AI for Safety and Efficiency Program Roadmap

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Highway Research Center

FOREWORD

This roadmap defines the strategic framework for the Federal Highway Administration's Office of Safety and Operations Research and Development (HRSO) Artificial Intelligence (AI) for Safety and Efficiency program. As AI emerges as a transformative force in preventing crashes and reducing congestion, a Federal role is critical to a nationally coordinated research program to ensure these technologies are adopted with trust and accountability. The primary purpose of this document is to promote the integration of AI research activities, identify critical research gaps, and establish a foundational research and development (R&D) evidence base for the future of roadway transportation.

This report defines the program's vision, mission, goals, and objectives. The roadmap defines research and development activities for fiscal year (FY) 25–FY36 structured around a data and AI ecosystem. This ecosystem is organized into five primary research areas: virtual data environment (building an open-source data platform and data benchmarks to ensure accountability), AI assurance (focusing on AI model risks, standards, and evaluation protocols to ensure trustworthiness), engineering specialist AI (customizing AI models for large-scale congestion forecasting and optimizing connected multimodal systems), Agentic AI (integrating multiple AI components to develop advanced systems such as digital twins for complex safety and operations), and early deployment (deploying validated solutions, including mature sample datasets and trustworthy model references, for widespread stakeholder use).

A broad spectrum of transportation and technology stakeholders will find this report useful, including State departments of transportation (DOTs) and local agencies seeking scalable tools and evidence-based strategies for responsible AI deployment, industry vendors and developers that require open-source data benchmarks and model references to evaluate their technologies, academic researchers collaborating on filling mid-term and long-term research gaps in roadway smart mobility, and Operating Administrations in the U.S. DOT to ensure cross-modal coordination and prevent duplication of efforts.

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Director, Office of Safety and Operations
Research and Development

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This roadmap outlines the Federal Highway Administration Office of Safety and Operations' strategic framework for integrating trustworthy and accountable artificial intelligence (AI) into roadway safety and operations from fiscal year (FY) 25 to FY36. The roadmap establishes a comprehensive data and AI ecosystem built on five key research areas: virtual data environments, AI assurance, specialist AI for large-scale operations, multimodal optimization, and Agentic AI. By prioritizing stakeholder engagement and scalable pilot testing, the program aims to accelerate the responsible adoption of AI to reduce traffic crashes, optimize infrastructure, and enhance overall transportation efficiency. Ultimately, the roadmap serves as a national guide for developing open-source benchmarks and model references to ensure AI applications in roadways are reliable, ethical, and aligned with Federal safety standards.</td></tr>
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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
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mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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LIST OF ABBREVIATIONS

AAI	agentic AI
AI	artificial intelligence
AIA	AI assurance
AIO	AI for optimizing connected multimodal transportation systems
AIS	AI for large-scale safety and operations
AV	automated vehicle
CDA	cooperative driving automation
DI	digital infrastructure
DOT	department of transportation
FHWA	Federal Highway Administration
HRSO	Office of Safety and Operations
IOOs	infrastructure owner-operators
ITS JPO	Intelligent Transportation Systems Joint Program Office
POC	proof of concept
POP	period of project
R&D	research and development
TFHRC	Turner-Fairbank Highway Research Center
TMC	transportation management center
USDOT	U.S. Department of Transportation
VDE	virtual data environment
V2X	vehicle-to-everything

CHAPTER 1. INTRODUCTION

BACKGROUND

Artificial intelligence (AI) is emerging as a transformative force in advancing traffic safety and operations. Specifically, by enabling advanced data processing, predictive analytics, and adaptive decisionmaking, AI has great potential to empower transportation systems to prevent crashes, reduce congestion, and optimize the movement of people and goods.[1,2,3] For instance, AI applications used for traffic signal control, crash prediction, and cooperative driving automation (CDA) offer scalable and real-time, data-driven solutions to support safer and smarter mobility, demonstrating significant improvements in roadway transportation safety and efficiency.[4,5]

While many State departments of transportation (DOTs) and stakeholders are enthusiastic about the potential of AI, questions remain about AI's trustworthiness and accountability—including issues of reliability, explainability, interpretability, transferability, and resilience.[1,6] These mixed perspectives underscore the important Federal role of a nationally coordinated research program for assured and trustworthy AI applications to address safety and operation issues that impact the roadway transportation system, which is a critical infrastructure sector vital to the United States. Moreover, the U.S. DOT (USDOT) Intelligent Transportation Systems Joint Program Office (ITS JPO) and some State DOT offices~~, s~~ have developed or are developing roadmaps for AI applications with different scopes and priorities. Many AI related activities and projects have been initiated in the Federal Highway Administration (FHWA) Office of Safety and Operations Research and Development (HRSO), located at the Turner Fairbank Highway Research Center (TFHRC). In light of these initiatives, HRSO has developed this AI roadmap to promote the integration and coordination of AI research activities within HRSO and strengthen collaboration, with related efforts across FHWA and USDOT aiming to enhance the overall collective impact of these activities and prevent duplication of efforts.

