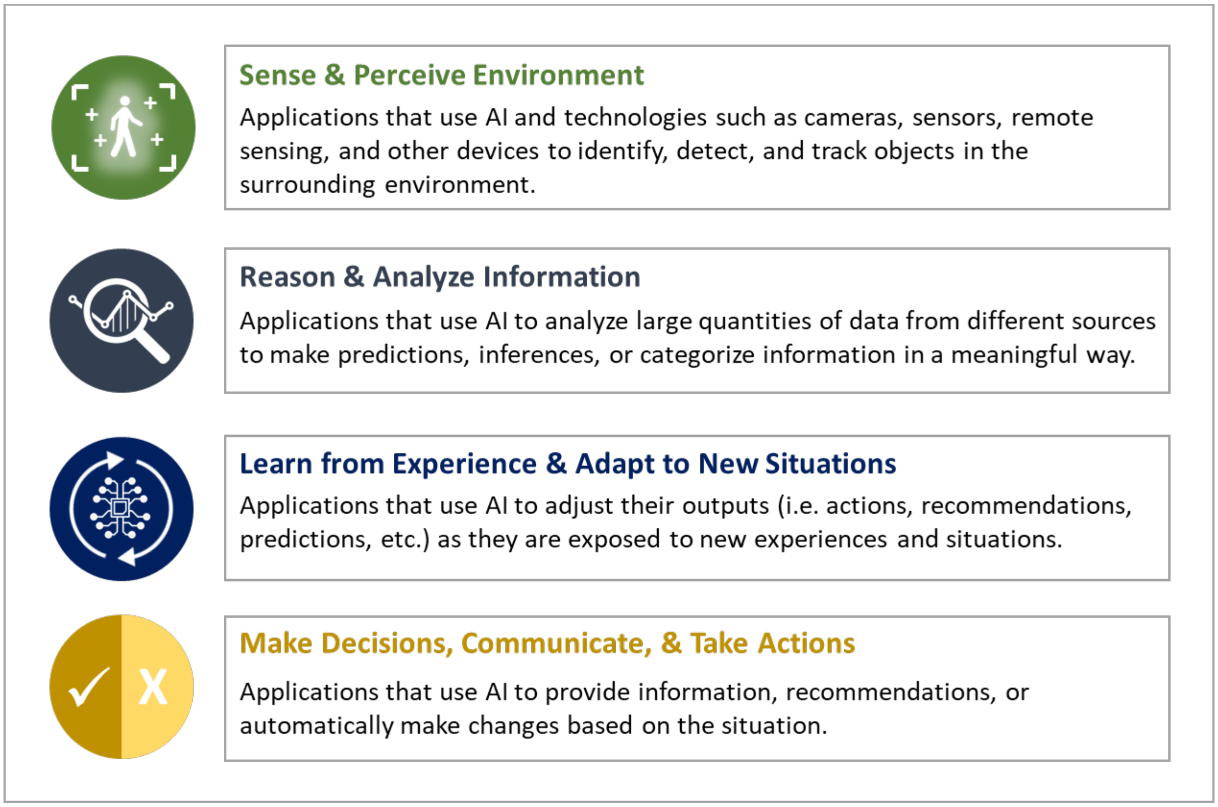


Figure 2. System Functions Enabled by AI.

Advanced Driver Assistance Systems and Automated Driving Systems

Definition

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.

Summary of Potential Applications

In this category, 9 existing and potential applications of AI are summarized in Table 2 to Table 10.

Table 2. Summary Description of AI for Automated Vehicle Decision-Making (CAV-01)

Item	Description
ID	CAV-01
Application	Automated Driving System Object and Event Detection and Response
Objective	Enable ADS to monitor the driving environment (detecting, recognizing, and classifying objects and events and preparing to respond as needed) and execute an appropriate response to such objects and events
Description	AI plays a central role in the development of automated driving capabilities. **Perception and Sensor Fusion** • The combination of sensor fusion and connectivity (to the latest traffic, weather and surface conditions) can help build a complete three-dimensional map of a vehicle’s environment. For example, machine learning and computer vision can be used to build models of the vehicle's static environment (objects,

	features, terrain) and dynamic environment (people and vehicles moving in the vehicle's environment) (Zhou, Navarro-Serment, and He, 2013). • Deep learning and other AI techniques can be used to train an ADS to recognize objects, such as traffic control devices, in the surrounding driving environment. AI-based techniques have been able to achieve “better-than-human” recognition rates of traffic control devices. In addition to detecting traffic control devices, AI-based techniques can be used to train a system to classify them (e.g., speed limit, stop sign, etc.). Such classification capabilities can be used to inform the driver, for lower levels of autonomy, or inform the ADS directly in its decision-making (Ciresan, Meier, and Schmidhuber, 2012). **Object and Event Detection and Response** • Deep learning has been used to train ADS in the advanced decision-making processes required for object and event detection and response (OEDR) and other core elements of the dynamic driving task (DDT). These algorithms can be recalibrated and retrained as the vehicles encounter diverse environments, collect more data and learn patterns (University of Pennsylvania, 2017). Since there are countless possible situations that an automated vehicle can encounter and it is extremely difficult and expensive to label all these data, reinforcement learning, and deep learning are emerging in this space. Instead of using labeled data, as in supervised learning, reinforcement learning allows automated vehicles to learn by experimentation and feedback (rewards), similar to how humans learn to walk (U.S. Department of Transportation, 2018).
AI Techniques	Machine Learning; Artificial Neural Networks; Deep Learning; Natural Language Processing; Object & Face Recognition; Comp Vision & Image Analysis
System Functions	Sense & Perceive Environment; Reason & Analyze Information; Learn from Experience & Adapt to New Situations; Make Decisions, Communicate, & Take Actions
Maturity	Concept → R&D → Prototype/MVP → Production

Table 3. Summary Description of AI for Driver Monitoring (CAV-02)

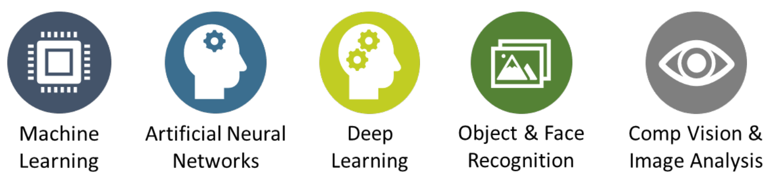
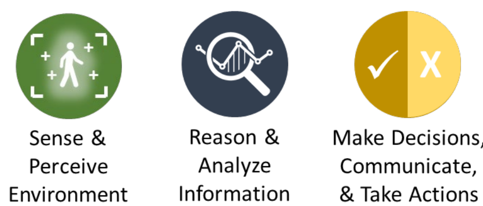
Item	Description
ID	CAV-02
Application	Driver Monitoring
Objective	Detect driver behavior and respond to cues
Description	AI can be embedded in vehicle safety systems and enable vehicles to monitor not only the road but also the driver. Using deep learning, advanced cameras and infrared sensors, AI software can detect driver behavior in multiple ways (Novosilska, 2018). It can detect whether a driver is in the vehicle and recognize who is operating the vehicle using facial recognition algorithms. AI can also detect distracted and drowsy driving by focusing on head position, eye openness, and posture. AI can read the driver's hand gestures and lips and respond without the driver having to take their eyes off the road. For example, the driver can hold a "thumbs up" sign to notify the vehicle to like a song or podcast, thus offering enhanced infotainment control.
AI Techniques	
System Functions	
Maturity	

Table 4. Summary Description of AI for Dangerous Driving Recognition (CAV-03)

Item	Description
ID	CAV-03
Application	Dangerous Driving Recognition

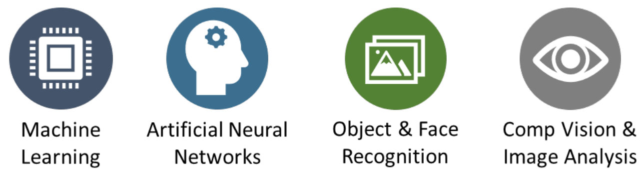
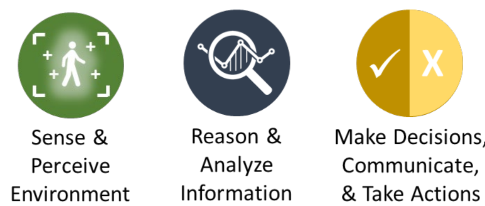
Item	Description
Objective	Recognize complicated driving patterns including dangerous driving
Description	Machine learning models can be developed to detect complicated driving patterns using vehicle sensory and message data from cameras and radios. An AI algorithm can classify dangerous driving patterns, such as tailgating. By classifying the dangerous behavior accurately, the vehicle can provide feedback to the driver or inform law enforcement or insurance companies if the behavior is repeated (Sampedro Garcia, Nikkhah, and Metz, 2017).
AI Techniques	
System Functions	
Maturity	

Table 5. Summary Description of AI for Vehicle Maintenance Prediction (CAV-04)

Item	Description
ID	CAV-04
Application	Vehicle Maintenance Prediction
Objective	Predict when to undergo preventative vehicle maintenance before issues arise
Description	This AI-enabled application can combine vehicle data with weather data to predict when the driver should consider preventative, routine vehicle maintenance (Sun, 2019). For example, an algorithm could learn to predict when weather changes could negatively affect tire pressure (Sampedro Garcia, Nikkah, and Metz, 2017).

Item	Description
AI Techniques	Machine Learning
System Functions	Sense & Perceive Environment; Reason & Analyze Information; Make Decisions, Communicate, & Take Actions
Maturity	Concept → R&D → Prototype/MVP → Production

Table 6. Summary Description of AI for Dynamic Platoon Gaps Identification (CAV-05)

Item	Description
ID	CAV-05
Application	Dynamic Platoon Gaps Identification
Objective	Inform safe and efficient platoon gaps dynamically
Description	Rather than drivers setting desired following distances for adaptive cruise control, AI can dynamically determine safe and efficient following distances. For example, AI can be embedded in Cooperative Automated applications to set inter-platoon time gaps between vehicles. The algorithm can respond dynamically to changing conditions, increasing gaps in response to adverse weather and road surface conditions such as ice (Thompson, 2019).
AI Techniques	Machine Learning; Object & Face Recognition; Comp Vision & Image Analysis

Item	Description
System Functions	Sense & Perceive Environment; Reason & Analyze Information; Learn from Experience & Adapt to New Situations; Make Decisions, Communicate, & Take Actions
Maturity	**Concept** > **R&D** > Prototype/MVP > Production

Table 7. Summary Description of AI for Smart Automotive Headlights (CAV-06)

Item	Description
ID	CAV-06
Application	Smart Automotive Headlights
Objective	Respond to changing road conditions for optimal visibility
Description	AI can be used to detect objects and recognize the surrounding environment. Machine learning can be used to predict the future location of precipitation and road objects (Narasimhan, 2018). Embedding this technology in automotive headlights allows them to respond dynamically to changing conditions and optimize visibility for all road users (Duke University, 2018).
AI Techniques	Machine Learning; Object & Face Recognition; Comp Vision & Image Analysis
System Functions	Sense & Perceive Environment; Reason & Analyze Information; Make Decisions, Communicate, & Take Actions
Maturity	Concept > **R&D** > Prototype/MVP > Production

Table 8. Summary Description of AI for Smart Stop/Start System (CAV-07)

Item	Description
ID	CAV-07
Application	Smart Stop/Start System
Objective	Improve situational awareness and determine when to turn off the engine
Description	An auto manufacturer has patented a smart stop/start system for vehicles to help reduce drivers' annoyance with untimely stopping. The system uses GPS and sensors to analyze the vehicle's surroundings and then determines if the system should be activated. This added layer of AI boosts the vehicle's situational awareness.
AI Techniques	 Machine Learning; Object & Face Recognition; Comp Vision & Image Analysis
System Functions	 Sense & Perceive Environment; Reason & Analyze Information; Make Decisions, Communicate, & Take Actions
Maturity	Concept > R&D > **Prototype/MVP** > Production

Table 9. Summary Description of AI for Boosting Limited Data (CAV-08)

Item	Description
ID	CAV-08
Application	Synthetic Training Data Production
Objective	Expand the availability of training data for ADS using data fusion and ML

Item	Description
Description	In general, limited data is a problem in transportation. It is a larger issue for emerging technologies such as Automated Driving Systems (ADS) since they rely heavily on the data they receive to interpret their surrounding environment. A key challenge for the development of ADS has been the lack of annotated real-world datasets that can used to train Deep Learning Neural Networks. Additionally, even if enough data exist to train deep learning models, differences between labeled training/source data and unseen test/target data could lead to poor performance. “Wild tasks” in real-world scenarios are often a challenge for machine learning algorithms due to the presence of low frequency edge cases. Researchers from Carnegie Mellon University (CMU) and the private sector have proposed a novel approach titled, “*Unsupervised Domain Adaptation (UDA) framework based on an iterative self-training procedure that can be solved by alternatively generating pseudo labels on target data and re-training the model with these labels.*” Although it is intuitive to collect and annotate data covering diverse scenes that will be encountered while driving in the real world to improve the network’s generalization ability, this type of “densely annotating images can be both time-consuming and labor-intensive” (Zhou, Yu, Kumar, and Wang, 2018). This research proposed to efficiently generate densely annotated images from rendered (synthetic) scenes, such as the SYNTHIA Dataset, the Grand Theft Auto V (GTA5) Dataset and the VIPER Dataset. This is a novel and innovative example of the use of synthetic rendered datasets to train neural network models with the goal of scene recognition to be used for AV operations. Various approaches to reduce the “*significant appearance gap between the simulated and the real scenes that can degrade the performance of trained models*” are also discussed. Use of synthetic data as a complementary data source to train neural networks used in the context of ADS has also been proposed and studied by Princeton University researchers who employed Grand Theft Auto scenes to collect such densely annotated data (Filipowicz, Jeremiah, and Alain, 2017). Thus, synthetic data fused with real-world data can be used to develop better trained deep learning networks that can used in ADS. Similar approaches can also be used to synthesize data for other areas suffering from lack of data (e.g., Transportation Systems Management and Operations applications).
AI Techniques	Machine Learning; Artificial Neural Networks; Deep Learning; Object & Face Recognition; Comp Vision & Image Analysis

