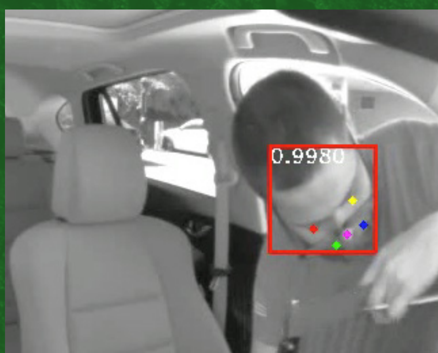
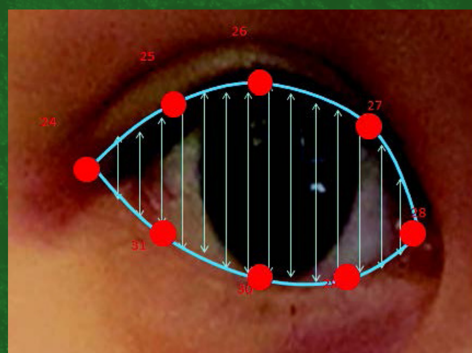
EXPLORATORY ADVANCED RESEARCH

Exploratory Advanced Research Program

The Role of Artificial Intelligence and Machine Learning






in Federally Supported Surface Transportation

2022 Updates

U.S. Department of Transportation
Federal Highway Administration

Notice

Quality Assurance Statement

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Introduction

When people hear the phrase “artificial intelligence” (AI), they might think of robots and machines that perform some of the functions that humans do, as such searching for victims in a partially collapsed building or comforting the elderly with personalized advice as part of monitoring their moods and home activity. When defined within the context of the transportation sector, AI conjures up futuristic images of self-driving, fully automated cars. Though these fantasies aren’t yet real, AI does have a lot of potential to positively impact our Nation’s transportation system in the near future.

The use of AI to enable computers to digest and analyze large amounts of data and form conclusions—a process known as machine learning—can create many improvements to transportation beneficial to the American public. Highlights include:

- Improving traffic flows at signalized intersections along specific routes or as part of integrated corridor management.
- Aiding traffic management centers with improving crash detection, predicting traffic slowdowns, and recommending detours.
- Facilitating traffic safety by warning vehicles of pedestrians obscured by parked vehicles who are starting to cross the street and monitoring real-time traffic and weather conditions.
- Discerning and anticipating how drivers might react in certain traffic situations.
- Providing information to travelers with disabilities to assist in their trip planning and increase their situational awareness.
- 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 structural health monitoring of highway assets.

What Is AI?

AI consists of the “thoughts” and conclusions that computers make after receiving data inputs. If human intelligence uses the brain to receive, store, and analyze information, AI uses various technologies to also receive, store, and analyze information.

In transportation, AI can benefit a wide range of technologies, from advanced driver assistance systems to predictive traffic modeling and control systems.

What Is Machine Learning?

Machine learning is a branch within AI in which computers use programming as a jumping-off point to create their own processes to analyze vast amounts of data. The machines themselves develop processes and algorithms to take these data and compute observations, trends, and conclusions about the data.

Within the transportation sector, machine learning technologies can be useful in finding data trends. For instance, machine learning can involve processing large amounts of traffic accident data that is analyzed with other types of data, such as weather conditions, traffic volume, and vehicular speeds, gaining insight for making certain intersections safer.

Neural networks can detect faces even under challenging circumstances, such as acute angles and occlusion.

The U.S. Department of Transportation (USDOT) has made it a priority to develop 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, a need exists to clarify how the Federal Government should invest in R&D. Clarifying this issue, the Select Committee on AI of the National Science and Technology Council published in 2019 an update of the *National Artificial Intelligence Research and Development Strategic Plan and the 2016-2019 Progress Report: Advancing Artificial Intelligence R&D.*(1) 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. 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.

By supporting long-term research that might not have immediate or clear benefits for private industry, FHWA EAR Program investments help realize the *National Artificial Intelligence Research and Development Strategic Plan.*[1] 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 two main areas: through leveraging big data (processing large amounts of traffic data to spot trends and identify relationships between disparate data streams) and developing video analytics research (analyzing video data to determine driver behavior in various traffic scenarios).

The researchers are training neural networks to detect traffic signals and signal states.
© Volpe National Transportation Systems Center.

