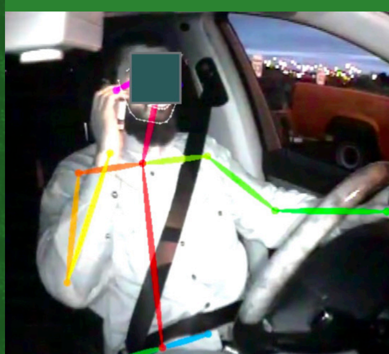
EXPLORATORY ADVANCED **RESEARCH**

Exploratory Advanced Research Program

The Role of Artificial Intelligence and Machine Learning



in Federally Supported Surface Transportation

2024 Updates

U.S. Department of Transportation
Federal Highway Administration

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Introduction

When people hear the phrase "artificial intelligence" (AI), they might think of computers that sort through large amounts of data to find and summarize useful information. People also may think about robots that can perform tasks in manufacturing or medical facilities. The same underlying algorithms that drive these examples also create the potential to positively impact our Nation's transportation system. Highlights include the following:

- Improving traffic flows at signalized intersections along specific routes or as part of integrated corridor management.
- Aiding traffic management centers by improving crash detection, predicting traffic slowdowns, and recommending detours.
- Facilitating traffic safety by warning vehicles of pedestrians who are obscured by parked vehicles and starting to cross the street and by monitoring real-time traffic and weather conditions.
- Allowing traffic engineers and urban planners to better understand what variables may reduce the potential for traffic crashes or injuries.
- Reducing highway infrastructure repair and reconstruction costs by augmenting data from the inspection and monitoring of highway assets.

What Is AI?

- Any artificial system that performs tasks under varying and unpredictable circumstances without significant human oversight or that can learn from experience and improve performance when exposed to datasets.
- An artificial system developed in computer software, physical hardware, or other context that solves tasks requiring human-like perception, cognition, planning, learning, communication, or physical action.
- An artificial system designed to think or act like a human, including cognitive architectures and neural networks.
- A set of techniques, including machine learning, that is designed to approximate a cognitive task.
- An artificial system designed to act rationally, including an intelligent software agent or embodied robot that achieves goals using perception, planning, reasoning, learning, communicating, decisionmaking, and acting.(1)

The U.S. Department of Transportation (USDOT) has prioritized developing technologies that promote traffic safety and improve mobility for all travelers. Supporting that USDOT priority, the Exploratory Advanced Research (EAR) Program of the Federal Highway Administration (FHWA) explores the development of AI and machine-learning technology within the surface transportation sector. By working with universities, private companies, and public entities conducting cutting-edge research in these fields, FHWA ultimately seeks to make surface transportation safer and more efficient.

Efforts to increase the use of AI and machine learning in federally supported surface transportation research are part of wider plans to develop and refine the Federal Government's role in developing technologies related to AI and machine learning. Since the AI research and development (R&D) landscape includes not only the Federal Government but also nonprofits and private-sector industries, clarifying how the Federal Government should invest in R&D is necessary. To that end, the Select Committee on AI of the National Science and Technology Council published an update of the *National Artificial Intelligence Research and Development Strategic Plan* and the *2016–2019 Progress Report: Advancing Artificial Intelligence R&D* in 2019.(2,3) The plan outlined how Federal Government agencies should prioritize Federally funded AI R&D, providing a framework for them to address long-term challenges while also acknowledging individual agencies' budgets, capabilities, and missions.

In 2023, this committee published another report, *National Artificial Intelligence Research and Development Strategic Plan 2023 Update*, that reaffirmed its previous plan and added an international collaboration element to AI research.(4) The National Science and Technology Council's 2024 report, *2020–2024 Progress Report: Advancing Trustworthy Artificial Intelligence Research and Development*, further demonstrates Federal agencies' commitment to national AI initiatives.(5) The Federal Government will continue to revise its plans on how to support R&D efforts for AI and machine learning as discoveries in both the public and the private sectors advance what technologies are available.

© Virginia Tech Transportation Institute.
Computer vision can annotate secondary behaviors inside the vehicle, extravehicular context, and interactions between the driver and the environment.(6)

EAR Program’s Involvement in R&D for AI and Machine Learning

By supporting long-term research that might not have immediate or clear benefits for private industry, EAR Program investments help realize the *National Artificial Intelligence Research and Development Strategic Plan*.[(2)] EAR Program-sponsored research demonstrates how AI and machine learning can enhance the safety and reliability of the Nation’s highway system. In particular, AI and machine-learning techniques have demonstrated their benefits to surface transportation in three main areas:

- Leveraging big data (processing large amounts of traffic data to spot trends and identify relationships between disparate data streams).
- Developing video analytics research (analyzing video data to determine driver behavior in various traffic scenarios).
- Generating synthetic data to advance efforts to analyze rare or hard-to-capture occurrences that are critical for ensuring system safety.