Item	Description
System Functions	Reason & Analyze Information; Learn from Experience & Adapt to New Situations
Maturity	Concept > R&D > Prototype/MVP > Production

Table 10. Summary Description of AI for Collaborative Intelligent Radio Networks (CAV-09)

Item	Description
ID	CAV-09
Application	Collaborative Intelligent Radio Networks (CIRNs)
Objective	Manage and share the radio frequency spectrum
Description	AI can be used for automated radio frequency spectrum management in the form of Collaborative Intelligent Radio Networks (CIRNs). CIRNs use AI to reason and collaborate to automate the process of spectrum sharing and management. The goal is to make radios smart enough to manage and optimize the spectrum by themselves. This is especially important for managing the increasingly crowded 5.9 GHz band (Defense Advanced Research Projects Agency, 2019).
AI Techniques	Machine Learning; Artificial Neural Networks; Deep Learning; Object & Face Recognition
System Functions	Learn from Experience & Adapt to New Situations; Make Decisions, Communicate, & Take Actions

Item	Description
Maturity	Concept → R&D → Prototype/MVP → Production

USDOT Role

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

Definition

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.

Summary of Potential Applications

In this category, two existing and potential applications of AI are summarized in Table 11 to

Table 12.

Table 11. Summary Description of AI for Misbehavior and Intrusion Detection (CS-01)

Item	Description
ID	CS-01
Application	Misbehavior and Intrusion Detection
Objective	Rapidly detect cybersecurity incidents to limit impact

Item	Description
Description	AI techniques can be used to rapidly detect intruders, malware, and other cyber incidents to limit the impact of these cybersecurity incidents. Recently, there have been several cyber-attacks against ITS systems, including hacking into and changing traffic signs, hacking into automated fare payments, infecting police surveillance cameras with ransomware, hacking into and manipulating radio communications between first responders, etc. AI can help detect intrusions and hackers by monitoring traffic on IT networks of state and local DOTs, transit providers and fleet operators. AI-based network intrusion detection systems can report malicious activity or violation to the network administrator. AI can further be used to classify true malicious activity from false alarms (Ghaleb, Zainal, and Mohammed, 2017). Machine learning can be used to identify malicious behaviors/devices/actors in a connected vehicle environment. For example, AI can be used to learn traffic patterns at intersections from Basic Safety Messages (BSMs) and quickly identify BSMs that fall outside a pre-defined normal range (Sarker and Shen, 2019). The data processing and classification can be further improved through use of supplementary image data. For example, image recognition systems can compare BSMs to images gathered from an intersection camera to verify messages in that area. While more resource intensive, misbehavior detection can potentially be more accurate by bringing in image data. AI can be used to detect malicious intrusions into a vehicle's network. Researchers proposed the use of advanced deep learning models to build an intrusion detection system to secure the in-vehicular network against a variety of attacks. Failure to detect such intrusion attempts can have drastic safety impacts. By employing their well-trained trained deep neural network model, the researchers were able to capture 98% of intrusion attempts in real-time successfully (Kang and Kang, 2016). New anti-hacking devices have been developed (Causevic 2017). For example, one device (based on a general-purpose microcontroller) serves as an intrusion-detection system for vehicles with certain automated features. The device learns to detect normal driving patterns while in "observation mode." Then, it monitors the driving system for anomalies using "detection mode." If the device detects an anomaly, it can either alert the driver to the issue via the display or prevent future anomalies of that type from entering the system again (Greenberg, 2014).
AI Techniques	 Machine Learning; Object & Face Recognition; Comp Vision & Image Analysis

Item	Description
System Functions	
Maturity	

Table 12. Summary Description of AI for Cyber Attack Prediction (CS-02)

Item	Description
ID	CS-02
Application	Cyber-Attack Prediction
Objective	Enhance the security of cyber technologies by proactively identifying risks to resources supporting critical functions and preventing future attacks
Description	As advances are made in communications technology and AI, bad actors will use AI to attack AI techniques being built to prevent cyber-attacks and will exploit any vulnerability or security gaps in the system. It becomes essential to predict these cyber-attacks and make the system more resilient. AI can be used to proactively identify risks to resources supporting critical functions and identify vulnerabilities and current threats based on intelligence sources. Furthermore, AI could perform risk analyses, suggest mitigation strategies, and prevent future cyber-attacks and unauthorized use of or exploitation of these resources. Future cyber-attacks in automated vehicles can be prevented through a series of ML techniques. ML can be used to establish behavioral profiles of potential attackers through data collection and pattern recognition. Classification based techniques can be used to detect when anomalies occur. Clustering based techniques can be used to detect abnormal patterns. Deep learning can be used to detect attacks on the central area network bus, and sequential techniques can be used for time-series anomaly detection (Critchley, 2018).

Item	Description
AI Techniques	Machine Learning
System Functions	Sense & Perceive Environment; Reason & Analyze Information; Learn from Experience & Adapt to New Situations; Make Decisions, Communicate, & Take Actions
Maturity	Concept > **R&D** > Prototype/MVP > Production

USDOT Role

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

Definition

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. AI can help enhance the capability of users to reliability and safely execute independent travel for all links in the travel chain.

Summary of Potential Applications

In this category, seven existing and potential applications of AI are summarized in Table 13 to Table 19. The applications in this category can fall into the USDOT's Accessible Transportation Technologies Research Initiative (ATTRI) Program's four technology development areas: Wayfinding and Navigation, Pre-Trip Concierge & Virtualization, Automation and Robotics, Safe Intersection Crossing, and additional emerging application areas.

Table 13. Summary Description for AI for Pre-Trip Concierge and Virtualization (AT-01)

Item	Description
ID	AT-01
Application	Pre-Trip Concierge and Virtualization
Objective	Provide pre-trip planning and en route travel information to travelers with disabilities
Description	Pre-trip concierge and virtualization provide pre-trip planning and en route travel information to travelers with disabilities, their family members, and caregivers, including creating a virtual environment for users to familiarize themselves with their travel before the trip (U.S. Department of Transportation, 2020). Online travel planning is gaining more popularity as users are becoming more comfortable with using mobile applications and services to plan their vacation and explore a new city. Currently, most travel planning applications are catered to everyday users. AI can be integrated with current travel planners to learn a user's preference including frequently visited locations to create a personalized trip itinerary based on their physical and cognitive abilities. This day-to-day itinerary can include hotel, shopping, sightseeing locations, and restaurants that are tailored to their unique preferences, abilities, and other user recommendations (Prats, 2018). There are opportunities to use virtual reality (VR) and augmented reality (AR) for accessibility as the technology matures. VR/AR can also help users safely experience a route in virtual reality before their trip. Users will be able to experience details, such as location of shops and landmarks, as they move through the virtual environment in the form of visual and audio cues. In addition, VR can help users learn a route that is not part of their everyday routine such as emergency evacuation routes for their apartment or office building, an alternative route during road and sidewalk construction, or the environment in a new travel destination (Avila, 2019).

Item	Description
AI Techniques	 Machine Learning; Comp Vision & Image Analysis; Object & Face Recognition; Natural Language Processing
System Functions	 Sense & Perceive Environment; Reason & Analyze Information; Make Decisions, Communicate, & Take Actions
Maturity	Concept > R&D > **Prototype/MVP** > Production

Table 14. Summary Description of AI for Outdoor Wayfinding and Navigation (AT-02)

Item	Description
ID	AT-02
Application	Outdoor Wayfinding and Navigation
Objective	Assist users with disabilities reach their destinations

Item	Description
Description	Wayfinding and navigation can help travelers, particularly those with disabilities, safely and independently reach their destinations by providing real-time information, localization and situational awareness to assist in navigating outdoor, including path planning and detouring around blocked routes or hazards. AI can be implemented to support users navigate the environment including locating services or landmarks with precision or assisting travelers find alternate routes when presented with an unexpected situation or change of itineraries (U.S. Department of Transportation, 2020). For example, AI can be integrated in these applications to detect construction sites and closed sidewalks to safely route wheelchair users around hazardous areas (Langston, 2017). Additionally, AI can learn users' preferences using historical data in order to recommend future similar routes and provide recommendations to other users who have similar preferences. AI-enabled applications can also help users arrive to their exact transit service pickup location using machine learning and object recognition. Many existing GPS-based navigation applications lack this pinpoint accuracy, which is critical for users with disabilities. Using their phone cameras and other assistive devices, AI can be integrated to identify small targets or landmarks, such as street signs and bus route numbers. This allows users to make it to their precise pickup location (Luo, 2019). AI could be embedded in wayfinding and navigation software as a responsive safety management layer, where it can detect potential hazards and send alerts to the user. For example, this layer could detect roadway and sidewalk hazards such as flashing red lights or nearby potholes. Additionally, the layer could warn users if they move outside the pedestrian crosswalk. Sidewalk assessment systems, that use robotic sensing, can also profile sidewalks and identify potential barriers to safe pedestrian travel (Starodub, Inc. research & development of prototype ULIP, 2020).
AI Techniques	Machine Learning; Comp Vision & Image Analysis; Object & Face Recognition; Artificial Neural Networks
System Functions	Sense & Perceive Environment; Reason & Analyze Information; Learn from Experience & Adapt to New Situations; Make Decisions, Communicate, & Take Actions
Maturity	Concept → R&D → **Prototype/MVP** → Production

Table 15. Summary Description of AI Indoor Wayfinding and Navigation (AT-03)

Item	Description
ID	AT-03
Application	AI Indoor Wayfinding and Navigation
Objective	Enable users with disabilities to travel through indoor environments
Description	Indoor wayfinding and navigation can help people with disabilities travel through unfamiliar complex indoor environments through localization, situational awareness and navigation applications. AI can enhance indoor navigation applications by providing precise localization and routing capabilities in locations where other technologies may not work, such as GPS. Applications in this category can help users identify and be aware of precise locations of objects and points of interest in their environment and assist with real time indoor navigation. AI-enabled indoor wayfinding and navigation requires comprehensive maps of indoor environments to operate effectively. These maps might include information on the locations of transportation hubs, hospitals, convention centers, and office buildings, as well as more granular information on the locations of elevators and ramps. The map creation process can be time consuming, skill intensive, and prone to human error. By analyzing sensor data from smartphones, wall cameras, and existing maps, AI has the potential to help automate the production and maintenance of indoor maps (Chaturvedi, 2019). Additionally, AI could help update maps for users in real-time while keeping track of the user's location within the space. This complex problem is known as simultaneous localization and mapping (SLAM) and is a common problem automated vehicles face. Augmented reality (AR) has the potential to help users familiarize themselves and navigate complex indoor spaces. AI can be integrated with AR to enable object recognition and tracking, gestural input, eye tracking, and voice command (Mejia, 2018). By interfacing with AI, AR can map indoor spaces, detect objects are in the environment, the location of the door entrance, who is in the room and what direction they are facing, and communicate distance to points of interest and obstacles. Users can explore and understand the environment through sounds, audio cues, tactile indications, smell, taste, temperature, proprioception, balance, acceleration and description of what is in the visual environment (Avila, 2019).
AI Techniques	 Machine Learning; Comp Vision & Image Analysis; Object & Face Recognition; Artificial Neural Networks

Item	Description
System Functions	
Maturity	

Table 16. Summary Description of AI for Environment Sensing and Situational Awareness (AT-04)

Item	Description
ID	AT-04
Application	Environment Sensing and Situational Awareness
Objective	Recognize and describe surroundings for users with sight, hearing, or cognitive disabilities
Description	Environment sensing and situational awareness applications that use AI can help people with disabilities understand their surrounding environment through scene narration, detecting and tracking object, or detecting adverse conditions by using cameras, sensors, or radar technology. For users with cognitive or visual disabilities, these applications can add context to an everchanging environment, allowing users to maintain necessary comfort and confidence level. For users with hearing disabilities, an application can help interpret audible cues to assist the user in perceiving and processing environment, thus allowing them to travel safely and independently. Environment sensing and situational awareness can be integrated into wayfinding and navigation applications to help provide environment and situation awareness for users with disabilities during their trip. For example, an application with AI can monitor the surrounding scene and detect adverse conditions using computer vision and object recognition to help pedestrians maneuver busy streets by reading signs, detecting weather conditions, recognizing traffic light colors, and distinguishing other transportation infrastructure components. These applications can also provide acoustic and context processing such as helping users with disabilities sense and understand the sounds in their environment (i.e. emergency vehicle sirens).