This AI roadmap, motivated by these potential applications for AI in roadway transportation, seeks to assess current capabilities and stakeholder needs and define the vision, mission, and strategic goals set forward for an HRSO-led AI for Safety and Efficiency program. Such a program can serve as a unifying platform—enhancing coordination, driving innovation at scale, and amplifying impact. AI for Safety and Efficiency can consolidate current and future AI efforts within HRSO under a shared mission—ensuring synergy, resource optimization, and national impact. Furthermore, this program can help HRSO and FHWA proactively identify research gaps, avoid duplication, anticipate future challenges, and shape a safe and effective AI-enabled transportation future.

The development of this AI program is in alignment with Executive Order 14179, which states that it is the policy of the United States to sustain and enhance America's global AI dominance in order to promote human flourishing, economic competitiveness, and national security.[1] Additionally, this program is consistent with the Office of Management and Budget (OMB) memorandum, "Accelerating Federal Use of AI through Innovation, Governance, and Public Trust," of April 3, 2025.[7]

HRSO ROLES IN THE AI FOR SAFETY AND EFFICIENCY PROGRAM

While AI holds vast promise by enhancing real-time decisionmaking, reducing crashes, and increasing operational efficiency, its deployment also raises concerns about trustworthiness and system accountability.(7) These human factor concerns reflect an urgent need for Federal leadership to ensure that AI applications used for transportation systems are safe, beneficial, and ensure public trust across a range of user settings. Specifically, FHWA's roles in this evolving landscape include the following:

- Providing leadership and strategic direction: FHWA can define a cohesive vision and strategic framework for AI application research and development (R&D) in roadway transportation safety and operations, aligning distinctive efforts and stakeholders toward shared goals in safety and efficiency.

- Advancing trustworthy AI applications: FHWA can spearhead critical R&D initiatives focused on trustworthy AI technologies and responsible adoption, addressing traffic safety and operations-relevant challenges, such as model reliability, explainability, transferability, cybersecurity, and resilience uncertainty.

- Developing scalable tools and strategies for responsible deployment: FHWA is well positioned to produce scalable tools, data samples, model references, and potential evidence-based strategies that help State DOTs and local agencies deploy responsible AI solutions for safety and operations confidently and effectively.

- Facilitating collaboration and knowledge-sharing: FHWA can bridge gaps between academia, industry, and public agencies by serving as a neutral convener—enabling coordinated innovation, avoiding duplication, and converging efforts.

As the national leader in highway R&D, HRSO is uniquely positioned to bring AI applications to maturity and facilitate their responsible adoption into highway safety and operations. Aligning with FHWA's roles, this roadmap, dedicated to roadway safety and operations, will be built with the scope, benefits, and approach elaborated in the following sections.

Scope

The scope for the AI for Safety and Efficiency program is as follows:

- Develop rigorous evaluation procedures and standardized metrics that enable State DOTs to evaluate the trustworthiness of AI applications, ensuring DOTs remain resilient against data anomalies and align with safety and operational standards.

- Develop data samples and AI model references for State DOTs and industry vendors to evaluate AI models with consistent and transparent data, performance, and governance.

- Engineer AI approaches (assess technical feasibility, define functional boundaries, and customize models) in roadway transportation applications (prediction, decision, and generation) to establish a foundational R&D evidence base for filling midterm, long-term, and system-wide research gaps.

- Establish a data and AI ecosystem (as discussed in the section titled Roadmap Structure) to ensure the accountability and trustworthiness of AI-enhanced roadway traffic safety and efficiency solutions and further accelerate responsible adoption and workforce development (training, technology transfer, and stakeholder engagement).

Benefits

Potential benefits of the AI for Safety and Efficiency program include the following:

- Providing open-source data benchmarks, evaluation procedures, and metrics for State DOTs and industry vendors to test, evaluate, and validate AI applications beyond development datasets, supporting the reduction of roadway transportation fatalities and serious injuries and the safe integration of new entrants, such as automated vehicles (AVs).

- Providing open-source AI model references for critical use cases, enabling State DOTs and industry vendors to compare performance levels and deploy best-in-class solutions to strengthen safety and operations management across all modes.

- Increased accountability and trustworthiness of AI models with a combination of open-source data benchmarks and model references, supporting responsible adoption and accelerated project delivery.

Approach

The research activities identified in this HRSO roadmap will be coordinated within HRSO, FHWA, ITS JPO, and other USDOT entities. The initial activities in the HRSO roadmap will be focused on AI research that supports the mission of HRSO, transportation safety, and operations. However, the overall framework and ecosystem established in the roadmap may potentially support other transportation topics, other FHWA offices, and other transportation modes.

Vision

Roadway transportation safety and efficiency are maximized through trusted and responsible AI application.

Mission

Enable AI-empowered research, development, and assessment to enhance road transportation safety and efficiency and accelerate responsible AI deployment.

Goals

FHWA supports USDOT in striving to accomplish its four strategic goals: safety, infrastructure, innovation, and efficiency.[1] The goals of this roadmap are dedicated to improving traffic safety and efficiency in roadway transportation and were crafted accordingly, in alignment with Executive Order 14179 and the OMB memorandum of April 3, 2025 as well as AI for ITS JPO goals, cited in the Background section.[1,7] The goals are summarized as follows:

- Goal 1: Accelerate the adoption of responsible AI applications in Transportation Systems.
- Goal 2: Stimulate the innovation of large-scale AI applications for System-Wide Safety and Efficiency.
- Goal 3: Optimize the coordination of connected Multimodal Transportation Systems
- Goal 4: Enable the assessment of integrative Smart Transportation Safety and Operations.