Researchers are training neural networks to detect traffic signals and signal states.[(6)]

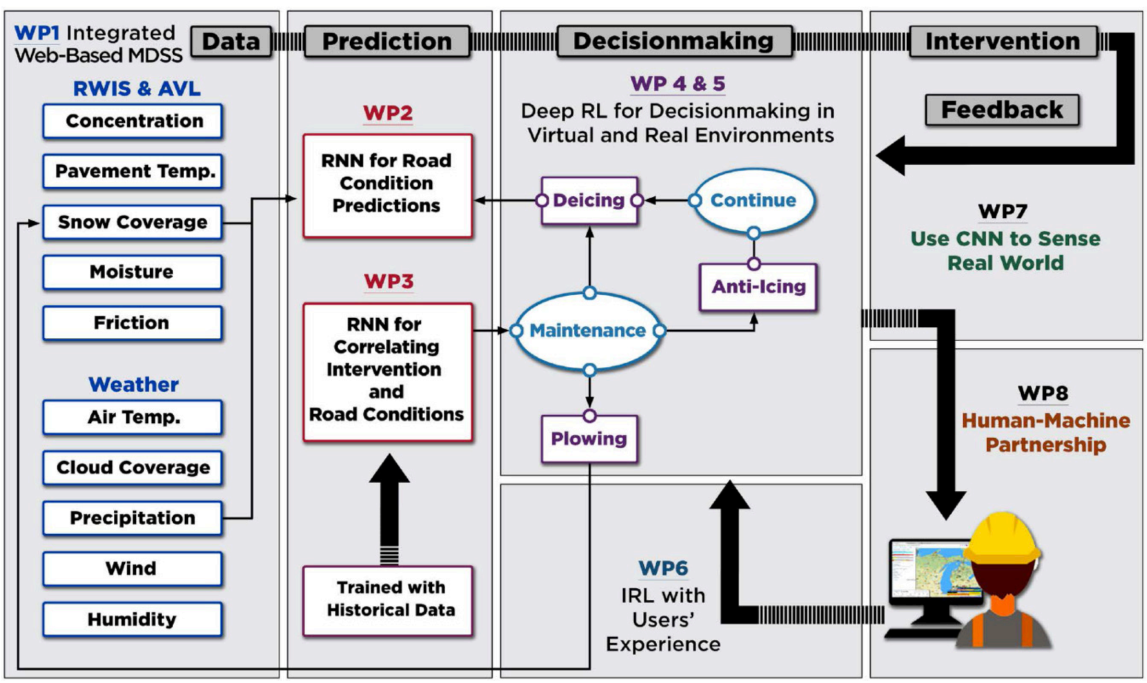
Making Sense of Big Data

In the area of data collection and analysis, FHWA's EAR Program has supported research projects that take advantage of new, large amounts of data that come from a range of sources including roadside cameras, Global Positioning System (GPS) and other mobile sensors on vehicles, improved wireless communication networks, and faster computer processing. These research projects seek to process massive amounts of transportation-related data—sometimes referred to as big data—from structured, semistructured, and unstructured datasets.[7]

Current EAR Program-Supported Research Projects

Despite decades of research, mitigating traffic congestion due to nonrecurring causes, such as crashes, disabled vehicles, and adverse weather events, remains quite difficult for highway system operations practitioners. This work requires an automated process of accurate, real-time prediction and proactive operational management that currently does not exist. Researchers from Carnegie Mellon University and the University of Washington Seattle, in their project **Predictive Real-Time Traffic Management in Large-Scale Networks Using Model-Based Artificial Intelligence**, aim to address this issue.[8] The project seeks to fuse prediction strategies—based on AI and machine learning guided by transportation network flow models—with operational strategies. The researchers want to predict nonrecurrent traffic conditions in large-scale networks up to 30 minutes ahead of the earliest time an incident is reported and proactively recommend real-time operational management strategies.

At the Michigan Technological University, the research project **Autonomous Winter Road Maintenance Decision Making Enabled by Boosting Existing Transportation Data Infrastructure with Deep and Reinforcement Learning** aims to boost the current model-driven winter maintenance with an AI-enhanced framework in which data can be analyzed in realtime for autonomous decisionmaking.[9] Such decisionmaking ability can be improved continuously as more data is obtained. For this purpose, the researchers will use recurrent neural networks to obtain a data-driven environment (i.e., road conditions) prediction ability; deep reinforced learning will be employed to reach an autonomous decisionmaking ability; and convolutional neural networks (CNN) will be investigated for accurate and real-time road condition sensing.



Overview of the autonomous winter road maintenance project, forming a closed-loop approach.[9]

Completed EAR Program-Supported Research Projects

Existing highway incident detection technologies fail to use available footage from traffic cameras installed on the highways. On the other hand, monitoring and analyzing the overwhelming quantity of camera data without assistive automated methods is intractable. Using AI, models can be trained to enhance images and provide robust detection and classification of traffic incidents, resulting in more cost-effective deployment of incident response resources.

The research project **Cooperative Perception and Control for Freeway Traffic System Operations** aimed to develop next-generation traffic system management and operations solutions for freeway systems based on cooperative driving automation.(10) The proposed solution concerned both cooperative perception (i.e., estimation and prediction using heterogeneous sources of data based on machine learning and filtering methods) and cooperative control (i.e., advanced AI algorithms customized for vehicle- and infrastructure-level control—cooperative merge, platooning, and speed harmonization). The project, conducted at the University of Cincinnati, focused on computational applications that could substantially increase freeway system safety and mobility. This study aimed to fulfill two objectives:

- Integrate traditional and nontraditional highway data to better explain and predict system performance.
- Provide decision support to experts in the design, operation, or management of highway systems.