Item	Description
AI Techniques	Machine Learning; Comp Vision & Image Analysis; Object & Face Recognition; Artificial Neural Networks; Natural Language Processing
System Functions	Sense & Perceive Environment; Reason & Analyze Information; Learn from Experience & Adapt to New Situations; Make Decisions, Communicate, & Take Actions
Maturity	Concept → R&D → Prototype/MVP → Production

Table 17. Summary Description of AI for Robotics and Automation (AT-05)

Item	Description
ID	AT-05
Application	Assistive Robotics and Automation
Objective	Improve mobility for users with disabilities using robotics

Item	Description
Description	Automated mobile robots can greatly improve mobility for people with disabilities. These robots use a variety of sensors and AI to safely and efficiently navigate complex environments, guiding their user to their desired destination (Cortés, et al., 2003). In addition to assisting users with activities in daily life, automated robots can also work with individual travelers and human transportation services to provide related concierge services at different stages of their travel and improve personal mobility across the transportation network. For example, researchers at Carnegie Mellon University are exploring the potential for service robots to assist travelers with and without disabilities through the complex transportation hub facilities. The transportation hub-based robots may provide navigation assistance, guidance through a station, information retrieval (e.g., “is the elevator working?”), and rendezvous with services (e.g., station staff) and other robotic unmanned systems (Traffic21, 2018). Other types of robotics such as smart leg sleeves and robotic exoskeletons can improve rehabilitation and mobility. These technologies can use AI to learn a user’s movement patterns and respond dynamically to help them walk. These technologies can be especially helpful in getting users the last few steps to their transit stop (SFU Innovates, 2019).
AI Techniques	Machine Learning; Comp Vision & Image Analysis; Object & Face Recognition
System Functions	Sense & Perceive Environment; Reason & Analyze Information; Learn from Experience & Adapt to New Situations; Make Decisions, Communicate, & Take Actions
Maturity	Concept; **R&D**; Prototype/MVP; Production

Table 18. Summary Description of AI for Embedded Assistive Devices (AT-06)

Item	Description
ID	AT-06
Application	Embedded Assistive Devices

Item	Description
Objective	Equip assistive devices with AI to improve mobility and independence for users with disabilities
Description	Embedding assistive devices such as wheelchairs, white canes, and robots with AI can offer enhanced mobility and independence to users with disabilities. For example, a robotic wheelchair can take users to their destinations safely by sensing the environment and predicting the most efficient route whilte avoiding obstacles (Cortés, et al., 2003). AI can provide enhanced control by using cameras and sensors to learn and detect the user's gestures such as facial expression or leaning motions and response with movements (Toyota Mobility Foundation, 2019). Additionally, an AI-equipped wheelchair can learn to read the gaze of a person with a disability, following it along the desired path while avoiding obstacles (Malewar, 2018). White canes can be equipped with AI to improve safety and mobility for people who are blind or have low vision. Sensors on the sides of the cane can improve environmental sensing. Adding AI allows the cane to understand the sensory data and respond with verbal navigation suggestions, such as "move to the left." An intelligent white cane can also learn the user's normal walking pace. AI-equipped white canes are especially important for transportation. For example, when navigating a bustling subway system, an intelligent white cane could enhance safety and mobility for the user (Ali, Hoorain, Khan, Fouzia, and Akbar, 2018).
AI Techniques	Machine Learning; Comp Vision & Image Analysis; Object & Face Recognition; Natural Language Processing
System Functions	Sense & Perceive Environment; Reason & Analyze Information; Learn from Experience & Adapt to New Situations; Make Decisions, Communicate, & Take Actions
Maturity	Concept; R&D; Prototype/MVP; Production

Table 19. Summary Description of AI for Safe Intersection Crossing (AT-07)

Item	Description
ID	AT-07
Application	Safe Intersection Crossing
Objective	Enable pedestrians to safely cross an intersection
Description	AI can be implemented at intersection crossings to improve safety for users with disabilities. These applications can be integrated with the current intersection infrastructure in the form of road markings and signaling devices. For example, AI can detect a pedestrian's intention to cross before they enter the intersection, using cameras, and automatically switch the crossing signal on. This application can also determine the length of time needed for the pedestrian to cross safely and adjust to the number of people crossing to optimize traffic flow (Graz University of Technology, 2019). Another example is to implement AI, specifically machine learning, for zebra crossings using LED lights in order to change the pattern, color, and size of the crossing based on the flow of pedestrians and vehicles. This application can be implemented to improve safety for pedestrians with disabilities by increasing the size or changing the location of the crossing (Innovation Hub, 2020).
AI Techniques	Machine Learning; Comp Vision & Image Analysis; Object & Face Recognition
System Functions	Sense & Perceive Environment; Reason & Analyze Information; Make Decisions, Communicate, & Take Actions
Maturity	Concept › R&D › **Prototype/MVP** › Production

USDOT Role

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

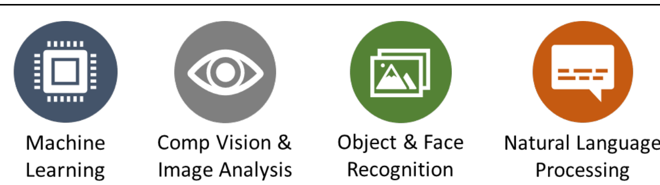
Definition

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 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.

Summary of Potential Applications

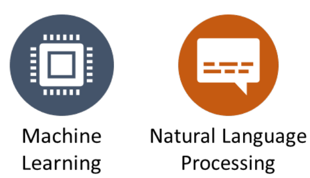
In this category, three existing and potential applications of AI are summarized in Table 20 to Table 22.

Table 20. Summary Description of AI for Smart Travel Itinerary Recommendations (TDS-01)

Item	Description
ID	TDS-01
Application	Smart Travel Itinerary Recommendations
Objective	Recommend travel destinations and route planning options by predicting traffic patterns, mining social media, and interpreting user preferences
Description	Many route planning applications use AI to predict traffic patterns, analyze current traffic data, and even learn user preferences to make effective route recommendations. AI can learn a user's usual driving patterns and improve future route suggestions by analyzing data on past routes. AI can learn from a user's past trips and recommend new destinations and sights. The AI platform can become smarter as users provide more information about their preferences and wish lists. Additionally, the platform can learn more about the user's preferences by analyzing who and what they follow on social media. The platform can mine online written reviews and derive user sentiments from them. In doing so, the application can better understand the nuances of different restaurants, destinations and tourist sights. Beyond learning an individual's patterns, this technology can also learn an organization's travel patterns and preferences (e.g., airlines, prices, times of day) and better customize travel management for the organization. This application can be a crossover to the Accessible Transportation and the Transportation Systems Management and Operations categories. For example, these learned travel behaviors can also be used by TMC managers in TSMO strategies such as Active Demand Management and Active Parking Management.
AI Techniques	

Item	Description
System Functions	
Maturity	

Table 21. Summary Description of AI for Predictive Traveler Information (TDS-02)

Item	Description
ID	TDS-02
Application	Predictive Traveler Information
Objective	Predict expected time of arrival (ETA) by route and mode
Description	Many applications use AI to classify traffic conditions and predict travel times for all destinations, routes and modes. This information is commonly used in route planners. These predictions have improved over time with growing data; however, big data storage and processing challenges accompany prediction accuracy. This application can be a crossover to the Accessible Transportation, Transit Operations and Management, Commercial Vehicle and Freight Management, and Transportation Systems Management and Operations categories.
AI Techniques	
System Functions	

Item	Description
Maturity	Concept > R&D > Prototype/MVP > **Production**

Table 22. Summary Description of AI for Enhanced Navigation Using Computer Vision (TDS-03)

Item	Description
ID	TDS-03
Application	Enhanced Navigation Using Computer Vision
Objective	Enhance navigation by providing visual directions using computer vision technology
Description	Mapping tools and navigation applications are becoming more sophisticated. Some are beginning to use computer vision to provide visual directions along routes using the user's phone camera. Additionally, tools can leverage computer vision and object recognition to show nearby restaurant and shop names for visual reference. This application can also be a crossover to the Accessible Transportation category.
AI Techniques	Machine Learning; Comp Vision & Image Analysis; Object & Face Recognition
System Functions	Sense & Perceive Environment; Reason & Analyze Information; Learn from Experience & Adapt to New Situations; Make Decisions, Communicate, & Take Actions
Maturity	Concept > R&D > **Prototype/MVP** > Production

USDOT Role

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

Definition

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.

Summary of Potential Applications

In this category, 10 existing and potential applications of AI are summarized in Table 23 to Table 31.

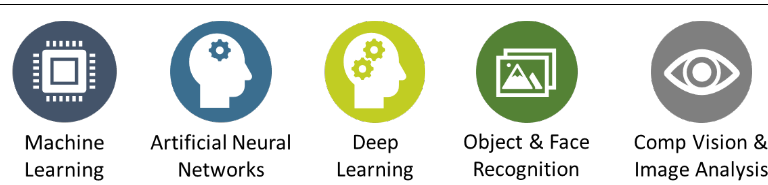
Table 23. Summary Description of AI for Data Fusion (TSM-01)

Item	Description
ID	TSM-01
Application	Data Fusion
Objective	Fuse data from multiple sources to improve data quality, enhance situational awareness, boost decision support systems, and improve TSMO strategies and programs

Item	Description
Description	AI can be used to fuse and make sense of disparate historical and real-time data, including in-vehicle, infrastructure-based sensor, Bluetooth reader, license-plate reader, closed-circuit television (CCTV) camera, road weather, traffic incident, traveler information, crowdsourced and social media data. Although data fusion using statistical techniques, probabilistic methods, and neural networks (an AI technique) have been around for more than three decades, recent advances in computing, data management, and AI algorithmic approaches, have the potential to enable robust data fusion in real-time and enable system-wide, proactive management of the multi-modal transportation system. AI-enabled data fusion can be used to improve data quality in real-time. Using AI techniques, data can be rapidly fused from multiple sources to fill gaps in data, fix errors and inconsistencies, improve the reliability of the data, and provide a more complete view of the system. Data fusion in real-time can support a range of TSMO strategies such as adaptive ramp metering integrated with adaptive traffic signal control, predictive traveler information with dynamic routing and dynamic pricing, etc. AI can be embedded in user-friendly software tools to boost decision support systems and enhance TSMO programs. TMC operators can proactively manage emerging events and situations, rather than reacting to them after formation of queues and bottlenecks. For example, the Delaware DOT is using digital radar and traffic sensor data to build an AI-based tool to improve its TMC and arterial corridor operations with the hope of automating many TMC operations (Thompson, 2019). The Southern Nevada TMC's cloud-based platform uses AI to help manage traffic and prevent crashes by aggregating data from many agencies and responders. Using AI to accelerate and improve data flows brings many benefits, including reduced incident response times (National Operations Center of Excellence, 2019).
AI Techniques	Machine Learning; Artificial Neural Networks; Deep Learning; Object & Face Recognition; Natural Language Processing; Comp Vision & Image Analysis
System Functions	Sense & Perceive Environment; Reason & Analyze Information
Maturity	Concept → R&D → Prototype/MVP → **Production**

Table 24. Summary Description of AI for Short-Term Traffic Prediction (TSM-02)

Item	Description
ID	TSM-02
Application	Short-Term Traffic Prediction
Objective	Predict traffic flow, vehicle arrivals, and queues before they occur for proactive management

Item	Description
Description	Short-term traffic prediction is essential for moving up the ATDM continuum to proactive management. Short-term prediction also enhances integrated management as agencies have enough time to share information and take coordinated, proactive actions. Deep learning and imagery analysis can be used for short-term predictions of vehicle trajectories on arterials. This is especially useful when data are sparse. Machine learning and object recognition can be used to detect existing queues and pedestrians, and predict vehicle arrivals at intersections, which can be used for optimizing traffic signal timings (Ghane, Patel, Mudliar, and Naik, 2017). Similar short-term predictions of queues and vehicle arrivals can also support work zone management. Machine learning can also be used to predict arrival times of transit buses at intersections, which is a key input to transit signal priority. Neural networks, fuzzy logic, and Bayesian belief networks have been applied to the problem of short-term traffic prediction on freeways and arterials. Delaware DOT, as part of the ATCMTD program grant, plans to develop AI technologies for traffic prediction (Gettman, 2019). Machine learning can be used to predict impending congestion, and bottlenecks. For example, ensemble methods that combined several machine learning algorithms such as Random Forest and Decision Trees were used to predict various traffic flow regimes (free flow, speed at capacity, and congested regimes) an hour in advance using Basic Safety Messages and non-CV data such as demand, weather and incident logs (Vasudevan, Curtis, Lowman, and O'Hara, 2016). This advance knowledge can be used by agencies to proactively make decisions and implement appropriate congestion mitigating actions, such as tailoring traveler behavior incentives based on traveler's history to manage system capacity and marshalling resources to mitigate the situation. Advance knowledge of emerging bottlenecks and queues can support several ATM (e.g., dynamic speed limits, queue warning, dynamic shoulder lanes) and ADM (e.g., dynamic pricing, dynamic HOV/Managed Lanes, dynamic routing) strategies. It is challenging for traffic engineers to design accurate traffic flow models, especially for unforeseen traffic scenarios and in different locations. Localities often have their own unique traffic models, but they are focused on particular regions and do not generalize well. To boost broader traffic model performance and support integrated decision-making following incidents, Berkeley Lab and Caltrans are using ensemble learning to combine many existing machine learning models (Frost, 2019).
AI Techniques	