Notably, AI is a strategic enabler of USDOT's long-term vision for safer, more efficient, and technologically advanced transportation systems. Therefore, each AI program goal contributes to multiple USDOT strategic priorities, including safety, infrastructure, innovation, and efficiency, offering unique value from interconnected perspectives.

Accordingly, the following sections present a holistic alignment of the AI program goals with these strategic areas, rather than a one-to-one mapping.

Safety

Accelerating responsible AI adoption targeted by Goal 1 can significantly enhance roadway transportation safety by enabling real-time hazard prediction, predictive maintenance, and proactive crash mitigation, improving responsive roadway traffic management; all of these benefits directly or indirectly support USDOT's top priority—safety. For example, AI-driven real-time analytics can detect anomalies and hotspots in highway transportation systems, triggering early interventions that prevent congestion and crashes from system views. Moreover, trustworthy, large-scale AI applications promoted by Goal 2 can help develop network traffic safety analysis, which can significantly and systematically reduce traffic crashes by setting human-factor-aware speed limits, prioritizing resource allocation to the areas with high return on investment, improving situational awareness, supporting smart and automated systems (e.g., CDA), and further enabling proactive and predictive traffic monitoring and maintenance to improve safety.

Infrastructure

Integrating responsible AI applications at scale across roadway transportation infrastructure systems, such as processing roadside sensor data and managing traffic signals, promoted by Goals 1 and 2, can improve network-wide roadway traffic mobility and efficiency, reducing travel and logistics costs. Moreover, by optimizing the coordination of roadway systems with other transportation modes—such as railways, ports, airports, and public transit—AI-driven solutions from Goals 3 and 4 can enhance overall transportation connectivity, streamlining port, rail, and highway operations, thereby improving port infrastructure performance and expanding access to transportation for small and rural communities. All these AI-driven innovations across roadway infrastructure systems will boost logistic optimization and supply chain integration and further economic productivity, contributing to U.S. economic strength and global competitiveness.

Innovation

Engineering AI technologies for roadway applications, driven by all four goals of the program, is an innovative technology that underpins the future of smart mobility, AVs, intelligent traffic management and operations, and infrastructure systems. Large-scale AI applications in roadway systems through Goals 2, 3, and 4 are central to transforming transportation systems into intelligent, adaptive, and connected multimodal networks that respond to real-time data and evolving demands for improved user experience and operational efficiency. AI application lays the foundation for advanced, integrated, and cooperative traffic management technologies in the future. For example, real-time roadway traffic operation data-sharing between buses, trains, and rideshare platforms enables dynamic trip planning and congestion avoidance, transforming how travelers interact with the transportation system and improving the adaptability of mobility. Goal 1 ensures these innovative AI technologies can be implemented with accountability and public trust.

Efficiency

All four goals of this AI program embrace innovation and accountability, aiming to collectively improve transportation system efficiency from different perspectives. Accelerating the adoption of responsible AI applications (Goal 1) and stimulating large-scale AI innovation (Goal 2) will ensure smarter roadway transportation management and operations to improve both local and network-wide traffic safety and efficiency through advanced predictive models and real-time analytics. Optimizing connected transportation systems (Goal 3) fosters seamless coordination across various roadway operations and management, reducing delays and improving access. Finally, enabling comprehensive assessments of integrative smart transportation safety and operations (Goal 4) provides data-driven insights to proactively address risks and streamline performance, creating a more reliable and efficient transportation ecosystem.

Objectives Within Goals

Each of the AI program goals can be further broken down into multiple objectives, guiding the research effort development.

Goal 1: Accelerate the adoption of responsible AI applications in Transportation Systems

Objectives include the following:

- Provide high-impact use cases to accelerate targeted AI innovations through stakeholder encouragement, emphasizing human-centered design and usability to ensure effective adoption by operators and end users.
- Provide guidance on data collection, documentation, access, maintenance, and governance.

- Provide open-source data and benchmark samples for high-impact use cases to ensure data quality, comparability, and accountability.

- Promote public trust through establishing AI assurance protocols, encompassing algorithm assurance design; risk and cybersecurity analysis; and testing, evaluation, validation, and verification standards. Prioritizing explainable and interpretable models helps ensure that AI systems are both transparent and reliable.

- Publish AI model references for high-impact applications, based on data benchmarks and AI assurance protocols, to increase AI applications' trustworthiness.

- Support continuous learning mechanisms for AI models and post-deployment audits to ensure models meet evolving needs, including human factors considerations.

Goal 2: Stimulate the innovation of large-scale AI applications for System-Wide Safety and Efficiency

Objectives include the following:

- Stimulate system-wide AI applications, ensuring system benefits in safety and efficiency for moving people and goods across multimodal transportation systems.

- Stimulate large-scale AI applications, involving distributed AI and edge computing for real-time decisionmaking in highly dynamic traffic situations.