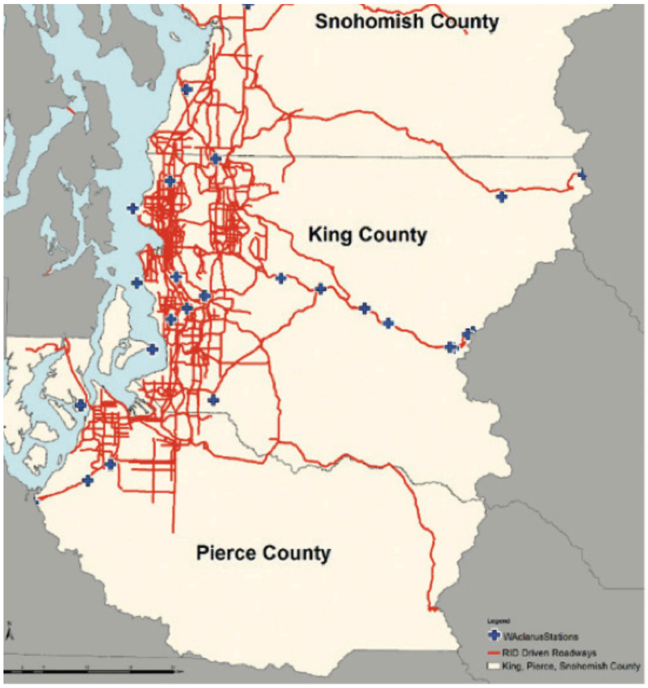
In a project designed to support State departments of transportation (DOTs), **Automated Environmental Data Analysis and Management for State DOTs**, researchers at the Road Ecology Center at the University of California, Davis used AI processes to analyze and detect animals in images.(12) The researchers maintained and improved upon a Web-based system for managing camera trap images, developed tools to determine if multiple images were of the same animal or group of animals, analyzed animal behavior using a video tagging tool, and worked with State DOT and natural resources agency staff to teach them how to use the tools and make sure the tools met their needs.(12) Camera traps are critical for monitoring animal behavior near roadways to improve highway safety and protect wildlife. Automating processes for sorting through camera trap images, identifying species, and processing the images results in reduced costs for State DOTs while increasing environmental surveillance. The tools the researchers developed to improve interactions between wildlife and highways could also address other environmental assessment and management needs.(12)

Source: FHWA.
Transportation systems management and operations testing scenarios. The arrows show the intended path of travel for each vehicle optimizing its approach to the intersection.(11)

© U.C. Davis Road Ecology Center.
Transportation systems management and operations testing Camera-trap image of two deer in a wildlife crossing.(13)

Researchers at the Palo Alto Research Center (PARC) developed automated methods to integrate information from large unrelated datasets. In their project, titled **Merging Information from Disparate Sources to Enhance Traffic Safety**, the PARC research team established machine-learning tools to process data from several datasets.(14) The team incorporated data from the second Strategic Highway Research Program's (SHRP2) Naturalistic Driving Study (NDS), which provided trip summary records of more than 36,000 baseline driving events, and another dataset with information describing the physical characteristics of the most frequently traveled roadway sections.(15) The PARC researchers also processed data from additional datasets, including weather data and video logs from Clarus roadway as well as video, radar, and photos from Chicago intersections. The machine-learning tools developed from processing and analyzing these datasets together enabled researchers to detect safety issues that might not have been readily spotted otherwise.(14)

CUBRC's project researchers developed a layered infrastructure to ingest, store, analyze, and display information. In their project titled **Knowledge Discovery in Massive Transportation Datasets**, the researchers produced the Transportation Research Informatics Platform (TRIP), a dashboard that provides users with a way to see streaming data and historical data of traffic in Seattle, WA.(14) The data included crashes, traffic volumes, roadway characteristics, weather and roadway surface conditions, work zones, and traffic laws.



An illustration of the study area being examined in TRIP, including 4,277 miles of centerline data and 27 roadway weather information stations.(13)

Using Video Analytics To Analyze Traffic Safety

In line with its promotion of real-time traffic safety research, the EAR Program has supported studies on new methods that use video analytics to establish baselines for evaluating high-risk driving behavior. Essential to this work has been the analysis of the SHRP2 NDS video database.(15) This database, consisting of 1.2 million hours of video collected from the vehicles of approximately 3,000 volunteers, has become the focus of much driver-safety research. Researchers from multiple universities and organizations have been developing machine-learning tools to process the vast amount of video available in the SHRP2 NDS data. By analyzing the NDS data, researchers hope to understand the correlations among driver behavior, road design, traffic, and other factors.

Current EAR Program-Supported Research Project

At Oak Ridge National Laboratory, in the **Research Standards and Technical Assessment Support** study, researchers developed calibration and measurement techniques to help the broader community of researchers wanting to work with NDS data.(16) Their techniques enabled benchmarking progress and technical assessment of EAR Program-sponsored research teams.