Item	Description
System Functions	Sense & Perceive Environment; Reason & Analyze Information
Maturity	Concept > R&D > **Prototype/MVP** > **Production**

Table 25. Summary Description of AI for Short-Term Travel Behavior Prediction (TSM-03)

Item	Description
ID	TSM-03
Application	Short-Term Travel Behavior Prediction
Objective	Derive trip purpose to predict short-term travel behaviors
Description	Using historical travel, GPS and land use data, machine learning models can derive trip purpose. This helpful feature can then be used with other data to predict short-term travel behaviors and vehicle trajectories. Incorporating trip purpose has shown to significantly increase destination prediction accuracy even after a short period of travel behavior learning (Krause and Zhang, 2019). This information can be support multiple ADM (e.g., dynamic route planning, dynamic priced lanes) and Active Parking Management (e.g., dynamic overflow transit parking, dynamically priced parking) strategies.
AI Techniques	Machine Learning
System Functions	Reason & Analyze Information

Item	Description
Maturity	Concept → **R&D** → Prototype/MVP → Production

Table 26. Summary Description of AI for Adaptive Ramp Metering (TSM-04)

Item	Description
ID	TSM-04
Application	Adaptive Ramp Metering
Objective	Enhance ramp metering strategy to rapidly adapt to anticipated or predicted conditions
Description	Ramp metering strategies can be enhanced by building in capability using AI to rapidly adapt to changing and anticipated conditions. Machine learning can be used to predict freeway congestion and vehicle arrivals based on data from sensors, CV messages, third-party weather and traffic information and other data sources. By predicting future congestion, transportation managers can optimize ramp metering strategies or implement adaptive ramp metering that automatically adapts to anticipated changes (Belletti, Haziza, Gomes, and Bayen, 2017). Fuzzy logic and neural network methods have been applied to ramp metering for individual ramp control and corridor operations. Fuzzy logic has seen success in the real world, with implementations at the California DOT in Northern and Southern California and Washington State DOT. In these systems, individual ramps are configured with relatively simple fuzzy rules that determine to raise the metering rate when the freeway is uncongested and the ramp queue is lengthy and vice versa (Gettman, 2019).
AI Techniques	 Machine Learning; Artificial Neural Networks; Deep Learning; Object & Face Recognition; Comp Vision & Image Analysis
System Functions	 Sense & Perceive Environment; Reason & Analyze Information; Learn from Experience & Adapt to New Situations

Item	Description
Maturity	Concept > R&D > Prototype/MVP > Production

Table 27. Summary Description of AI for Proactive Incident Management (TSM-05)

Item	Description
ID	TSM-05
Application	Proactive Incident Management
Objective	Detect and predict traffic incidents to respond efficiently and proactively
Description	AI techniques such as machine learning and NLP can be used to detect and predict incidents based on data from sensors, videos and images, CV messages, third-party weather and traffic information social media data and other data sources. Using AI to detect potential incidents in video feeds or images could reduce the incident detection time. AI could potentially be embedded within CCTV cameras to detect incidents, or AI could be used in the TMC to process the CCTV feeds in real-time to detect incidents. AI can hasten the data analysis process and allow TMC operators to respond more efficiently and proactively to incidents. Nevada and Florida DOTs use an AI system that fuses information from a variety of sources to detect and report suspected incidents. It is expected that the AI methods would improve the ability to react to incidents faster by detecting them sooner and in locations where traditional detection is lacking or where traffic levels are low (e.g., rural areas with limited cellular coverage). In addition to the traditional sources (i.e., radar and loop detectors), the AI system processes feeds from existing CCTV cameras to identify incidents using neural networks. This neural network is trained to recognize scenes that are ‘incidents’ and “not incidents,” as well as “incident may be likely to occur.” In both cases, the application software was deployed in areas with good existing coverage of cameras and traditional point detection. Neither agency has used traditional software incident detection methods for some time due to the unreliability of such software and since highway patrol incident warnings have tended to outperform software detection methods in recent years. Both agencies were able to proactively position highway patrol assets accordingly and provide advance warnings of downstream congested areas on dynamic message signs. Delaware DOT is using a neural network model that detects incidents based on re-identification of vehicle signatures from one set of in-pavement loops to another (Gettman, 2019). Data mining and NLP can be used to identify abnormal traffic events, such as crashes, in social media messages. Connecting these messages to traffic states inferred from

Item	Description
	GPS data provides additional context to transportation management staff (Zheng, *et al.*, 2018). Machine learning can be used to predict car crash risk on road segments. By training a supervised machine learning model using road, time, weather and demographic data, it is possible to predict where and when crashes are likely to occur. Roadway maintenance crews and engineers can use this information to improve roadway safety by redesigning dangerous segments and adding new signage (Wilson, 2018). The Strategic Highway Research Program (SHRP2) offers continuous video and sensor data for analytics and AI development. Machine learning and video analytics can be used to parse through this huge amount of data, break it down into “bite-sized chunks”, and flag crucial portions. This can help analysts better understand how crashes happen and what can be done to prevent them. Car manufacturers, TMC operators and transportation policymakers can use these insights to improve vehicle and roadway safety (Thompson, 2019). Machine learning algorithms such as Bayesian Networks (BNs) can be used to predict incident durations for real-time operations (Ozbay and Noyan, 2006). These algorithms can automatically adapt to future conditions by learning the patterns of new incidents and their respective conditions (Demiroluk and Ozbay, 2014). Thus, this machine learning model can be used in real-time by agencies to predict expected delays and queues due to incidents, which can be used in decision support tools.
AI Techniques	Machine Learning; Artificial Neural Networks; Deep Learning; Object & Face Recognition; Comp Vision & Image Analysis; Natural Language Processing
System Functions	Sense & Perceive Environment; Reason & Analyze Information; Learn from Experience & Adapt to New Situations
Maturity	Concept; R&D; Prototype/MVP; Production

Table 28. Summary Description of AI for Multimodal Intelligent Traffic Signal System (TSM-06)

Item	Description
ID	TSM-06

Item	Description
Application	Multimodal Intelligent Traffic Signal System
Objective	Optimize traffic signal systems to service all modes of transportation by predicting vehicle and pedestrian arrivals, queues, and delays
Description	Adaptive traffic signal systems have been operating successfully in many countries since the early 1970's. Historically, these systems have optimized the movement of a specific mode (e.g., transit vehicles, general vehicles). Multi-Modal Intelligent Traffic Signal System (MMITSS) is the next generation of traffic signal system that seeks to service all modes of transportation, including general vehicles, transit, emergency vehicles, freight fleets, and pedestrians and bicyclists in a connected vehicle environment (University of Arizona, University of California PATH Program, Savari Networks, Inc., Econolite, Center for Transportation Studies, California, 2016). MMITSS consists of five applications, including Intelligent Traffic Signal Control (I-SIG), Transit Signal Priority (TSP), Mobile Accessible Pedestrian Signal System (PED-SIG), Freight Signal Priority (FSP), and Emergency Vehicle Preemption (PREEMPT). I-SIG is an overarching system optimization application that accommodates signal priority, preemption, and pedestrian movements. TSP and FSP are applications that provide signal priority to transit vehicles at intersections and along arterial corridors and to freight vehicles along an arterial corridor near a freight facility, respectively. PED-SIG is an application that allows for an automated call from the smart phone of a visually impaired pedestrian to the traffic signal, as well as audio cues to safely navigate the crosswalk. PREEMPT provides signal preemption to emergency vehicles and accommodates multiple emergency requests. MMITSS make use of data fusion and predicted queue lengths, delay, and travel times to optimize the signal system. Scalable Urban Traffic Control (Surtrac) is another next generation decentralized traffic control system that offers fully responsive network-wide control, allowing individual intersections to control their own local traffic. Using data mining and AI, Surtrac builds a timing plan in real-time by: (1) observing traffic, (2) computing a phase scheduling, and (3) communicating information to downstream signals. Surtrac is designed to optimize for all modes of travel, including pedestrians, bicycles, transit and connected and automated vehicles. Surtrac has been deployed in Pittsburgh, PA; Quincy, MA; and Portland, ME (Rapid Flow, 2018). Deep reinforcement learning is an active area of research for traffic signal control. One of the current drawbacks of using deep reinforcement learning for optimizing traffic signals is the time it takes to adapt.
AI Techniques	Machine Learning; Object & Face Recognition; Comp Vision & Image Analysis

Item	Description
System Functions	
Maturity	

Table 29. Summary Description of AI for Video Analytics for Planning and Maintenance (TSM-07)

Item	Description
ID	TSM-07
Application	Video Analytics for Planning and Maintenance
Objective	Plan and maintain road infrastructure from smartphone video data and AI
Description	Mobile applications can use computer vision to process and label road video data collected from smart phones. For example, an AI-enabled application could automatically assess pavement conditions, traffic signs, road surface conditions, and weather conditions from anonymous user-submitted data. With this information, the application could alert crews to downed, damaged, or visually obscured signs. Additionally, using color grading, AI could derive air and road temperatures and road roughness information. Overall, applications like these could be useful tools for TMCs, road maintenance crews and others in transportation planning and maintenance.
AI Techniques	
System Functions	

Item	Description
Maturity	Concept → R&D → Prototype/MVP → **Production**

Table 30. Summary Description of Chatbots for Natural Language Q&A (TSM-08)

Item	Description
ID	TSM-08
Application	Chatbots for Natural Language Q&A
Objective	Improved NLP allows catered responses to queries
Description	AI-enabled chatbots can enhance 511 systems and TMC operations. 511 systems make use of NLP to understand a user's requested route. These systems historically have been limited in both their technical capability (understanding user phrases with background noise, i.e., while driving) and the phraseology expected from the user (bus stop identification numbers, freeway names and sections, etc.). Agencies have started to capitalize on recent enhancements made to NLP capabilities in digital assistants. For example, Metropolitan Transportation Commission (MTC) Bay Area 511 now has an Alexa skill to pass through requests for 511 information for the same phraseology that works with their interactive voice response (IVR) module (Gettman, 2019). AI-enabled chatbots can easily be extended to TMC operations. These chatbots could help reduce the learning curve and simplify decision-making for TMC operators. In 2018, the City of Surprise, AZ developed a Google Assistant interface to their adaptive traffic control system. The chatbot system allows the traffic engineer to query status data using voice commands from a phone or computer (Gettman, 2019). Chatbots can be used to automate voice commands. For example, traffic engineers can use chatbots for querying data, pulling up performance dashboards, generating problem reports (e.g., on detector failures), etc.
AI Techniques	Machine Learning; Natural Language Processing
System Functions	Reason & Analyze Information; Make Decisions, Communicate, & Take Actions

Item	Description
Maturity	Concept > R&D > **Prototype/MVP** > Production

Table 31. Summary Description of AI for Multimodal Decision Support (TSM-09)

Item	Description
ID	TSM-09
Application	Multimodal Decision Support
Objective	Augment real-time multimodal decision support systems by applying AI techniques for data processing, enhanced situational awareness, and decision-making

Item	Description
Description	Real-Time Multimodal Decision Support Systems (RTMDSS) are interactive, software-based systems that support multimodal, transportation operational decision-making in real time to increase system efficiency and improve individual mobility, providing safe, reliable, and secure movement of people and goods. An effective RTMDSS uses AI techniques to: extract useful information from data fused from multiple sources and knowledge bases, detect and predict anomalies, generate feasible set of response plans based on business rules (i.e., predefined and agreed-upon organizational and inter-agency permissions, constraints, or criteria), evaluate effectiveness of competing response plans based on traffic state prediction using AI techniques and AMS tools, determine the most effective response plan, identify agencies that need to take coordinated action, and convert recommendations into actions (automated decisions). An RTMDSS plays a central role in a TSMO program, especially when moving towards the higher end of the integrated and active management spectrum (i.e., full integration with proactive management). Delaware DOT was awarded an ATCMTD grant for their Artificial Intelligence Integrated Transportation Management System (AIITMS) Deployment Program. AIITMS is a multi-modal AI transportation management and control system that will collect and analyze high-resolution data collected from freeways, traffic signals, and connected and automated vehicles The system will use machine learning to automate monitoring and control functions within the TMC (Delaware Department of Transportation, 2017). It will detect anomalies, alert operators to incidents and other events, disseminate real-time travel information, generate traffic congestion solutions, and predict impacts for future events. Delaware DOT plans to use reinforcement learning to train neural networks to manage traffic control systems as a “game” (e.g., chess) by predicting the impacts of certain traffic control actions and selecting the most effective control strategies (Gettman, 2019). A lesson learned during implementations of DSS for Integrated Corridor Management in Dallas and San Diego indicates there is still a lot to be learned from developing a DSS. As each region is different, with different partners, road networks, and issues, there is no off-the-shelf DSS that is “one size fits all” (Hatcher, 2019). Agencies looking to deploy a new RTMDSS or improve an existing DSS engine may want to systematically add capability to perform various functions of a DSS using AI techniques. AI could also be applied to long-term forecasting and could help select TSMO strategies during the planning stage. In this case, AI would look at the system level and cover descriptive, predictive, and prescriptive analysis for resource allocation and project selection. However, the TSMO decision-maker would still play a crucial role in vetting these AI-generated recommendations.