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 onboard 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.[2]

Current EAR Program-Supported Research Projects

Researchers at the Michigan Technological University are investigating the potential to shift winter maintenance decisionmaking from a model-driven to an AI-enhanced framework. In their project **"Autonomous Winter Road Maintenance Decision Making Enabled by Boosting Existing Transportation Data Infrastructure with Deep and Reinforcement Learning"** (to be completed in 2023), the researchers hope to develop a data-driven maintenance decision support system to help State department of transportation (DOT) highway maintenance professionals plan for weather events through improved data processing, predictive road condition methods, and computer-supported decisionmaking. The team is investigating opportunities from AI to analyze real-world situations in real time. Recurrent neural networks (RNNs) and road condition predictions provide a data-driven environment. Deep reinforced learning takes the RNN predictions and puts them into action using machine learning to make autonomous decisions. Convolutional neural networks provide real-time road condition sensing. To test these machine learning models in the field, researchers are working with the MI DOT and MI county road agencies to conduct field tests. They are developing a closed-loop approach that consists of data gathering, condition predictions, decisionmaking, validation, and human intervention. This approach maximizes AI's capability to significantly improve winter maintenance operations, safety, and mobility; reduce labor hours and costs; and indirectly enhance pavement design and management.

For the project **"Predictive Real-Time Traffic Management in Large-Scale Networks Using Model-Based AI"** (to be completed in 2023), researchers at Carnegie Mellon University aim to leverage AI to support traffic operators. Operating transportation highway networks in real time is challenging. Planned and unplanned incidents (e.g., hazardous weather conditions, accidents, and local events) on highway networks can catastrophically impact mobility and safety. When these nonrecurrent incidents occur, traffic operators do not know when to employ certain mitigating strategies, or how to deal with the overwhelming increase in traffic data. Mitigating nonrecurrent incidents requires accurate and ahead-of-curve, real-time predictions as well as proactive operational management. Unfortunately, nonrecurrent incidents are difficult to address using traditional modeling methods. This research project proposes to develop AI-guided transportation network flow theories, models, and algorithms to achieve two main goals: to predict nonrecurrent traffic conditions in large-scale networks at least 30 minutes ahead and to proactively recommend operational management strategies in real time. Prediction and operational strategies are intimately coupled. The prediction will be made by a machine that learns not only historical multisource traffic data but also considers operational strategies that are currently being or will be recommended/engaged. Operational strategies are made and updated in real time using model-based AI with the ahead-of-curve prediction. Case studies will be conducted in one small municipality network and two large-scale regional networks.

The research project **"Cooperative Perception and Control for Freeway Traffic System Operations"** (to be completed in 2023) aims to develop next-generation traffic system management and operations solutions for freeway systems based on cooperative driving automation. The proposed solution concerns 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 proposed work taking place at the University of Cincinnati focuses on computational applications that could substantially increase freeway system safety and mobility. Their study aims to fulfil two objectives: integrate traditional and nontraditional highway data to better explain and predict system performance and provide decision support to assist experts in the design, operation, or management of highway systems.