Completed EAR Program-Supported Research Projects

For the project **Traffic Incident Detection and Analysis System**, researchers at Tufts University and the City College of New York leveraged AI to improve the detection of highway incidents.(17) In this study, researchers created a novel framework using AI and image-processing algorithms. The framework aimed to exploit the potential of currently installed highway camera infrastructures for incident detection, including spotting wrong-way driving, crashes, hazardous objects in the roadway, and bicyclists or pedestrians in tunnels. One drawback of existing highway incident detection technologies is their scalability. Monitoring and analyzing the overwhelming quantity of camera data without assistive automated methods is challenging. Using AI, models can be trained to enhance images and provide robust detection and classification of traffic incidents, resulting in more cost-effective deployment of incident-response resources. This research project focused on overcoming challenges, including the following:

- The lack of a robust automatic incident detection system capable of emphasizing key events with minimal false alarms.
- The problems inherent in current learning algorithms, which significantly degrade in performance under adverse weather conditions.
- The unavailability of a dataset with diverse footage of highway incidents to foster the development and validation of AI algorithms.

In the project **SHRP2 NDS Video Analytics Research**, a research team from the Volpe National Transportation Systems Center developed a video-processing tool that uses machine learning to train neural networks to identify and classify roadway features and driving conditions. In phase I, the team focused on detecting and mapping work-zone features, such as barrels, cones, and signs. During phase II, the researchers trained neural networks to detect traffic signals and signal states as well as weather events and roadway weather conditions visible in the forward-facing video stream from the SHRP2 NDS dataset.(15) Once extracted, these data can be added into the SHRP2 NDS time series, which includes radar and GPS data, or the roadway information database.(18) The inclusion of this information into those databases will enable safety researchers and other stakeholders—such as representatives from the insurance industry or vehicle manufacturers working on advanced transportation solutions like autonomous vehicle development—to access the processed data by querying the databases for features of interest. The algorithms developed in this project could also inform future projects focused on other unextracted data, such as detecting and counting lanes, mapping work zone structure, and identifying other roadway features relevant to transportation safety initiatives. The project furthers the original mission of the SHRP2 NDS data—to find strategic solutions to enhance highway safety, reduce congestion, and improve roadway and bridge renewal—by making the datasets more accessible to end users working on innovating roadway safety.

Researchers at the University of Michigan, in the study **Automated Video Processing Algorithms to Detect and Classify High-Level Behaviors**, developed improved video-processing algorithms that can identify more complex behavior and actions of individuals (i.e., pedestrians, drivers, bicyclists) in various traffic situations.[19] The research team wanted to build on existing video-processing algorithms that can identify basic behavior "primitives" (like when a subject's hand is near their head) but can't always identify a "high-level" behavior (like talking on a cellphone). Specifically, the researchers aimed to do the following:

- Use a bottom-up machine-learning approach to train an algorithm to recognize high-level behaviors using object detection, human pose estimation, and behavior classification.
- Use a top-down approach to catalog primitives and high-level behaviors and develop a statistical prediction model to link them.
- Combine object-recognition and body-pose algorithms with a cost-prediction model to infer human intent and predict future behavior.
- Improve algorithm performance and processing speed to ensure the outcomes of the first three aims are practical for large-scale automated video processing.

The research team identified several categories of high-level behaviors:

- Behaviors of people outside the vehicle, such as the presence of a pedestrian or cyclist in the road or another vehicle turning left.
- Information-gathering behaviors of drivers, such as checking the blind spot or looking for pedestrians.
- Distractions and secondary tasks, including eating or talking with a passenger.
- Driving-related behaviors, like changing lanes or parking.
- Travel- and route-related behaviors, such as searching for an address or parking spot.

The researchers targeted several of these categories, developing algorithms capable of identifying specific actions as well as generalized behaviors that fit within those same categories.