- Promote AI models' transferability and generalizability across regions and use cases.

- Promote public–private partnerships to leverage industry advances and accelerate deployment.

Goal 3: Optimize the coordination of connected Multimodal Transportation Systems

Objectives include the following:

- Integrate AI into advanced driver assistance systems to enhance vehicle and infrastructure cooperative traffic safety and operations, aiming to optimizing traffic flow.

- Integrate AI into automated driving systems to promote CDA and engaged traffic operations.

- Integrate AI into interdependent safety and operation optimization in multimodal transportation systems.

- Encourage cross-mode data sharing to enable holistic, system-wide AI solutions.

Goal 4: Enable the assessment of integrative Smart Transportation Safety and Operations

Objectives include the following:

- Enable the assessment of AI-enhanced transportation management center (TMC) functions for real-time and proactive traffic management and coordination using digital twins.

- Enable the assessment of multimodal transportation system optimization.

- Enable the assessment of AI-empowered traffic operations and safety with smart AV fleets.

- Enable the assessment of integrated traffic operations and infrastructure management.

- Enable the assessment of interdependent urban planning design and traffic operations.

CHAPTER 2. AI FOR SAFETY AND EFFICIENCY PROGRAM ROADMAP FOR FISCAL YEARS (FY) 2025–2036

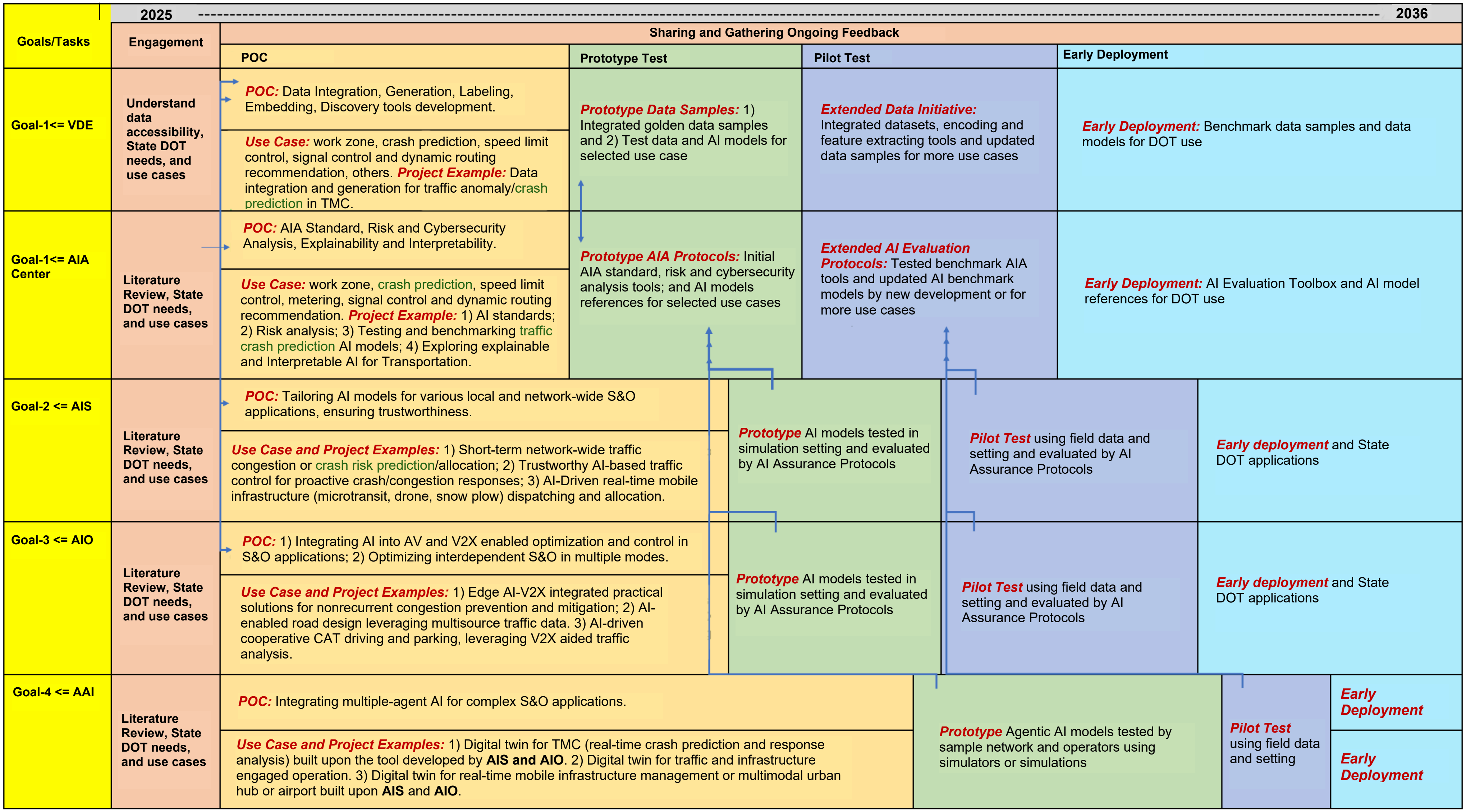
The need for the AI for Safety and Efficiency Program for traffic safety and operations and its purpose (including vision, mission, goals, and tasks) are presented in chapter 1. This section explains the work to be performed from FY25 to FY36 to achieve the program purpose.