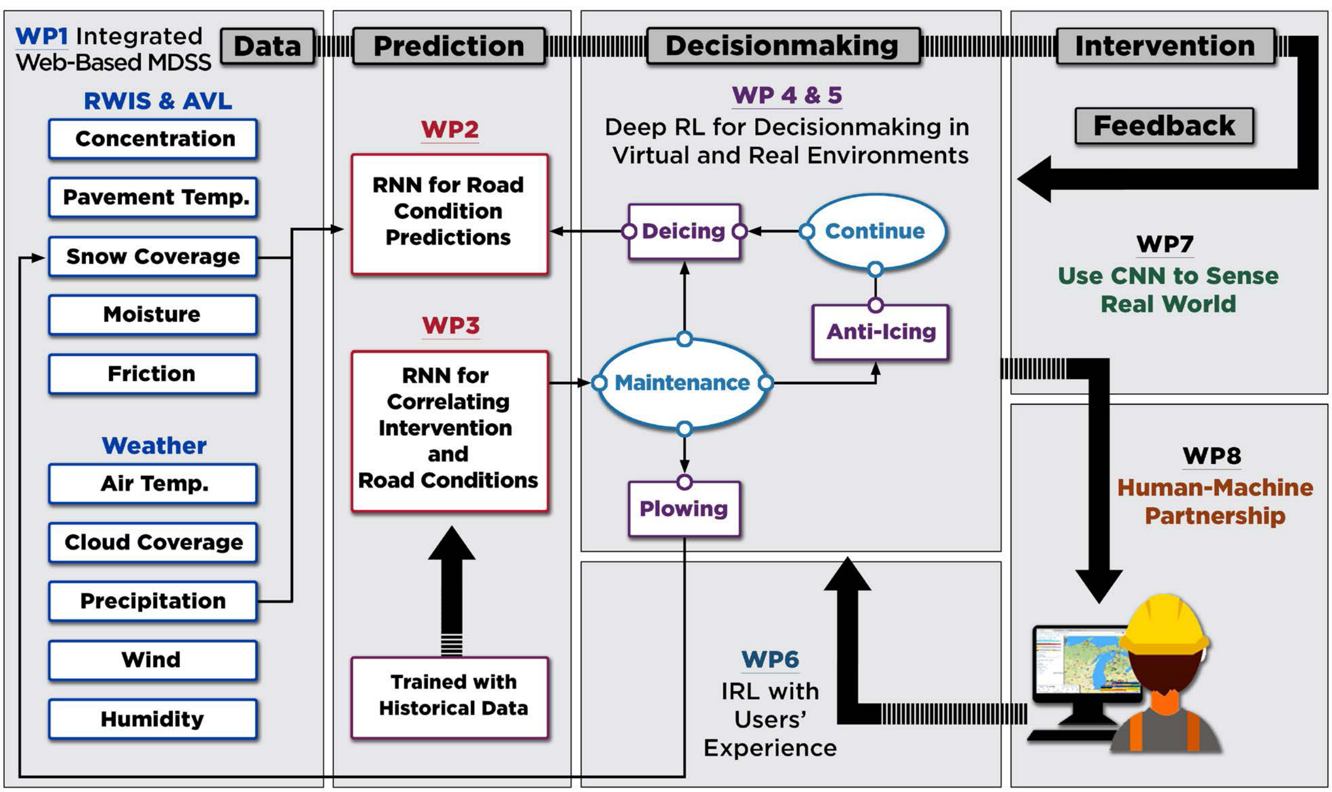
Completed EAR Program-Supported Research Projects

In one project designed to support State DOT's, **"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.(3) 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.(3) 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.(3)

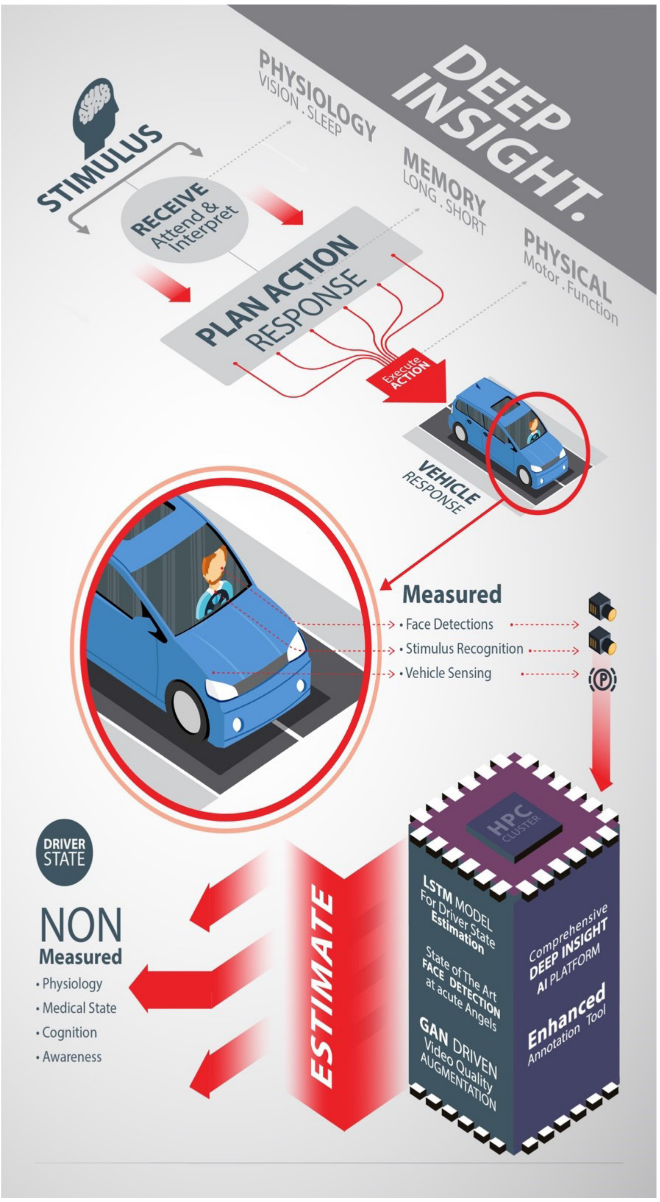
PARC's project researchers developed automated methods to integrate information from large unrelated datasets. In their project, titled **"Merging Information from Disparate Sources to Enhance Traffic Safety,"** the PARC research team established machine-learning tools to process data from several datasets. They incorporated data from the second Strategic Highway Research Program's (SHRP 2) 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. 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 so readily spotted otherwise.(2)