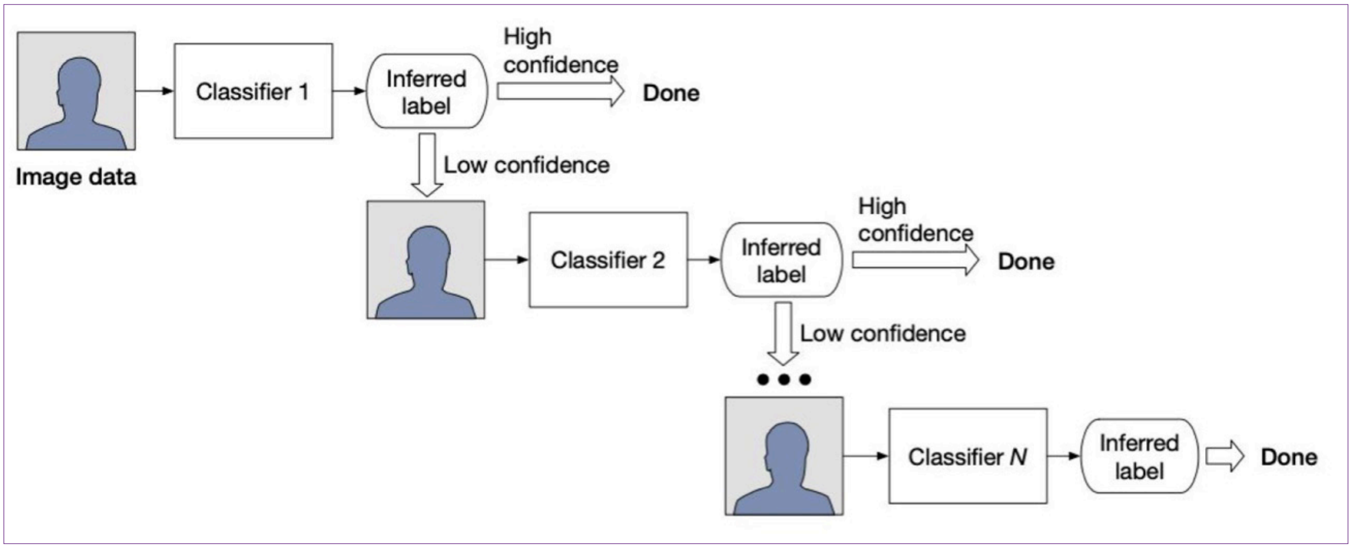
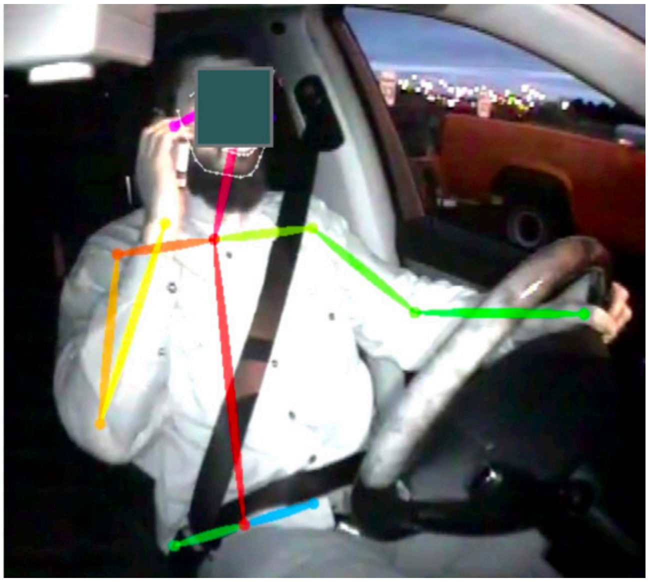


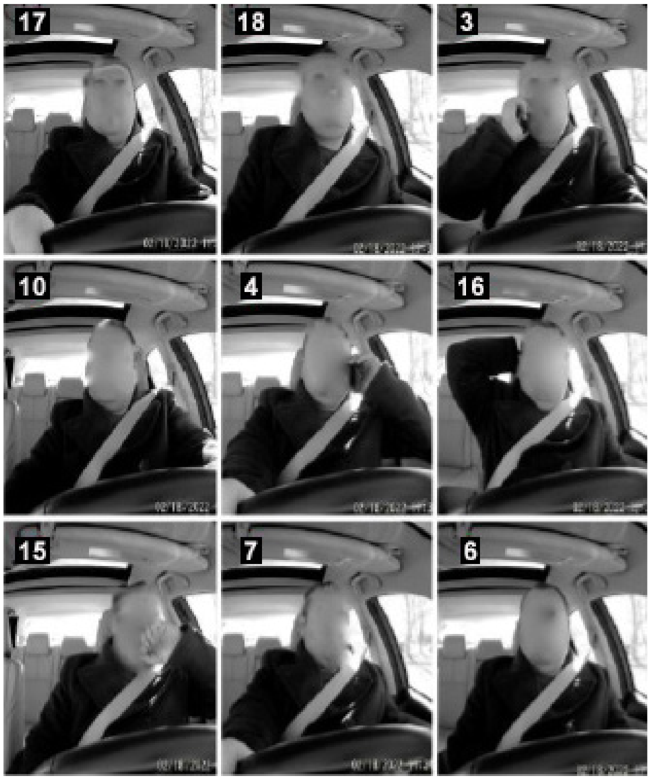
Illustration of the general cascade concept.[6]

In the study **Video Analytics for Automatic Annotation of Driver Behavior and Driving Situations in Naturalistic Driving Data**, researchers at Virginia Tech Transportation Institute worked on developing computer vision methods that would facilitate automatic generation of annotations from the SHRP2 NDS database using the continuous videos.[20,15] The study aimed to make it easier for researchers to create smaller data subsets from the more than 1 million hours of video data that make up the SHRP2 NDS database. The research team developed and evaluated a series of deep neural network models (including CNN and RNN) to capture the spatial and temporal information embedded in the video. Enhanced access to very large datasets with appropriate video annotations will facilitate a quantum leap forward in transportation safety research. Such work could make it possible to explore questions that are currently out of reach of investigators, including the interactions between human drivers and other road users, road infrastructure elements, and roadside objects.