Item	Description
AI Techniques	Machine Learning; Artificial Neural Networks; Deep Learning; Object & Face Recognition; Natural Language Processing; Comp Vision & Image Analysis
System Functions	Sense & Perceive Environment; Reason & Analyze Information; Make Decisions, Communicate, & Take Actions; Learn from Experience & Adapt to New Situations
Maturity	Concept → R&D → **Prototype/MVP** → **Production**

USDOT Role

This category is aligned with the FHWA's Organizing and Planning for Operations Program (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

Definition

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.

Summary of Potential Applications

In this category, seven existing and potential applications of AI are summarized in to Table 32 to Table 38.

Table 32. Summary Description of AI for Digital Conversion of Paper Documents (CVO-01)

Item	Description
ID	CVO-01
Application	Digital Conversion of Paper Documents
Objective	Process paper documents and convert to digital format
Description	Office paperwork tasks are often the source of bottlenecks in freight operations. AI, in the form of image and language processing, can be used to process paper documents and rapidly enter data into the computer system. AI can pull important information from the forms, enter the data digitally, and sort it appropriately, saving tremendous labor hours. AI can perform automated actions for expected, routine decisions (Pyzyk, 2019).
AI Techniques	Machine Learning; Natural Language Processing
System Functions	Reason & Analyze Information; Make Decisions, Communicate, & Take Actions
Maturity	Concept > R&D > Prototype/MVP > **Production**

Table 33. Summary Description of AI for Fleet Travel Planning (CVO-02)

Item	Description
ID	CVO-02
Application	Freight Dynamic Travel Planning
Objective	Enhance traveler information for freight-specific needs
Description	AI can be used for predictive analytics by freight managers. Using integrated data on wait times at intermodal facilities, traffic conditions, incidents, road closures and work zones, route restrictions (e.g., hazardous materials, oversize/overweight), and truck parking availability, the AI-powered application can predict route travel times and expected time of arrivals. These can be used for pre-trip as well as en route travel planning and routing. The application can also communicate the real-time travel information, parking, and routing with drayage companies, drivers, and intermodal facilities (Brewster, Giragosian, & Newton, 2015).
AI Techniques	
System Functions	
Maturity	

Table 34. Summary Description of AI for Drayage Optimization (CVO-03)

Item	Description
ID	CVO-03
Application	Drayage Optimization

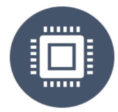
Item	Description
Objective	Improve load matching and optimize truck and load movements between freight facilities
Description	AI can be embedded into the transportation management system for improve driver-load matching and drayage optimization. AI can learn from historical data and decide driver loads. With a tight labor market in trucking, this can offer respite to managers (Pyzyk, 2019). Using predicted travel information and port terminal conditions, the application can assign individual trucks with the "best time" windows for pick-up or drop-off.
AI Techniques	 Machine Learning
System Functions	 Reason & Analyze Information
Maturity	 Concept R&D Prototype/MVP Production

Table 35. Summary Description of AI for Automated Shipping Port Management (CVO-04)

Item	Description
ID	CVO-04
Application	Automated Shipping Port Management
Objective	Predict optimal loading schedules and container arrangements

Item	Description
Description	AI can be used for automated shipping port management in various ways. Real-time truck routing data can be used by AI to predict optimal loading schedules in response to travel changes. Additionally, AI embedded in automated cranes can decide which containers to stack or unload in which order to optimize efficiency and other metrics. Some states are already using this technology (AI in automated loading cranes) at their ports. AI is also used for predictive maintenance of port equipment (Transport Topics, 2018).
AI Techniques	Machine Learning
System Functions	Sense & Perceive Environment; Reason & Analyze Information; Make Decisions, Communicate, & Take Actions
Maturity	Concept → R&D → **Prototype/MVP** → Production

Table 36. Summary Description of AI for AV/ADAS-Equipped Commercial Motor Vehicle (CVO-05)

Item	Description
ID	CVO-05
Application	AV/ADAS-Equipped Commercial Motor Vehicle
Objective	Enable AV/ADAS-equipped commercial motor vehicles to observe and respond to the environment
Description	AI can be used by equipped commercial motor vehicles comprising on-board systems that include sensors to observe the dynamic driving environment including the roadway, signage vehicles, other road users and obstacles. In addition, processors within the system can figure out how to respond to environment, send commands, and act accordingly (International Transport Forum, 2017).

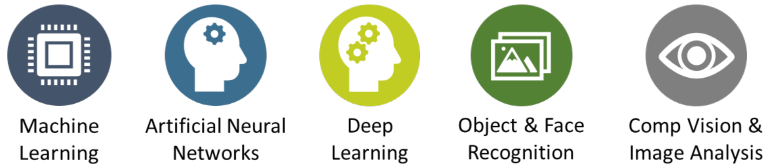
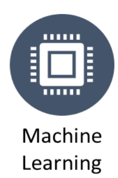
Item	Description
AI Techniques	
System Functions	
Maturity	

Table 37. Summary Description of AI for Fleet Maintenance (CVO-06)

Item	Description
ID	CVO-06
Application	Fleet Maintenance
Objective	Increase efficiency of tracking and monitoring fleet repair and maintenance
Description	AI can improve fleet maintenance in a variety of ways. First, AI can reduce unplanned truck downtime by monitoring engine data in real time and alerting managers to abnormal metrics. Second, AI can increase efficiency in the repair process by providing technicians helpful insights that are difficult to see or track over time. Third, AI can improve fuel efficiency by detecting potential pressure problems before fault codes occur. Fourth, AI can help ease data overload by fusing data from multiple sources and highlighting the most critical areas (Rondhini, 2019).
AI Techniques	

Item	Description
System Functions	
Maturity	

Table 38. Summary Description of AI for Unsafe and Distracted Driver Behavior Detection (CVO-07)

Item	Description
ID	CVO-07
Application	Unsafe and Distracted Driver Behavior Detection
Objective	Detect unsafe and distracted driver behaviors and automate remedial coaching
Description	AI can be used to recognize if a driver is having problems based on their driving pattern and behaviors. Patterns for driver fatigue, like yawning, and distraction can be instantly detected as can other behaviors like following distances that are unsafe given current speeds, road and traffic conditions. The system can automate remedial coaching for the driver (Marsh, 2019).
AI Techniques	
System Functions	

Item	Description
Maturity	Concept > R&D > Prototype/MVP > **Production**

USDOT Role

This category is aligned with the missions of the FHWA Office of Freight Management and Operations and Federal Motor Carrier Safety Administration (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

Definition

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 machine learning 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/ADAS technology.

Summary of Potential Applications

In this category, seven existing and potential applications of AI are summarized in Table 39 to Table 45.

Table 39. Summary Description of AI for Transit Asset Condition Monitoring and Diagnostics (TOM-01)

Item	Description
ID	TOM-01
Application	Transit Asset Condition Monitoring and Diagnostics

Item	Description
Objective	Assess transit asset condition including diagnosing malfunctioning transit railcar systems and subsystems
Description	AI can help assess transit asset condition as well as predict when and where potential issue might occur. For example, The Georgia Metropolitan Atlanta Rapid Transit Authority (MARTA) uses AI and machine learning to better predict, identify, and repair potential issues to its transit equipment. This Transit Asset Management (TAM) tool provides asset inventory, condition assessment, performance measures, and decision support (Dosu, 2019). Additionally, a rail industry joint research and development laboratory set up with the support of the European Union Regional Development Fund, focuses, among other things, on preventive maintenance and AI learning. One of its ongoing AI projects is developing the possibility for a train to transmit its “health diagnostic” to a fleet supervisor, who will be able to organize maintenance remotely, using voice recognition software (Marsh, 2019). More specifically, AI can be applied to diagnose malfunctioning transit railcar systems and subsystems, leading to improved safety and cost savings. For example, an on-board AI system can perform complete systems startup and shutdown diagnosis and continuously monitor the systems while the railcar is in operation. In addition, the on-board AI program can perform fault identification and prediction. Research has been conducted in this area for many years. For example, the Washington Metropolitan Area Transit Authority (WMATA) previously tested a diagnostic AI assistant for transit railcar propulsion systems (Kahric, 1999).
AI Techniques	Machine Learning; Object & Face Recognition; Natural Language Processing
System Functions	Sense & Perceive Environment; Reason & Analyze Information; Make Decisions, Communicate, & Take Actions
Maturity	Concept → R&D → **Prototype/MVP** → Production

Table 40. Summary Description of AI for On- and Off-Board Transit Monitoring (TOM-02)

Item	Description
ID	TOM-02
Application	On- and Off-Board Transit Monitoring
Objective	Prevent transit crashes by proactively monitoring passenger and operator behaviors as well as potentially hazardous abnormalities outside the transit vehicle
Description	AI can help monitor passenger and operator behaviors on-board transit as well as help monitor the surrounding environment off-board. First, AI can help monitor on-board behaviors. Traditional CCTV is already widely used in the bus sector, but only to offer reflective playback opportunities for operators. Until recently, CCTV solutions have been unable to act as a crash prevention tool. With AI, fleet safety managers can monitor operator and passenger behavior in real time, decreasing risks that can lead to crashes (Liu, Liao, & Scelfo, 2019). This on-board video-based monitoring covers driver and passenger behavior. Risky operator behavior could include cell phone use and other forms of distracted driving. AI can detect if an operator is on their phone while driving, which could be missed if the feeds from all of the buses are monitored manually. Risky passenger behaviors could include swinging on bars or standing on seats in the bus. Using AI to automatically detect the risk of potential incidents, whether from operator or passenger behaviors, could help TMC and fleet safety managers know which bus or transit car's feed to monitor more closely. According to a study by the International Association of Public Transport (UITP) Asia-Pacific Centre for Transport Excellence, AI-enabled video analytics has been labeled as one of the "low hanging fruits" with respect to AI in public transportation since it is relatively easy to deploy with few barriers to development (Ho, et al., 2018). While transit agencies in Singapore have used this technology for operator monitoring and crash risk prediction, video-based transit surveillance remains controversial in the United States due to privacy concerns (Breitenbach, 2016). In addition to on-board operator and passenger behaviors, AI can also monitor events from stationary transit infrastructure. For example, AI can monitor and filter camera image feeds from conventional railroad crossing cameras for signs of abnormal behavior. If the machine learning-based algorithm detects a potential issue, it can quickly alert supervisors. Additionally, by using object recognition to filter only images containing potential hazards, this can reduce bandwidth burdens. Testing for this kind of AI-enabled railroad crossing application is happening in Machida City, Tokyo, Japan (Weekes, 2020).

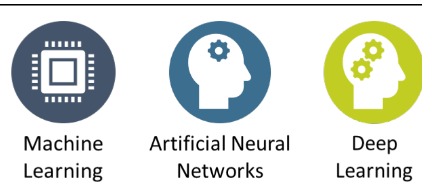
Item	Description
AI Techniques	Machine Learning; Object & Face Recognition; Comp Vision & Image Analysis
System Functions	Sense & Perceive Environment; Reason & Analyze Information; Learn from Experience & Adapt to New Situations
Maturity	Concept > R&D > Prototype/MVP > Production

Table 41. Summary Description of AI for Automated Buses and Shuttles (TOM-03)

Item	Description
ID	TOM-03
Application	Automated Buses and Shuttles
Objective	Optimize automated transit fleets to provide safe, smart, and reliable travel for riders

Item	Description
Description	Small scale automated bus trials have been initiated in many countries to improve travel for riders. For example, automated buses or shuttles have been tested in the United States, China, the Netherlands, Japan, Sweden, Taiwan, Singapore, Scotland, and Australia. Technology costs are unknown at this point, because the transit bus automation systems that exist are prototypes rather than commercialized products. Although the technology may not be available currently, bus manufacturers are working with suppliers to understand the development timelines for new features and have high-level roadmaps for their introduction (Federal Transit Administration and Volpe National Transportation Systems Center, 2019). The low-speed automated shuttle concept encompasses a range of small (typically 4-15 passengers), low-speed (typically 10-25 mph), and automated (SAE Level 4) shuttles. Vehicles share similar sensor configurations, relying upon combinations of cameras, radar, lidar, ultrasonic sensors, and GPS. As of the beginning of August 2018, the Volpe project team had identified and documented more than 260 demonstrations and pilots (some planned, some ongoing, and some completed), in North America, Europe, Asia, Oceania, and Africa. These low-speed shuttles, in many cases, aim to fill the first-mile/last-mile gaps with accessing the fixed route transit system. For example, a few selected domestic low-speed automated shuttle deployments are currently ongoing in Dublin and San Ramon in California; Gainesville and Jacksonville in Florida; Weymouth, Massachusetts; Ann Arbor and Detroit in Michigan; Las Vegas, Nevada; Greenville, South Carolina; and Arlington, Texas. (Joshua Cregger, 2018). Additionally, Lake Nona in the city of Orlando, Florida is integrating an AI-enabled scheduling platform with its electric automated shuttles operating on fixed routes (Lake Nona News, 2019).
AI Techniques	 Machine Learning · Artificial Neural Networks · Deep Learning · Object & Face Recognition · Comp Vision & Image Analysis
System Functions	 Sense & Perceive Environment · Reason & Analyze Information · Learn from Experience & Adapt to New Situations · Make Decisions, Communicate, & Take Actions
Maturity	Concept > R&D > **Prototype/MVP** > Production