ROADMAP AND ACTIVITIES

Figure 1 provides a visual representation of the roadmap and activities. Note that figure 1 does not specify years. Many of the research activities can be conducted in parallel. In addition, figure 1 only provides some project examples. AI as a tool can be used for broad, interdependent projects in areas that include, but are not limited to, AMS (analysis, modeling, and simulation); CDA; and vehicle-to-everything (V2X).

ROADMAP STRUCTURE

The HRSO AI program roadmap is organized as a matrix, with rows representing key research areas and columns outlining progressive effort tracks. This structure systematically supports the R&D and deployment of AI technologies for transportation safety and operational applications, ensuring a clear path from ideation to implementation. The research areas are closely aligned with program goals and objectives and interconnected, collectively advancing the program's mission. The following sections provide a detailed overview of the roadmap's structure, highlighting its research areas, effort tracks, and interrelationships.



Source FHWA.

AAI = agentic AI; AIA = AI assurance; AIO = AI for optimizing connected multimodal transportation systems; AIS = AI for large-scale safety and operations; CAT = connected autonomous track; POC = proof of concept; S&O = safety and operations; VDE = virtual data environment.

Figure 1. Diagram. AI for Safety and Efficiency program sample activities FY 2025–2036.

Research Areas (Rows)

The roadmap is divided into five primary research areas, each targeting a critical program goal and executing its corresponding objectives. These research areas combine to form the data and AI ecosystem shown in figure 2, which ensures AI applications' trustworthiness and accountability, paving the way for responsible adoptions. Each of the following research areas is associated with specific use cases and project examples, such as work zone management, crash prediction, signal control, and AI-driven, real-time infrastructure dispatching, ensuring practical applicability to transportation challenges:

- **Virtual Data Environment (VDE)—**This research area aligns with Goal 1 of the AI program, aiming to accelerate responsible AI adoption from a data perspective. The research focuses on building an open-source data platform to support AI applications in roadway transportation safety and operations. The emphasis is on developing enabling technologies for data discovery, integration, generation, training data preparation, and benchmarking to enhance AI applications in roadway safety and operations. Along with this goal, this research area will generate needs for data collection and strategies for documentation, sharing, and maintenance. The ultimate objective is to develop data-centric AI tools, which create well-documented and curated golden data samples (highly curated benchmark datasets that serve as accountable benchmarks) to enable accountability of AI-driven solutions for high-impact use cases in roadway transportation systems.

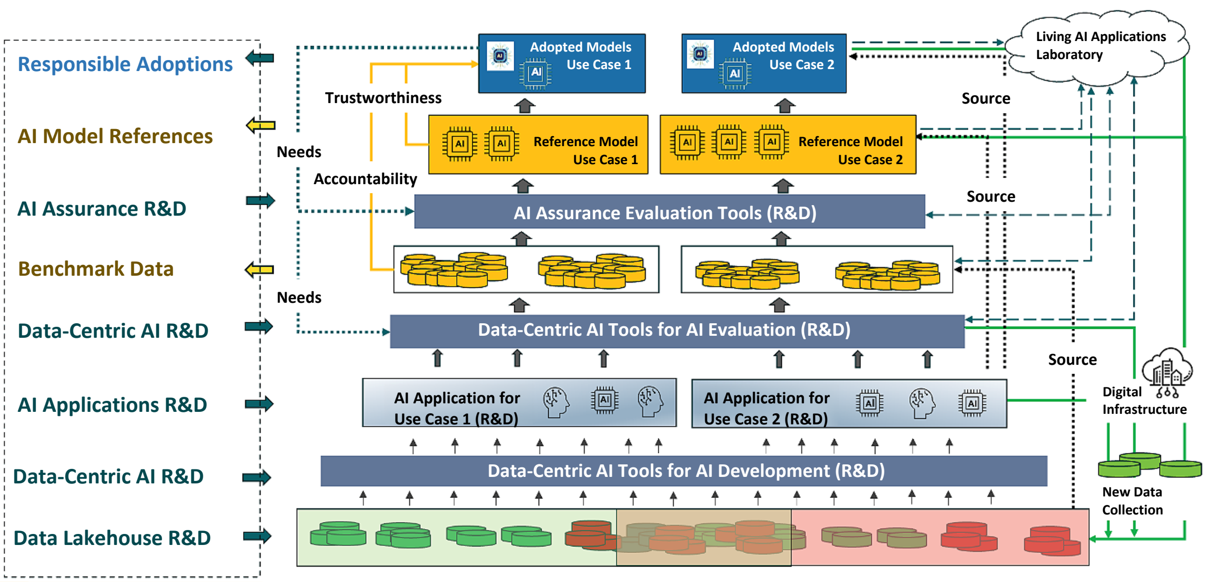
- **AI Assurance (AIA)—**This research area supports Goal 1 of the program: focusing on accelerating the adoption of trustworthy AI through a model-centric approach. AIA research centers on designing robust algorithms, quantifying model risks and establishing AIA standards and evaluation tools to ensure trustworthy features, such as interpretability, explainability, and reliability throughout the AI lifecycle in applications. The R&D activities seek to establish AIA evaluation protocols, risk analysis tools, and AI model references tailored to use cases, ensuring safe and trustworthy AI deployment.