Researchers at Iowa State University, Syracuse University, the University of Missouri, and the University of Nebraska Medical Center, in the project **Deep InSight: Deep Extraction of Driver State from Naturalistic Driving Dataset**, designed a driver-state estimation platform to improve the capacity to analyze large datasets related to human driving behaviors.[21] This Deep InSight platform incorporated RNN models trained to automatically detect and estimate human behaviors and deal with detection challenges, such as extreme-angle face detection when a driver is looking to the side or down. These RNNs are ideal for applications that involve complex interactions and input from multiple sensors, crucial for automated evaluation of driver state. Evaluating driver state requires tracking combinations of cues over many frames—from multiple camera views—and merging those with vehicle sensor data over time. The platform also makes it easier for researchers to manually check those automated annotations and verify the model's performance.



A visual dictionary of human action helps identify secondary behaviors such as using a cellphone while driving.[20]

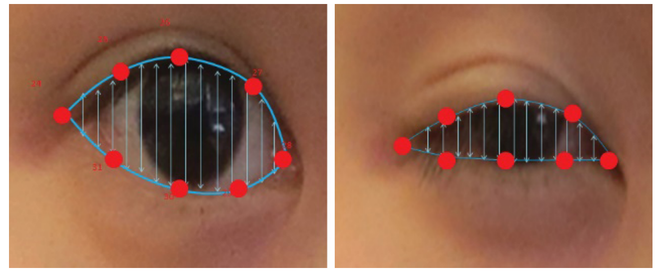


Source: FHWA.
Study participant performing distracted driving behaviors.[21]

Through the project **Driver Video Privacy Challenge**, researchers at the West Big Data Innovation Hub investigated ways to responsibly address critical data-sharing bottlenecks for assessing driver behavior video data. The objectives of the project were as follows:

- Identify the most effective methods of deidentification that still preserve the behavioral information and insights available in the data.
- Investigate the potential of how facial-masking tools, developed to protect the privacy of research participants, could fail.
- Bring together video analytics experts and stakeholders to share best practices for questions of data privacy and ethics.

The project provided an opportunity for a wide range of researchers and stakeholders to work together to offer technical solutions and insights as well as shape future transportation research. In particular, preserving the privacy of participants who contribute to video data like the SHRP2 dataset is an ongoing challenge for researchers and industry representatives who want to responsibly use these massive databases.[15] Multistakeholder collaboration on privacy-preserving practices has the potential to transform transportation research and the broader scientific community by increasing access to new data for answering complex questions about how people—drivers, cyclists, and pedestrians—can safely interact when traveling on the Nation's roadways.

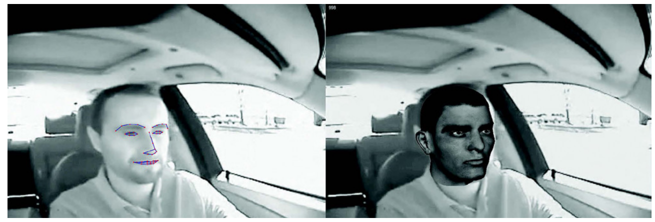


Examples of how the distance between the curves of the eyelids could be used for eye openness classification.[16]

At Carnegie Mellon University, researchers in a study called **Machine Learning for Automated Analysis of Large Volumes of Highway Video** developed machine-learning tools to process and analyze the NDS data.[16] The researchers developed learning algorithms that could separate important data from less important data as well as recognize and assemble desired factors. The tools address ways to automate the interpretation of ambiguous video data by building a sequence of context-dependent predictions. Additional video analytics projects at Carnegie Mellon included developing an automated real-time system to analyze drivers' emotional states as well as their levels of distraction and fatigue (called **DB-SAM: CMU Driver Behavioral Situational Awareness System**) and creating an automated image-distorting technique that could mask faces while still preserving facial behaviors (called **Automation of Video Feature Extraction for Road Safety-Automated Identity Masking**).[16]

SRI International, in its project **DCode: A Comprehensive Automatic Coding System for Driver Behavior Analysis**, developed a comprehensive coding system, known as DCode that could assist researchers wanting to analyze SHRP2 data.[16,15] The coding system allows researchers to extract driver behavior features, such as when holding a mobile phone, head poses, and facial expressions. Data on the surrounding environment are also available. The organization also produced a face-masking technique that preserves facial characteristics, such as expressions and head poses.

© SRI International.
The DCode System will extract driver behavior features and recognize various actions. It will also track contextual features.[16]



© SRI International.
A driver's identity is protected using an avatar to replace his face in all frames.[16]

A research team at the University of Wisconsin–Madison, in a study called **Quantifying Driver Distraction and Engagement Using Video Analytics**, developed automated and semiautomated video coding using an open-source software platform that could ultimately quantify driver distraction and engagement.[16] The platform would enable feature extraction, behavior characterization, and visualization of SHRP2 data.