Table 42. Summary Description of AI for Multimodal Mobility on Demand (MOD) (TOM-04)

Item	Description
ID	TOM-04
Application	Multimodal Mobility on Demand (MOD)
Objective	Improve multimodal mobility on demand for individual users and the transportation network with AI
Description	The United States Department of Transportation (USDOT) uses the term Mobility on Demand (MOD) to represent its vision for future mobility. MOD envisions a safe, reliable and carefree mobility ecosystem that supports complete trips for all, both personalized mobility and goods delivery. USDOT achieves this vision by leveraging innovative technologies and facilitating public private partnerships to allow for a user-centric approach that improves mobility options for all travelers, and delivery of goods and services (U.S. DOT Intelligent Transportation Systems Joint Program Office, 2020). On-demand multimodal transportation is becoming possible with progress in analytics and AI. AI can improve capabilities for subsystems in the MOD ecosystem in a variety of ways. For example, researchers from the Massachusetts Bay Transportation Authority (MBTA) On-Demand Paratransit Pilot Program performed a K-means clustering analysis of the pilot participants with the goal of systematically identifying types of users with common travel behaviors (Gonzales, Sipetas, & Italiano, 2019). While no current MOD implementations use AI, there is an opportunity to incorporate it into existing methods to predict user travel based on their past behavior and current needs. By understanding common behaviors across groups of users, a MOD platform can better anticipate individual user needs and preferences while simultaneously optimizing the entire transportation network. In addition to dynamically optimizing individual user experiences, AI could optimize travel demand across modes for the entire transportation network as data exchange and integration occur. Combining predictive and prescriptive models allows online real-time stochastic optimization and dynamic pricing at the system level (Van Hentenryck, 2016). Data mining and machine learning allow activity-based models of mobility and demand forecasting.
AI Techniques	

Item	Description
System Functions	
Maturity	

Table 43. Summary Description of AI for Transit Customer Service and Trip Reservation (TOM-05)

Item	Description
ID	TOM-05
Application	Transit Customer Service and Trip Reservation
Objective	Improve the user booking experience and automatically schedule expected trips

Item	Description
Description	AI can enhance transit booking in a variety of ways. For example, AI can be used to help transit agencies handle telephone calls from customers by accepting natural language commands and filtering out extensive background noise, which can be common in outdoor environments. While some transit agencies have been using interactive voice response (IVR) for over a decade, AI-enabled chatbots could improve customer service. Chatbots can conversationally interact with callers regarding service routes and schedules, fare information, and complaints. They can also perform call transcription and recording. The chatbots can take trip reservations (e.g. ADA complimentary paratransit, general demand-response service) from customers, freeing staff to have more time to interact with customers who need individualized assistance. Furthermore, ITS and other technologies can serve a valuable role in the coordination of mobility services for the transportation-disadvantaged as provided by transit, paratransit, and human service transportation providers. These technologies are integrated through the concept of a Travel Management Coordination Center (TMCC), a concept previously piloted by two USDOT initiatives: Mobility Services for All Americans (MSAA) and Veterans Transportation and Community Living Initiative (VTCLI) (Hemily, 2017). AI and machine learning could help the TMCC determine appropriate eligibility for the trip for customers who are eligible for multiple programs that provide transportation services, based on a user's profile and their trip's origin/destination. Additionally, AI could help the TMCC appropriately bill the right funding programs by learning each program's eligibility rules and user patterns. AI can use historical data to predict when and where booking demand is likely to exist, helping to proactively schedule operators and maintenance activities. For example, AI can learn that specific users will require service to and from regular doctors' appointments and the system can then proactively schedule the rides with the customer. The Geisinger Clinic in Pennsylvania plans to use AI to improve its TMCC operations. They received FY2019 funding from an Access & Mobility Partnership Grant to extend eligibility and geographic reach to a transportation pilot program that increases transportation access using mobility management, artificial intelligence and technology solutions, and community partner integration (Federal Transit Administration, 2019).
AI Techniques	

Item	Description
System Functions	
Maturity	

Table 44. Summary Description of AI for Transit Dispatching (TOM-06)

Item	Description
ID	TOM-06
Application	Transit Dispatching
Objective	Automatically dispatch transit to meet demand in real-time

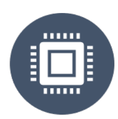
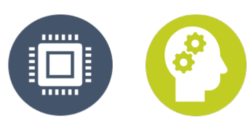
Item	Description
Description	Machine learning with real-time data monitoring of fleet performance can automate route dispatching to meet transportation demand in real-time. AI-enabled fleet dispatching can help transit agencies and mobility service providers deliver predicable mobility services with their fleets. AI-enabled platforms could integrate historical and real-time data including weather, traffic, service alerts, and transit feeds. The platform could use machine learning to convert these schedules into work assignments, pushing the information to agencies and operators. Transit riders could also receive real-time updates. In addition to fixed-route bus fleets, paratransit dispatching could also benefit from AI. Typical paratransit systems require advanced scheduling and operators are given a static route and schedule to complete for the day. A delay that impacts a paratransit vehicle during its assigned run will have cascading impacts on all of the customers scheduled to be picked up by that vehicle, potentially leading to missed appointments and work hours. Dispatch systems that leverage AI could help mitigate these challenges. Dynamically re-assigning trips to different vehicles with AI based on real-time delays could allow customers to experience a more high-quality trip and reduce the delay and overall trip time that they experience. AI can also provide necessary updates to customers, as needed. For example, the Massachusetts Bay Transportation Authority (MBTA) is implementing an On-Demand Paratransit Pilot Program. Researchers for the program propose a model to estimate the marginal cost of each requested trip and optimize allocation of the RIDE (MBTA's door-to-door shared-ride paratransit service) vans or alternative providers. To optimize the allocation of trips to paratransit and TNCs, the researchers used machine learning to predict the likely effect of system changes (Gonzales, Sipetas, & Italiano, 2019).
AI Techniques	 Machine Learning
System Functions	 Reason & Analyze Information; Learn from Experience & Adapt to New Situations; Make Decisions, Communicate, & Take Actions
Maturity	

Table 45. Summary Description of AI for Transit Routing and Delay Prediction (TOM-07)

Item	Description
ID	TOM-07
Application	Transit Routing and Delay Prediction
Objective	Optimize routing, forecast delays, and estimate trip duration
Description	AI can better optimize transit routing and predict delays in changing circumstances. AI has helped advance demand responsive public transportation with flexible on-demand bus services (Rusul Abduljabbar, 2019). These demand responsive systems operate with flexible routes and schedules without fixed stops. They often cater to rural communities to augment service for areas or times of days where there is not enough demand for a fixed route. For example, researchers developed a mathematical model for optimizing demand-responsive transit systems using a zonal strategy and conducted a case study for a presumptive demand-responsive transit system in northwest Calgary, Canada (Wang, Wirasinghe, Kattan, & Saidi, 2018). Additionally, Nassau Inter-County Express (NICE), the local bus system serving Nassau County in New York and eastern portions of the borough of Queens, is using an AI-enhanced routing platform for its fleet (Nassau Inter-County Express, n.d.). Furthermore, the New York City Department of Education has launched a new school bus routing and tracking platform, which sends real-time automatic updates to parents and students (Thompson S. , 2019). In addition to optimizing routing, AI could improve transit delay and duration prediction for fixed route services. Machine learning can learn the factors that impact on-time performance (Vogel, 2018). For example, if there is an incident that affects bus routes, AI could help to more accurately predict when the bus would reach a particular stop. This system can forecast traffic delays and the duration of a bus trip by using machine learning with real-time traffic forecasts and data from bus routes to improve the accuracy of transit timing (Fabrikant, 2019). Improved predictions systemwide allow customers to assess their mobility options more realistically and make their own tradeoffs. Some navigation apps now provide live traffic delays for public transportation. These systems are driven by machine learning models that analyze data from real-time traffic information and transit schedules. They can also predict how long a bus trip will take and suggest alternative transit routes.
AI Techniques	 Machine Learning, Deep Learning

Item	Description
System Functions	
Maturity	

USDOT Role

This category is aligned with the FTA's Office of Research, Demonstration and Innovation focus areas (U.S. Department of Transportation, 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. Thus, although the private sector leads development of applications under this category, USDOT has an opportunity to foster innovation through data sharing and AI-enabled solutions.

Emergency Management

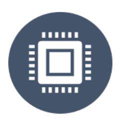
Definition

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.

Summary of Potential Applications

In this category, three existing and potential applications of AI are summarized in Table 46 and Table 48.

Table 46. Summary Description of AI for Improved Emergency Planning (EM-01)

Item	Description
ID	EM-01
Application	Improved Emergency Planning
Objective	Improve emergency planning by identifying high-risk crash locations, identifying populations vulnerable to natural calamities, and planning for evacuation needs of specific population groups
Description	Agencies can improve their emergency and evacuation plans by identifying high-risk crash locations, identifying populations vulnerable to natural calamities, and being responsive to the needs of specific population groups, who require assistance during local or multi-jurisdictional emergency evacuation. These specific population groups include people with disabilities, people with medical conditions, the aging population, people with no access to transportation, and people with pets (Houston, et al., 2009). AI can be used to identify high-risk crash/incident locations that can hamper emergency evacuation operations under the threat of major natural catastrophes such as Hurricanes Sandy and Katrina. Machine learning techniques can use historical crash and incident data including occurrences during disaster conditions to produce predictions for similar future events. Previous research employed classification tree and random forest models in conjunction with crash/incident data as well as socio-demographic and transportation data to explore the pattern of evacuation zoning by using zone category as the response variable and geographic features, evacuation mobility, and demographic-economic features as predictors (Xie, Ozbay, Zhu, and Yang, 2017). Clustering algorithms can also be used to identify areas that are susceptible to natural calamities. Machine learning can be used to predict high-risk facilities and localities, and potential severity of impact. These predictions can be used to identify vulnerable populations and develop specific plans for evacuating people who require assistance.
AI Techniques	 Machine Learning  Artificial Neural Networks
System Functions	 Reason & Analyze Information

Item	Description
Maturity	

Table 47. Summary Description of AI for Improved Emergency Response (EM-02)

Item	Description
ID	EM-02
Application	Improved Emergency Response
Objective	Improve emergency response using chatbots for citizen interaction and communication with EMS, scanning social media for early warnings, and rapid reallocation of resources and assets
Description	AI can be used to rapidly respond to emergencies and disasters (Lahoti, 2018). AI-powered chatbots can be used to interact with citizens during an emergency. The chatbots can ask them to upload information such as their location, description of the emergency, and photographs of the disaster. The AI system can validate this information with other sources and an assessment can be made in real-time of the type and urgency of response required. The chatbot can also inform the citizen on what their next step should be. It can also perform call transcription and recording. The information can be rapidly passed along to first responders. AI chatbots can also be used by first responders to communicate with an emergency center on the nature and extent of the emergency and other needs. An AI-enabled application can scan social media messages and filter out fake tweets and information to assess and identify impending calamities, which can be used to provide early warnings to citizens. Machine learning techniques can be used to rapidly re-allocate and optimize resources and re-route evacuations.
AI Techniques	

Item	Description
System Functions	Reason & Analyze Information; Learn from Experience & Adapt to New Situations; Make Decisions, Communicate, & Take Actions
Maturity	Concept → R&D → Prototype/MVP → Production

Table 48. Summary Description of AI Training Tools for EMS Personnel (EM-03)

Item	Description
ID	EM-03
Application	AI Training Tools for EMS Personnel
Objective	Improve effectiveness of training tools for EMS personnel by learning from high-performing crises decision makers
Description	AI can help train EMS personnel for emergency response. Existing products offer real-time, AI-assisted situational awareness and critical decision-making support. AI creates realistic response scenarios based on actual operational and incident experiences. The AI-enabled software interacts with students to coach them on situational awareness and decision-making, which it learned by observing high-performing crises decision-makers.
AI Techniques	Machine Learning; Artificial Neural Networks
System Functions	Sense & Perceive Environment; Reason & Analyze Information; Learn from Experience & Adapt to New Situations; Make Decisions, Communicate, & Take Actions

Item	Description
Maturity	Concept, R&D, Prototype/MVP, **Production**

USDOT Role

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

Definition

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.

Summary of Potential Applications

In this category, four existing and potential applications of AI are summarized in Table 49 to Table 52. It should be noted that there are several AI-enabled applications that solve problems specific to Air Traffic Control and Management but have limited applicability to ITS problems.

Table 49. Summary Description of AI for 4-D Trajectory Prediction (ATM-01)

Item	Description
ID	ATM-01
Application	4-D Trajectory Prediction
Objective	Enhance trajectory prediction for decision support
Description	Part of the NextGen Performance-Based Navigation (PBN) plan by 2030 is to accurately predict an aircraft's 4-D trajectory (Federal Aviation Administration, 2016). By integrating automation tools and operations, including PBN routing, Trajectory Based Operations, and time-based metering capabilities, this could enhance decision support systems (Federal Aviation Administration, 2018). Trajectory prediction could be adapted for ITS for CV/AV and transit, enabling state and local agencies to more effectively manage their systems.