- **Engineering Specialist: AI for Large-Scale Safety and Operations (AIS)—**This research area advances Goal 2 of the program by engineering and customizing AI models for scaling up their applications in transportation systems and operations, prioritizing scalability and transferability. AIS research targets network-wide applications, including precise congestion forecasting, dynamic crash risk assessment, and real-time traffic management and analysis, to drive efficient and reliable transportation solutions with system benefits.

- **Engineering Specialist: AI for Optimizing Connected Multimodal Transportation Systems (AIO)**—This research area supports Goal 3 of the program by advancing the integration of AI into AVs, V2X systems, and shared mobility, representing cutting-edge vehicle technology to optimize multimodal roadway transportation operations. AIO research focuses on enhancing roadway safety and efficiency through coordinated operations across various transportation modes.

- **Agentic AI (AAI)**—This research area directly supports Goal 4 of the program by integrating multiple AI components to develop advanced systems for complex safety and operations. AAI research focuses on creating digital twins and multiagent-based AI models to enable adaptive crash response, optimized truck string operations, and real-time multimodal transit management. The goal is to enable multiple trustworthy AI models to work collaboratively, competitively, or independently to achieve improved traffic safety and efficiency under various conditions.

Data and AI Ecosystem



Source FHWA.

Figure 2. Diagram. Data and AI ecosystem.

Notably, the research areas start with VDE, AIA, AIS, and AIO to develop specialist AI, focusing on a specific or single task, such as speed prediction, and then further extending to agentic AI involving multiple specialist AI agents with highly complex and autonomous functions. The VDE and AIA aim to benchmark data samples and AI models for different use cases; meanwhile, AIS, AIO, AIA, and AAI concentrate on developing a domain-specific AI foundation for use cases and their adoption in roadway transportation.

Specifically, the data-centric AI research under VDE begins with developing innovative automated tools that are designed to discover, clean, and process the vast, heterogeneous datasets collected from sensing and digital infrastructure (DI). These tools help ensure that high-quality data are ready for AI applications and enable seamless data sharing and reuse across correlated use cases. This foundational capability is vital given that the sheer scale and diversity of transportation data render manual discovery and preprocessing impractical.

Building on the data foundation, data-centric AI research next focuses on training data development—including labeling, encoding, transforming, and embedding technologies—and further extends to inference data development, such as data augmentation, strategic sampling, synthetic data generation, etc. This research facilitates the preparation and assurance of high quality training data for AI modeling for use cases and further evaluation for ensuring trustworthiness, addressing the unique challenges posed by high-dimensional and multimodal inputs.[(-8,9)] For instance, traffic data sourced from DI—such as cameras, Global Positioning Systems, and Internet of Things devices—encompass diverse text and digital formats. This variety benefits from customized processing and embedding technologies, which harmonize disparate data streams for integration into various AI models across different transportation applications. Another example is traffic crash (risk) prediction. This AI application often meets a data imbalance issue in both model development and evaluation. Datacentric AI tools such as data augmentation, synthetic data generation, and reinforcement aided labeling are critical tools to address these issues.--

This data-centric AI research mentioned in the preceding paragraph will use advanced AI techniques, such as representation learning and automated labeling, to address the new challenges raised by AI applications R&D, even though traditional data mining and database technologies may help to a certain extent. Overall, these data-centric tools should act as automated engines, retrieving and delivering this “data fuel” to the domain-specific AI model development in AIS, AIO, and AAI. Meanwhile, the efforts of AIS, AIO, and AAI will concentrate on developing domain-specific AI models for transportation applications by embedding domain knowledge into data encoding, model selection, and framework development. Concurrently, as the data foundation and AI application R&D evolve, they will generate the raw material necessary to construct data benchmarks (i.e., golden data samples). Combining these golden samples with the assurance frameworks developed in parallel by AIA enables the creation of AI model references for high impact use cases. These references serve as standard benchmarks, against which newly developed models can be evaluated for performance, safety, and reliability. Golden data samples and AI model references will be published by FHWA and USDOT.-

Third-party developers, such as private companies, may submit their models for evaluation and future improvement to a certification agency (if established in the future) following the AIA developed evaluation protocols. Collectively, the certified golden data samples and AI model references will form the backbone to ensure trustworthiness and accountability, thereby accelerating responsible adoptions of those AI applications. More importantly, those efforts of AIO, AIS, and AIA serve as an external catalyst, driving innovation in data, assurance, and model references in the ecosystem. This foundation forms a transparent and trustworthy data and AI ecosystem for fostering innovation and accelerating responsible AI applications for enhancing the safety and efficiency of multimodal transportation.