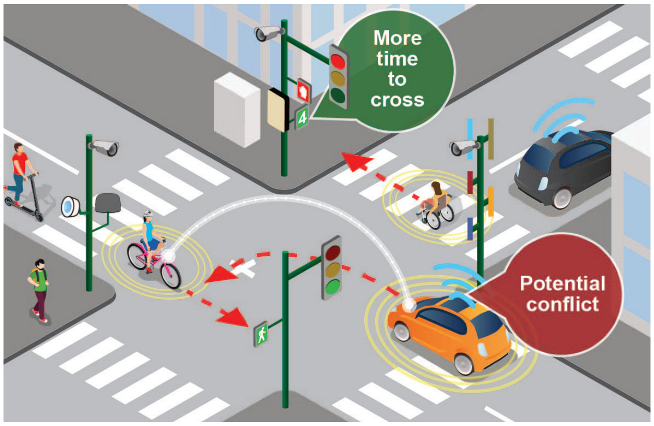
Because the amount of data is so vast, plenty of research opportunities still exist to analyze the SHRP2 NDS data.[15] FHWA seeks further studies that aid in analyzing video, creating reduced privacy-compliant datasets, and refining data-security methods.

Using Machine Learning To Help Vulnerable Road Users

Building on earlier AI techniques applied to driver behavior, FHWA is supporting research that integrates the power of AI algorithms into systems that can improve safety for everyone on the roadway. Using video cameras and other sensors, these systems detect, predict, and communicate potential conflicts increasing situational awareness beyond what a single human could perceive.

Current Ongoing EAR Program-Supported Research Projects

A University of Tennessee Chattanooga project titled **Advanced Artificial Intelligence Research for Equitable Safety of Vulnerable Road Users** aims to develop a safe, AI-based, flexible, and equitable (SAIFE) system to detect, classify, and track vulnerable road users (VRUs) at intersections while enhancing resiliency against sensor failure.[22] This system will use various real-time sensors to create sensor fusion algorithms that can accurately classify VRUs. The SAIFE system will then perform AI-based multiple-object tracking and trajectory prediction, which will facilitate situational awareness, such as automated conflict and risk assessments.



Simulated example of SAIFE system in use.[22]

Researchers at Texas A&M Transportation Institute are developing a novel framework for traffic safety analysis. The 3-year study, called **Digital Twin-Enabled Extended Active Safety Analysis for Mixed Traffic**, seeks to build a predictive, extended active safety approach for mixed traffic of human-driven vehicles and connected and automated vehicles through a digital twin technique.[23]

A 3-year study called **PANORAMA: An Interpretable Context-Aware AI Framework for Integrated Real Time Intersection Detection and Signal Optimization,** led by Southern Methodist University, is developing an AI system that detects VRUs and adjusts traffic signal timing at intersections.[22]

Benefits of PANORAMA system.[22]

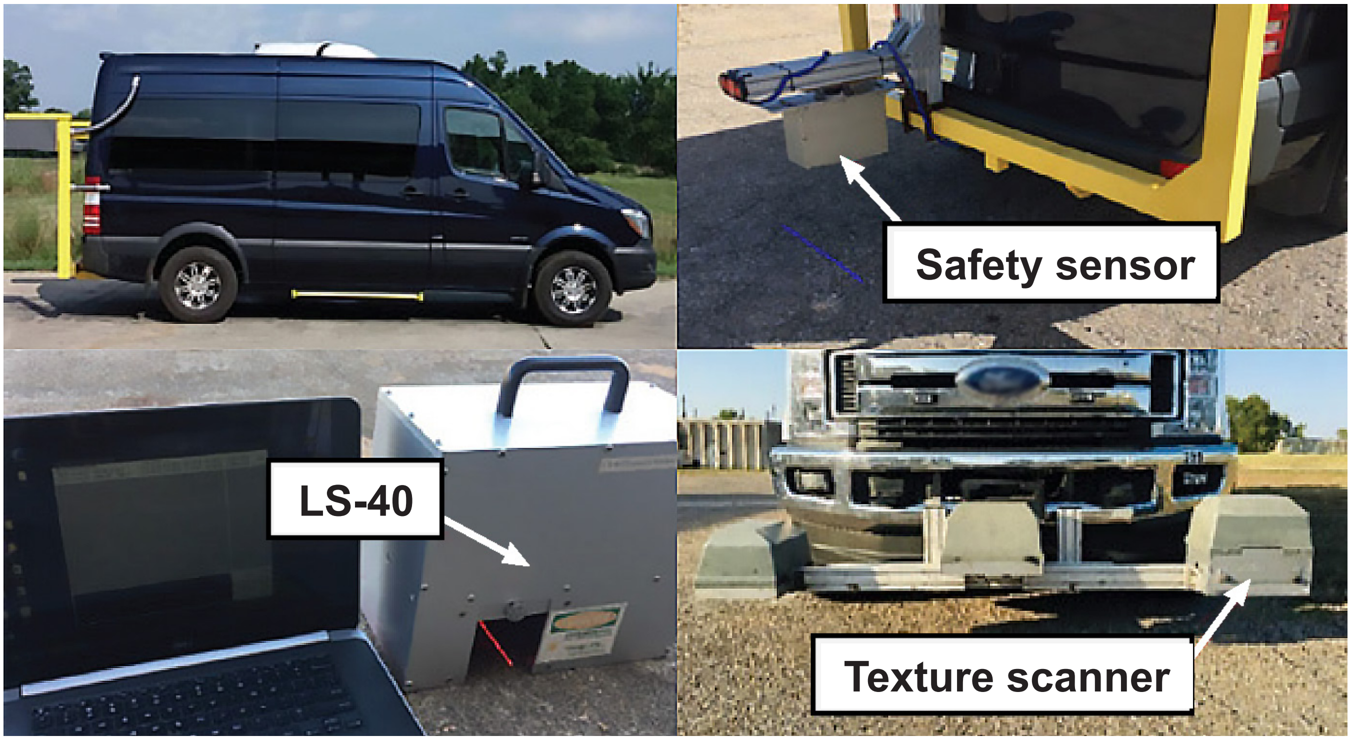
Using Machine Learning To Improve Infrastructure Asset Conditions