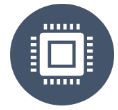
Item	Description
AI Techniques	 Machine Learning
System Functions	 Reason & Analyze Information
Maturity	Concept → **R&D** → Prototype/MVP → Production

Table 50. Summary Description of AI for Space-Based Automatic Dependent Surveillance-Broadcast (ATM-02)

Item	Description
ID	ATM-02
Application	Space-Based Automatic Dependent Surveillance-Broadcast (ADS-B)
Objective	Detect and resolve potential conflicts in historically difficult-to-track locations
Description	Improved oceanic surveillance could be the next opportunity for ADS-B coverage for the FAA. As part of a project called Advanced Surveillance Enhanced Procedural Separation (ASEPS), the FAA is analyzing two methods of improving surveillance coverage in oceanic service volumes: Space-Based ADS-B reports and more frequent Automatic Dependent Surveillance – Contract (ADS-C) reports (Federal Aviation Administration, 2016). Enabling surveillance across the globe via satellites could improve controller situational awareness. Using Space-Based ADS-B data, AI could be used to detect and resolve potential conflicts, even in historically difficult-to-track locations. This application may be adapted for ITS to resolve potential conflicts for CV/AV.

Item	Description
AI Techniques	Machine Learning; Object & Face Recognition; Comp Vision & Image Analysis
System Functions	Sense & Perceive Environment; Reason & Analyze Information; Learn from Experience & Adapt to New Situations; Make Decisions, Communicate, & Take Actions
Maturity	Concept > **R&D** > Prototype/MVP > Production

Table 51. Summary Description of AI for Terminal Flight Data Manager (ATM-03)

Item	Description
ID	ATM-03
Application	Terminal Flight Data Manager (TFDM)
Objective	Predict congestion bottlenecks from coordinated data feeds
Description	The Terminal Flight Data Manager is a surface management solution for bustling airports. It streamlines data feeds and coordinates decision-making between gates and towers. With growing congestion on the airport surface due to the increase in commercial air traffic nationwide, the need for efficient aircraft traffic planning on the airport ground is critical (Federal Aviation Administration, 2018). AI could be used in this system to precisely predict congestion bottlenecks. This application may be adapted for ITS to support Traveler Decision Support Tools.
AI Techniques	Machine Learning

Item	Description
System Functions	Reason & Analyze Information
Maturity	Concept > **R&D** > Prototype/MVP > Production

Table 52. Summary Description of AI for Remote Virtual Towers (ATM-04)

Item	Description
ID	ATM-04
Application	Remote Virtual Towers
Objective	Recognize scenes from live video feeds
Description	This technology allows air traffic controllers to operate from anywhere in the world using cameras and real-time video. The digital displays can have automated overlays that provide additional information and highlight items of interest. AI can be trained to recognize objects or scenes of interest from the live video feeds. This would improve the safety and efficiency of airport operations (Zazulia, 2019). This application may be adapted for ITS to support TMC staff recognize queues and incidents.
AI Techniques	Machine Learning; Object & Face Recognition; Comp Vision & Image Analysis
System Functions	Sense & Perceive Environment; Reason & Analyze Information

Item	Description
Maturity	Concept → **R&D** → Prototype/MVP → Production

USDOT Role

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

Definition

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.

Summary of Potential Applications

In this category, six existing and potential applications of AI are summarized in Table 53 to Table 58.

Table 53. Summary Description of AI for Drone-Enabled Emergency Event Detection and Assessment (RS-01)

Item	Description
ID	RS-01
Application	Drone-Enabled Emergency Event Detection and Assessment
Objective	Detect incidents and emergencies through remote sensing, helping first responders and emergency medical services (EMS) respond safely and quickly

Item	Description
Description	High-resolution imagery from remote sensing devices, such as satellites and drones, can allow AI algorithms to extract roadway features, detect vehicles, and detect incidents more accurately. Machine learning techniques have been applied in this context for incident detection, including for traffic bottleneck detection. AI algorithms can detect whether an incident has occurred on the road. By learning traffic flow characteristics from sensor data along the road, algorithms can classify incident occurrence. This information can be rapidly shared with EMS and maintenance personnel, allowing them to respond quickly to crashes and other traffic incidents (Kahaki and Nordin, 2011). Light detection and ranging (LiDAR) technology and unmanned aerial systems (UAS) photography and video feeds are now enhancing how asset management and inspections are processed. The three-dimensional (3D) point cloud data and high-resolution video generated by UASs is overwhelming in content. Machine learning tools such as neural networks and other image processing algorithms are applied to 3D point clouds to extract information and features (Gettman, 2019). AI-enabled drones can provide accurate information about damaged infrastructure, buildings, and HAZMAT situations making rescue efforts safer and less time-consuming. Additionally, UAS and deep learning could be leveraged for crash investigation. AI could perform automated detection of vehicles and assets on the scene of the crash directly from videos or images. It could also perform an assessment of the scene, measuring and calculating impacts to detected entities. This application is also relevant to Transportation Systems Management and Operations as well as Emergency Management categories.
AI Techniques	Machine Learning; Artificial Neural Networks; Deep Learning; Object & Face Recognition; Comp Vision & Image Analysis
System Functions	Sense & Perceive Environment; Reason & Analyze Information
Maturity	Concept → **R&D** → Prototype/MVP → Production

Table 54. Summary Description of AI for Regional Traffic Monitoring Through Remote Sensing (RS-02)

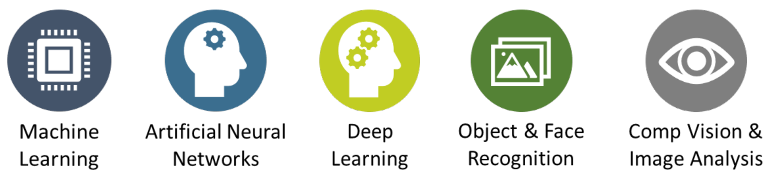
Item	Description
ID	RS-02
Application	Regional Traffic Monitoring Through Remote Sensing
Objective	Monitor traffic flow and emerging issues through remote sensing
Description	Remote sensing and AI can improve traffic surveillance, monitoring, and management. Once trained using historical data, AI can predict congestion and other traffic states given subtle changes in traffic flows. Rather than having human analysts regularly monitor incoming traffic data, AI can monitor and alert TMC operators of potential issues (National Aeronautics and Space Administration, 2019). This application is also relevant to Transportation Systems Management and Operations category.
AI Techniques	
System Functions	
Maturity	

Table 55. Summary Description of AI for Environmental Impact Assessment Through Remote Sensing (RS-03)

Item	Description
ID	RS-03
Application	Environmental Impact Assessment Through Remote Sensing
Objective	Detect land use change through remote sensing and predict environmental impacts

Item	Description
Description	AI can predict future environmental impacts, such as deforestation, impacts on local and regional hydrology, urban heat, and smog. AI can learn to detect change from data collected from satellite imagery, hyperspectral sensors (which use the electromagnetic spectrum), Light Detection and Ranging (LIDAR) sensors, and other sources. Furthermore, AI can predict environmental and other impacts from land use change scenarios, such as adding new parking lots or roads. AI can boost smart urban planning (National Aeronautics and Space Administration, 2019).
AI Techniques	Machine Learning; Object & Face Recognition; Comp Vision & Image Analysis
System Functions	Sense & Perceive Environment; Reason & Analyze Information
Maturity	Concept > **R&D** > Prototype/MVP > Production

Table 56. Summary Description of AI for Transportation Infrastructure Management Through Remote Sensing (RS-04)

Item	Description
ID	RS-04
Application	Transportation Infrastructure Management Through Remote Sensing
Objective	Classify critical infrastructure through remote sensing and direct maintenance crews to areas in need of repairs

Item	Description
Description	AI can analyze and classify remote sensing imagery of critical transportation infrastructure, including pavement, bridges, pipelines, rail lines, harbors, and airports. AI can make transportation infrastructure management more efficient and effective by providing decision support, directing maintenance crews directly to areas in most need of repair. This saves valuable work time, better prevents crashes from damaged infrastructure (such as potholes or bridge collapses), and limits roadway slowdowns due to human surveying (National Aeronautics and Space Administration, 2019). This application is also relevant to Asset Management and Roadway Construction and Maintenance category.
AI Techniques	Machine Learning; Object & Face Recognition; Comp Vision & Image Analysis
System Functions	Sense & Perceive Environment; Reason & Analyze Information
Maturity	Concept > **R&D** > Prototype/MVP > Production

Table 57. Summary Description of AI for Safety Hazards and Disaster Assessment Through Remote Sensing (RS-05)

Item	Description
ID	RS-05
Application	Safety Hazards and Disaster Assessment Through Remote Sensing
Objective	Detect potentially hazardous infrastructure before it becomes problematic

Item	Description
Description	AI can learn to detect safety hazards on, near, or under roadway infrastructure. For example, AI can scan radar data and detect pipeline leaks before they turn catastrophic. Additionally, AI can improve impact predictions to transportation networks, identify transportation lifelines, and support decision making for EMS deployment following hazards and disasters. Furthermore, AI can classify transportation safety risks in different geographical areas from anticipated weather events (National Aeronautics and Space Administration, 2019). This application is also relevant to Transportation Systems Management and Operations; Emergency Management; and Asset Management and Roadway Construction and Maintenance categories.
AI Techniques	Machine Learning; Object & Face Recognition; Comp Vision & Image Analysis
System Functions	Sense & Perceive Environment; Reason & Analyze Information
Maturity	Concept → **R&D** → Prototype/MVP → Production

Table 58. Summary Description of AI for Urban Air Mobility and Automated UAV Delivery (RS-06)

Item	Description
ID	RS-06
Application	Urban Air Mobility and Automated UAV Delivery
Objective	Navigate and deliver packages and people within urban centers

Item	Description
Description	This application involves urban aerial transportation, encompassing everything from small package delivery drones to passenger-carrying air taxis above populated areas. Urban aerial delivery concepts and systems are early in development but given the opportunities available, this field is being aggressively explored both domestically and internationally (National Aeronautics and Space Administration, 2019).
AI Techniques	Machine Learning; Artificial Neural Networks; Deep Learning; Object & Face Recognition; Natural Language Processing; Comp Vision & Image Analysis
System Functions	Sense & Perceive Environment; Reason & Analyze Information; Learn from Experience & Adapt to New Situations; Make Decisions, Communicate, & Take Actions
Maturity	Concept → R&D → Prototype/MVP → Production

USDOT Role

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

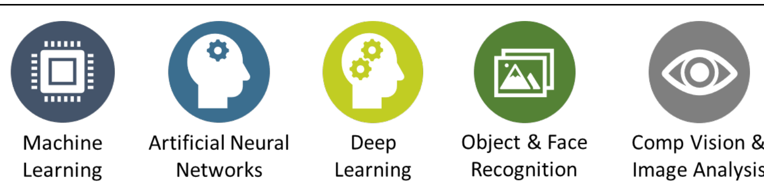
Definition

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.

Summary of Potential Applications

In this category, three existing and potential applications of AI are summarized in Table 59 to Table 61.

Table 59. Summary Description of AI for Pavement Monitoring and Predictive Road Maintenance (RCM-01)

Item	Description
ID	RCM-01
Application	Pavement Monitoring and Predictive Road Maintenance
Objective	Assess road pavement condition to predict road maintenance and alert users to potential hazards
Description	Machine learning can be used for road weather pavement condition sensing and prediction. This information can be used by traffic managers to re-route snowplows, dispatch maintenance crews, re-route traffic, etc. AI can also be used to detect pavement hazards, such as potholes, and alert drivers and maintenance crews to these issues before they cause major vehicle damage (Hoang, 2018). Beyond classifying hazards in real time, deep learning algorithms can predict what kind of maintenance a road requires from evaluating cracks, fractures and other road damage (Mathur, 2018). This application can be a crossover to Commercial Vehicle and Freight Management, and Transportation Systems Management and Operations categories. For example, the pavement information can be used in freight route planning and for ADM strategies.
AI Techniques	

Item	Description
System Functions	Sense & Perceive Environment; Reason & Analyze Information; Make Decisions, Communicate, & Take Actions
Maturity	Concept → R&D → **Prototype/MVP** → Production

Table 60. Summary Description of AI for Road Roughness Evaluation from Connected Vehicles (RCM-02)

Item	Description
ID	RCM-02
Application	Road Roughness Evaluation from Connected Vehicles
Objective	Assess road conditions from connected vehicle data
Description	Connected vehicle data can shed light on road condition, such as roughness. These data can be used to train machine learning algorithms to classify road segments into roughness categories, without the need for advanced technicians or special vehicle instruments (Zhang, Sun, Bridgelall, and Sun, 2018).
AI Techniques	Machine Learning; Object & Face Recognition; Comp Vision & Image Analysis
System Functions	Sense & Perceive Environment; Reason & Analyze Information
Maturity	Concept → **R&D** → Prototype/MVP → Production

Table 61. Summary Description of AI for Roadway Asset Extraction/Management from Image Data (RCM-03)

Item	Description
ID	RCM-03
Application	Roadway Asset Extraction/Management from Image Data
Objective	Classify and sort useful road assets from images
Description	Machine learning algorithms can extract roadway and roadside assets, such as traffic signals, guardrails, line paintings and rumble strips, from large databases. This extraction saves resources and valuable analyst time by labeling, sorting and flagging images automatically. This information can inform maintenance crews of problematic roadway assets (e.g., signs, pavement, bridges, retaining walls, etc.) without them having to survey the entire landscape themselves (Makehmir, Coram, Firbank, Palsat, and Palesch, 2018).
AI Techniques	
System Functions	
Maturity	

USDOT Role

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.