Notably, the R&D areas shown in figure 2 follow three iterative cycles, each integrating dynamic and feedback elements into the system to enhance functionality continuously. First, the golden data samples from VDE and the model references from AIA establish accountability and trustworthiness, supporting the adoption of AI for specific use cases. Conversely, practical adoption provides feedback and identifies needs that help refine these golden datasets and model benchmarks, creating a mechanism of mutual improvement. (See the dotted blue and solid yellow lines in figure 2.) Next, the AI model development and benchmarking activities across the research areas of AIA, AIS, AIO, and AAI generate feedback for DI, guiding new data collection efforts. This progress, in turn, enriches the data sources that support future benchmarking of data and models and ongoing AI model development and adoption. (See the green solid lines in figure 2.) Last, the R&D efforts across VDE, AIA, AIS, AIO, and AAI—together with field testing and real-world adoption—inform both software and hardware development, ultimately shaping a living AI application laboratory. These collective efforts, reinforced by the interactive iterative cycles, aim to establish and nurture the data and AI ecosystem illustrated in figure 2. This ecosystem enables trustworthy and accountable AI R&D and evaluation, thereby accelerating responsible adoption.

Effort Tracks (Columns)

The columns in figure 1 represent five progressive effort tracks that outline the development lifecycle of each research area, described as follows:

- **Stakeholder Engagement—**This initial phase plans various efforts, including developing AI technical working groups within FHWA and with professionals from USDOT, State DOTs, industry, and academia. These groups form an early deployer cohort to capture lessons and obtain insights from infrastructure owner-operators (IOOs), such as State DOTs, Metropolitan Planning Organizations, and toll authorities, participating in domestic and international conferences, symposiums, and workshops and aiming to identify research needs and high impact use cases for all research areas.

  Fostering stakeholder engagement through these working groups will help FHWA identify data collection and AI method requests and recognize edge cases that may be underrepresented in the existing data and need special attention. Moreover, the stakeholder engagement will continuously share the findings and results throughout all phases of the lifecycle to gather ongoing feedback. This continuous sharing allows for mutual learning and ensures that parallel progress being made by other community members can inform and be informed by HRSO's AI research.

- **Proof of Concept (POC)—**This phase focuses on establishing foundational concepts and testing technical feasibility. POC activities may include developing preliminary standards, models, and tools and identifying high impact use cases. For example, the effort to develop a VDE involves exploring data integration and generation, feature discovery, and embedding tools; meanwhile, the studies for establishing AIA research will define testing, evaluation, verification, and validation processes for assessing selected AI models.

- **Prototype Test—**This phase builds on POC by developing and testing prototypes in controlled settings, such as simulations, or in selected existing use cases. For instance, VDE development efforts will build initial golden sample datasets for selected use cases to evaluate the corresponding AI models developed by different agencies, aiming to understand their capacities and limitations. Then, AIA will test candidate AI models and recommend initial references. Meanwhile, AIS and AIO research may initially test new use cases, such as traffic signal control, crash risk prediction, or multimodal coordinated traffic operations, in simulated or local settings to validate their performance, providing the sources for future golden sample datasets and model references. As task-specific breakthroughs are made, AAI, such as digital twins, will start to be built, and effective interactions between multiagent systems will need to be accessed to ensure complex series of events are reliably handled with transparent roadway decisionmaking.

- **Pilot Test—**This phase involves testing prototypes of AI applications with real-world field data and settings to assess their practicality and effectiveness in selected DOTs. Meanwhile, the VDE and AIA research should demonstrate and accumulate the applications of golden data samples and AI model references for more use cases. For example, the endeavor to enable AIO will test AI models for cooperative driving and traffic operation strategies in real-world traffic intersection scenarios, ensuring they perform reliably under various operational conditions. AIA protocols and sample datasets should be applied to ensure trustworthiness and accountability if available. The pilot test will also align with workforce development activities that address the needs of State DOTs and local agency professionals. For example, the implementation and testing phases will provide firsthand experience and understanding the capabilities of AI applications.

- **Early Deployment—**The final phase focuses on deploying validated solutions for use by State DOT and other stakeholders. This process includes deploying more mature sample datasets, AIA evaluation toolboxes, and trustworthy AI model references and applications for widespread adoption by State DOT or industry stakeholders working on transportation systems.

Interconnections and Progression

The rows of the roadmap structure in figure 1 and the ecosystem in figure 2 integrate interdependent R&D activities to achieve program goals. While each research area primarily targets a specific goal, the goals mutually reinforce and collectively contribute to all goals and objectives of the roadmap. For example, the development of the VDE effort facilitates the discovery and preparation of high-quality data. This effort provides benchmark samples to train and evaluate AI models developed for large-scale applications and multimodal transportation optimization in the areas of AIS, AIO and AAI. Simultaneously, the AIA research conducts AI standard evaluation analysis and establishes evaluation protocols and references to support AI model comparison and maturity. Together, these VDE and AIA efforts accelerate the development and deployment of responsible AI within AIS, AIO and AAI. This development and deployment, in turn, will generate new data acquisition needs for AI at State DOTs or traffic operators, while providing AI model examples for establishing data benchmarks and AI model references. Last, those trustworthy specialist AI agents enable complex Agentic AI for advanced, integrative, and smart safety and operations.