FHWA is supporting AI research to enhance current inspection and asset condition assessment methods. Integrating emerging AI tools into existing processes and applying the AI tools to new and traditional data for finding patterns that would be difficult for people to recognize allows State and local agencies to have better information for keeping pavements and bridges open and in good condition for the driving public.

Current Ongoing EAR Program-Supported Research Projects

Researchers for the **Advanced Vision-Based Assessment of Infrastructure Systems** project are developing technologies to help with visual bridge component inspection.[24] These technologies will automatically and quantitatively assess transportation infrastructure maintenance needs in realtime. Led by a team of researchers at the University of Texas at Austin, this project is creating a new visual inspection system that uses a pair of virtual reality goggles to overlay what the human eye sees when surveying bridge components for maintenance needs.

An Oklahoma State University (OSU) research team wants to enhance the automation of pavement information collection at highway speed for use in pavement condition safety and evaluation. Through the project titled Artificial Intelligence Approaches to Multi-Object Evaluations of Pavement for Condition and Safety, researchers are developing novel approaches to pavement engineering while increasing safety.[25] The research team is developing new AI approaches, using deep-learning methods, to better monitor pavement conditions for safety. This project is mapping pavement surface conditions using lasers and then feeding those images into a database to train an AI software program. The commercially available OSU-engineered data collection system—validated at the Federal level and by many States—is analyzing the three-dimensional image data from the pavement surface.



Pavement condition and texture collection instruments. Clockwise from left to right: Pave3D 8K condition survey system, 0.1-mm 3D laser safety sensor, a high-speed laser texture scanner, and a LS-40 ultra-high-resolution area scanner.[25]

Additional Opportunities and Challenges for AI and Machine Learning Research

FHWA is supporting two general categories of research for AI and machine learning: one applying AI and machine learning to collected datasets and a second applying AI and machine learning to real-time systems.

The first general research category involves studying and analyzing collected datasets. This category encompasses the big data projects and the video analytics projects described previously. Using FHWA access to video and sensor data from the SHRP2 NDS study, additional research can provide better insight not only into how and why crashes happen but also how and why drivers avoid crashes.(15) Other research areas within this general category include the following:

- Developing forecasting and prediction tools for data validation to ensure quality control.
- Gathering data to apply to a variety of topics, such as freight movement and nondestructive technologies, measuring the conditions of structures and pavements.

The second general category is developing tools to provide real-time operational support, such as the timing of traffic signals. This research category includes real-time AI applications that require long-term development due to the advanced technologies needed. Tools for real-time operational support can also be used to assist the travel and mobility of populations with disabilities, including disabled passengers who must use multiple transportation modes.

Overall, AI research needs to maintain trustworthiness. AI components need to be fair, avoiding bias or tracking and mitigating bias. AI components also need to be transparent so both the government agencies that want to use them and the public that can benefit from them can understand the source of decisions.

Conclusion

The FHWA EAR Program will continue to support AI and machine-learning research, particularly as they can be applied to traffic safety. Given the ever-evolving nature of these disciplines, the opportunities to develop transportation-related tools that aid the greater public good are almost as vast as the data available.

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Getting Involved With the EAR Program

To take advantage of a broad variety of scientific and engineering discoveries, the EAR Program involves both traditional stakeholders (State DOT researchers, University Transportation Center researchers, and Transportation Research Board committee and panel members) and nontraditional stakeholders (investigators from private industry, related disciplines in academia, and research programs in other countries) throughout the research process.

EAR Program Results

As a proponent of applying ideas across traditional research fields to stimulate new problem-solving approaches, the EAR Program strives to develop partnerships with the public and private sector. The program bridges basic research (e.g., academic work funded by National Science Foundation grants) and applied research (e.g., studies funded by State DOTs). In addition to sponsoring projects that advance the development of highway infrastructure and operations, the EAR Program is committed to promoting cross-fertilization with other technical fields, furthering promising lines of research, and deepening vital research capacity.

EXPLORATORY ADVANCED **RESEARCH**

Recommended citation: Federal Highway Administration, *The Role of Artificial Intelligence and Machine Learning in Federally Supported Surface Transportation: 2024 Updates* (Washington, DC: 2024) https://doi.org/10.21949/1521537

U.S. Department of Transportation
Federal Highway Administration

FHWA-HRT-25-020
HRT-10/01-25(500)E