Risks and Barriers to Use of AI

USDOT investments in R&D and demonstrations of AI-enabled applications for addressing transportation problems come with a few risks and barriers that are common across the 11 categories.

- **Lack of Technology Neutrality:** The USDOT may want to foster fair market competition by avoiding giving the impression of supporting a particular technology (AI technique or sub-field) or company. USDOT investments in R&D and demonstrations of AI-enabled applications under this category (and other categories) may not want to prescribe the type of AI technique or sub-field.
- **Market Competitor:** The USDOT may not want to be in competition with the private industry, who are leading research and development of AI solutions for various categories. Instead, the USDOT may want to play the role of a market facilitator. It is suggested that USDOT investments in R&D and demonstrations result in products that are open source to allow for adoption by the market. Additionally, where possible, data may be released as open data to facilitate further development of AI solutions. The USDOT may want to support public-private partnerships through investments in the areas of data sharing, user privacy, human-machine interface, and driver distraction.
- **Liability:** When a vehicle, device, equipment, or system is enabled by an AI-enabled application, the question remains as to who should be held liable if there is a fatality, crash, incident or significant loss in productivity and economy? Who is liable if a USDOT-supported cybersecurity solution is hacked or is biased? The USDOT may want to play a central role, working with the private sector, in developing policies and regulations for these emerging technologies that balance user safety and innovation effectively.
- **Computing Power:** AI techniques are enabled by massive amounts of data, commonly referred to as “big data.” Many legacy systems/architectures 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, advanced analytics, and computing.
- **Privacy:** AI is fundamentally designed to use massive amounts of data impacting the privacy of individuals through data manipulation, speech or face recognition, and tracking. While AI can anonymize these personally identifiable data, there are risks of bad actors backing out the information. A possible solution is to have users opt-in to services, the USDOT may want to develop policies and guidelines on what type of user data may be tracked, when and for what purpose.
- **Bias:** AI-enabled applications are only as good or as bad as the training data. If there is bias in the data, the AI-enabled applications can also be biased leading to unethical and unfair consequences.
- **Ethics:** AI-enabled applications can be used for profiling to discriminate against individuals/populations based on unfair criteria.
- **Transparency:** AI techniques are often seen as “black boxes.” This can lead to mistrust among stakeholders, which can be a barrier to adoption.
- **Transfer Learning:** While AI techniques can perform exceedingly well on certain tasks, they are less capable of generalizing to new circumstances/environments. USDOT investments in AI solutions for a corridor cannot automatically be applied to a similar corridor; the AI-enabled applications will need to be adapted.

- **Talent/Workforce:** As AI is an emerging technology, quality control could become a problem. The models are only as good as the data, assumptions and the specific AI techniques used. Budget will need to be allocated towards building talent in AI and advanced data analytics. Another looming issue is that AI is likely to replace repetitive jobs.

Chapter 4. Conclusions

Artificial Intelligence is revolutionizing every walk of life, allowing machines to learn from experience, adapt, and perform tasks that have historically required human cognition. The US government elevated AI as one of its key priority science and technology areas. In response, 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. As the USDOT embarks on advancing AI in transportation, it is essential to focus on high-value scenarios that can be used to motivate and inform stakeholders, accelerate the impact of AI deployment, and form a template for potential field tests and deployments that demonstrate the transformational power of AI. Otherwise, a scatter-shot approach may misinform stakeholders and unnecessarily demotivate deployment—simply because AI cannot be applied as a panacea with uniform results.

This report identified 11 broad categories of AI-enabled applications that can be applied to address specific transportation problems and needs and summarized existing and potential applications of AI under each category based on a review of literature, which represents a snapshot in time. The report also summarized the potential role of USDOT for investing in AI-enabled applications under each category. Finally, this report summarized risks and barriers to use of AI that are common across all 11 categories.

By funding research and deployment in the 11 categories, the USDOT will have a better understanding of the limits of the technologies, and the policies that will need to be implemented or revised. Moreover, the USDOT can facilitate or serve as a catalyst for innovation, taking the state of the art to the practitioner. The research products and lessons learned can be transferred to the state and local agencies for future adoption.

Next Steps

The research team will identify practical real-world scenarios where AI offers the potential to address transportation needs. Relevant AI-enabled applications will be identified based on the summary descriptions in Chapter 3 and interviews of AI experts from the public and private sectors. This research will help inform the development of a 5-year roadmap for the AI Program.

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Appendix A

The research team identified 11 categories of AI that can be mapped to the Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT) Version 8.3 (www.arc-it.net). The table below shows how the existing ARC-IT taxonomy can be mapped to the 11 AI-enabled application Categories. The first column combines levels 2 and 3 of the ARC-IT Taxonomy.

Table 62. Mapping AI for ITS Categories to ARC-IT Taxonomy Combined Levels 2 and 3

ARC-IT Taxonomy Combined Levels 2 and 3	AI-enabled application for ITS Categories (11 Unique Categories)
Alternative Fuels-Charging / Fueling Information	Advanced Driver Assistance Systems, Connected and Automated Vehicles
Alternative Fuels-Charging / Fueling Payment	Advanced Driver Assistance Systems, Connected and Automated Vehicles
Alternative Fuels-Inductive Charging	Advanced Driver Assistance Systems, Connected and Automated Vehicles
Arterial Management-Enforcement	Transportation Systems Management and Operations
Arterial Management-Information Dissemination	Transportation Systems Management and Operations
Arterial Management-Lane Management	Transportation Systems Management and Operations
Arterial Management-Parking Management	Transportation Systems Management and Operations
Arterial Management-Surveillance	Transportation Systems Management and Operations
Arterial Management-Traffic Control	Transportation Systems Management and Operations
Commercial Vehicle Operations-Carrier Operations & Fleet Management	Commercial Vehicle and Freight Operations
Commercial Vehicle Operations-Credentials Administration	Commercial Vehicle and Freight Operations
Commercial Vehicle Operations-Electronic Screening	Commercial Vehicle and Freight Operations
Commercial Vehicle Operations-Safety Assurance	Commercial Vehicle and Freight Operations

ARC-IT Taxonomy Combined Levels 2 and 3	AI-enabled application for ITS Categories (11 Unique Categories)
Commercial Vehicle Operations-Security Operations	Commercial Vehicle and Freight Operations
Crash Prevention & Safety-Animal Warning	Advanced Driver Assistance Systems, Connected and Automated Vehicles
Crash Prevention & Safety-Bicycle Warning	Advanced Driver Assistance Systems, Connected and Automated Vehicles
Crash Prevention & Safety-Collision Avoidance	Advanced Driver Assistance Systems, Connected and Automated Vehicles
Crash Prevention & Safety-Collision Notification	Advanced Driver Assistance Systems, Connected and Automated Vehicles
Crash Prevention & Safety-Highway-Rail Crossing Warning	Advanced Driver Assistance Systems, Connected and Automated Vehicles
Crash Prevention & Safety-Intersection Collision Warning	Advanced Driver Assistance Systems, Connected and Automated Vehicles
Crash Prevention & Safety-Pedestrian Safety	Advanced Driver Assistance Systems, Connected and Automated Vehicles
Crash Prevention & Safety-Road Geometry Warning	Advanced Driver Assistance Systems, Connected and Automated Vehicles
Crash Prevention & Safety-Weather Warning	Advanced Driver Assistance Systems, Connected and Automated Vehicles
Crash Prevention & Safety-Work Zone Warning	Advanced Driver Assistance Systems, Connected and Automated Vehicles
Driver Assistance-Adaptive Cruise Control	Advanced Driver Assistance Systems, Connected and Automated Vehicles
Driver Assistance-Connected Eco-Driving	Advanced Driver Assistance Systems, Connected and Automated Vehicles
Driver Assistance-Driver Communication	Advanced Driver Assistance Systems, Connected and Automated Vehicles
Driver Assistance-Drowsy Driver Warning Systems	Advanced Driver Assistance Systems, Connected and Automated Vehicles
Driver Assistance-Intelligent Speed Control	Advanced Driver Assistance Systems, Connected and Automated Vehicles
Driver Assistance-In-Vehicle Monitoring	Advanced Driver Assistance Systems, Connected and Automated Vehicles

ARC-IT Taxonomy Combined Levels 2 and 3	AI-enabled application for ITS Categories (11 Unique Categories)
Driver Assistance-Lane Keeping Assistance	Advanced Driver Assistance Systems, Connected and Automated Vehicles
Driver Assistance-Navigation/Route Guidance	Advanced Driver Assistance Systems, Connected and Automated Vehicles
Driver Assistance-Object Detection	Advanced Driver Assistance Systems, Connected and Automated Vehicles
Driver Assistance-Platooning	Advanced Driver Assistance Systems, Connected and Automated Vehicles
Driver Assistance-Precision Docking	Advanced Driver Assistance Systems, Connected and Automated Vehicles
Driver Assistance-Roll Stability Control	Advanced Driver Assistance Systems, Connected and Automated Vehicles
Driver Assistance-Vision Enhancement	Advanced Driver Assistance Systems, Connected and Automated Vehicles
Electronic Payment & Pricing-Multi-use Payment	Traveler Decision Support Tools
Electronic Payment & Pricing-Parking Fee Payment	Traveler Decision Support Tools
Electronic Payment & Pricing-Pricing	Traveler Decision Support Tools
Electronic Payment & Pricing-Toll Collection	Traveler Decision Support Tools
Electronic Payment & Pricing-Transit Fare Payment	Traveler Decision Support Tools
Emergency Management-Emergency Medical Services	Emergency Management
Emergency Management-Hazardous Materials Management	Emergency Management
Emergency Management-Response & Recovery	Emergency Management
Freeway Management-Enforcement	Transportation Systems Management and Operations
Freeway Management-Information Dissemination	Transportation Systems Management and Operations
Freeway Management-Lane Management	Transportation Systems Management and Operations
Freeway Management-Ramp Control	Transportation Systems Management and Operations
Freeway Management-Special Event Transportation Management	Transportation Systems Management and Operations

ARC-IT Taxonomy Combined Levels 2 and 3	AI-enabled application for ITS Categories (11 Unique Categories)
Freeway Management-Surveillance	Transportation Systems Management and Operations
Information Management-Data Archive	Transportation Systems Management and Operations
Information Management-Multimodal Traveler Information Management	Transportation Systems Management and Operations
Information Management-Performance Management	Transportation Systems Management and Operations
Intermodal Freight-Asset Tracking	Commercial Vehicle and Freight Operations
Intermodal Freight-Drayage Operations	Commercial Vehicle and Freight Operations
Intermodal Freight-Freight Terminal Processes	Commercial Vehicle and Freight Operations
Intermodal Freight-Freight Tracking	Commercial Vehicle and Freight Operations
Intermodal Freight-Freight Travel Planning	Commercial Vehicle and Freight Operations
Intermodal Freight-Freight-Highway Connector System	Commercial Vehicle and Freight Operations
Intermodal Freight-International Border Crossing Processes	Commercial Vehicle and Freight Operations
Road Weather Management-Information Dissemination	Transportation Systems Management and Operations
Road Weather Management-Response & Treatment	Transportation Systems Management and Operations
Road Weather Management-Surveillance, Monitoring, & Prediction	Transportation Systems Management and Operations
Road Weather Management-Traffic Control	Transportation Systems Management and Operations
Roadway Operations & Maintenance-Asset Management	Asset Management and Roadway Construction and Maintenance
Roadway Operations & Maintenance-Information Dissemination	Asset Management and Roadway Construction and Maintenance
Roadway Operations & Maintenance-Work Zone Management	Asset Management and Roadway Construction and Maintenance
Roadway Operations & Maintenance	Asset Management and Roadway Construction and Maintenance
Traffic Incident Management-Clearance & Recovery	Transportation Systems Management and Operations
Traffic Incident Management-Information Dissemination	Transportation Systems Management and Operations
Traffic Incident Management-Mobilization & Response	Transportation Systems Management and Operations

ARC-IT Taxonomy Combined Levels 2 and 3	AI-enabled application for ITS Categories (11 Unique Categories)
Traffic Incident Management-Surveillance & Detection	Transportation Systems Management and Operations
Transit Management-Information Dissemination	Transit Operations and Management
Transit Management-Operations & Fleet Management	Transit Operations and Management
Transit Management-Safety & Security	Transit Operations and Management
Transit Management-Transportation Demand Management	Transit Operations and Management
Transportation Management Centers-Permanent TMCs	Transportation Systems Management and Operations
Transportation Management Centers-Temporary TMCs	Transportation Systems Management and Operations
Traveler Information-En Route Information	Traveler Decision Support Tools
Traveler Information-Multimodal Traveler Information	Traveler Decision Support Tools
Traveler Information-Pre-Trip Information	Traveler Decision Support Tools
Traveler Information-Tourism & Events	Traveler Decision Support Tools
N/A	Accessible Transportation
N/A	Cybersecurity
N/A	Air Traffic Control and Management
N/A	Remote Sensing

U.S. Department of Transportation
ITS Joint Program Office – HOIT
1200 New Jersey Avenue, SE
Washington, DC 20590

Toll-Free “Help Line” 866-367-7487

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