The columns of the roadmap structure in figure 1 ensure logical progression across effort tracks for each research area, fostering iterative development and refinement. The stakeholder engagement activities, listed at the start and continuing throughout all phases of the lifecycle, complement technical progression by fostering collaboration and knowledge-sharing. The planned activities, such as building the TFHRC AI technical group, forming an early deployer cohort, participating in conferences, and identifying high-impact use cases, ensure that the roadmap remains aligned with industry and IOOs needs and global advancements. For example, early engagement with stakeholders can help identify relevant use cases and data needs and enable better alignment with State DOT data collection efforts, enhancing the available data resources for VDE development.

Additionally, the VDE's POC work on data-centric AI for data discovering, training, and inference data development directly informs the prototype development of golden data samples and AI model references, which are then extended and tested by the use cases of other research areas in the pilot phase before being deployed for State DOT use. Similarly, the AAI research area builds on foundational and tested work from other areas, integrating multiple, trustworthy AI components (e.g., the integration of network traffic crash risk prediction and coordinated signal control) to create complex digital twins for advanced applications. Moreover, the prototype or pilot-tested datasets and AI models will enrich the VDE and AIA protocols for benchmarking and reference publications.

Use Cases and Project Examples

Each research area in the roadmap is supported by specific use cases and project examples to demonstrate practical applications. Crash prediction serves as a unifying example across all five research areas, illustrating their integration and progression; meanwhile, additional use cases highlight the broad applicability of each area. For example, the AIA area includes projects, such as AI risk analysis and benchmarking for traffic crash prediction models, whereas the AAI area explores digital twins for adaptive crash response and real-time microtransit management. These examples together show how the roadmap transforms theoretical advancements into practical solutions for transportation challenges, including work zone safety, crash prediction, and dynamic routing. Moreover, each research area will incorporate human factors whenever applicable to make AI-empowered solutions, such as predictions and operations, interpretable, trustworthy, and actionable for operators and planners. Specifically, accounting for driver behavior variability in AI-assisted predictions and operations ensures models support safe, effective decisionmaking.

PROJECTS FOR FY25–FY36

The following section provides a high-level overview of the currently planned key projects to be started before the end of FY32 in each goal area.

Ongoing FY25 Projects

Goal 1

Title: Data Generation and Integration to Support Trustworthy AI Applications in a Traffic Management Center—Phase I: Traffic Anomaly Prediction Use Case

Period of Project (POP): Fall, 2025–Summer, 2027

Description: This project will develop integrated datasets with a wide spectrum of data quality, such as temporal-spatial coverage, designated to evaluate selected AI use cases under different data quality conditions, enabling trustworthy AI development and accelerating AI's adoption in transportation. The project tasks include collecting, generating, processing, and integrating datasets from various available sources; developing innovative methods to encode and fuse the data in ways that enhance the AI model's ability to learn from complex, multisource information; and feeding the prepared data into an AI model designed for a targeted use case and rigorously testing its performance under varied conditions. The methodologies developed and results will contribute to best practices in a data ecosystem for AI technology applications in transportation, setting a foundation for future AI R&D.

Goal 1

Title: AIA Standards: Quantitative and Qualitative Approaches

POP: Fall, 2024–Spring, 2027

Description: The purpose of this report is to define how quantitative and qualitative approaches can be used to test and evaluate AI systems in the ITS domain. Specifically, it aims to explain the roles of quantitative (metric-driven and objective) and qualitative (surveys, focus groups, and interviews) methods in assessing AI systems' performance; demonstrate how these approaches map to trustworthiness attributes (e.g., safety and security); and show how to integrate these approaches across the lifecycle of AI system development, from concept through decommissioning, within a systems engineering paradigm. This process also ensures a smooth integration of multiple deliverables from this project and similar projects at the ITS JPO.

FY 2026–2036 Projects (To Be Determined)

Subsequent versions of this document will include more details about projects planned for FY26 -FY36.

GLOSSARY

Agentic AI: A class of AI that focuses on autonomous systems that can make decisions and perform tasks without or with limited human supervision.[10,11] Refers to an advanced type of AI agent capable of autonomous, proactive, and goal-directed behavior in complex, dynamic settings, such as AVs and AI-enhanced TMCs. (Multiagent AI systems are a type of agentic AI.)

AI accountability: A trustworthiness pillar; maintains clear lines of responsibility and keeps decision processes visible.[12]

AI assurance: Refers to the processes, frameworks, and methodologies used to ensure that AI systems are safe, reliable, trustworthy, and aligned with ethical, legal, and technical standards throughout lifecycles.[13]

Data-centric AI: The discipline of systematically engineering the data used to build an AI system involves tasks and methods for building effective training data, designing proper inference data, and maintaining the data. Emphasizes curating, cleaning, labeling, and augmenting datasets to enhance AI model accuracy, robustness, and fairness (Zha et al.).[14]

Key trustworthiness pillars: Safe, secure, and resilient; privacy-enhanced, fair, explainable, and interpretable; accountable and transparent; valid and reliable.[12]

Responsible AI: Development of AI systems focusing on ethics, fairness, privacy, transparency, and system performance.[12]

Task-specific or specialist AI: AI applications designed and trained to excel at a specific, narrow task or within a particular domain, such as speed prediction.

Trustworthy AI system: An AI system that consistently meets stakeholder expectations for safety, security, privacy, fairness, and reliability and remains transparent and accountable.[12]

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