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, a dashboard that provides users with a way to see streaming data and historical data of traffic in Seattle, WA. The data included crashes, traffic volume, roadway characteristics, weather and roadway-surface conditions, work zones, and traffic laws.(2)



Using Video Analytics to Help Analyze Driver Behavior

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 SHRP 2 NDS video database. 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.(4) Researchers from multiple universities and organizations have been developing machine-learning tools to process the vast amount of video available in the SHRP 2 NDS data. By analyzing the NDS data, researchers hope to understand the correlations among driver behavior, road design, traffic, and other factors.(5)



Deep InSight platform design including tools and stages. © REACTOR Lab.

Current EAR Program-Supported Research Projects

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. Their techniques enabled benchmarking progress and technical assessment of EAR Program-sponsored research teams.(6)

For the project **"Traffic Incident Detection and Analysis System"** (to be completed by 2023), researchers at Tufts University and the City College of New York are leveraging AI to improve the detection of highway incidents.(5) In this study, researchers are creating a novel framework using AI and image-processing algorithms. The framework aims 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. Utilizing 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 focuses on solving challenges including:

- 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.

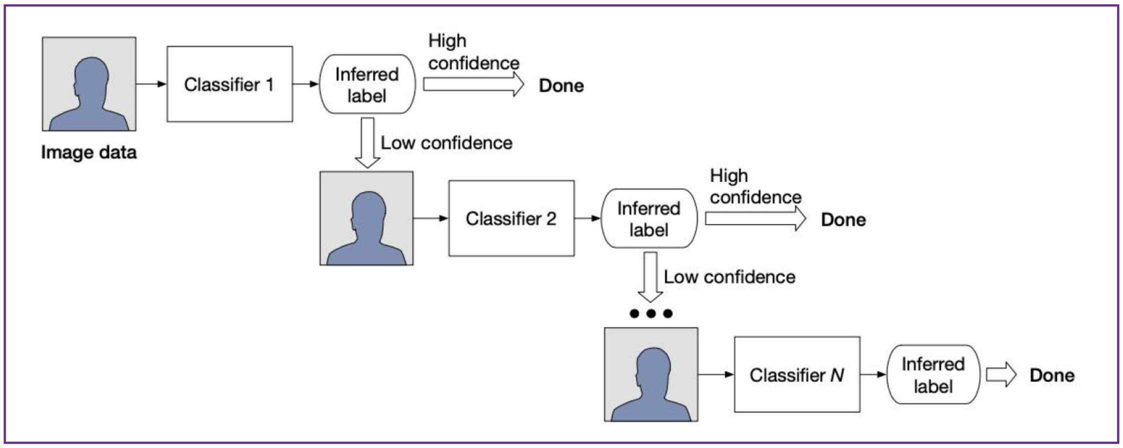


Illustration of the general cascade concept. © University of Michigan Transportation Research Institute.

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. 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.

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 included:

- Identifying the most effective methods of deidentification that still preserve the behavioral information and insights available in the data.
- Investigating the potential of how facial-masking tools, developed to protect the privacy of research participants, could fail.
- Bringing 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 SHRP 2 dataset is an ongoing challenge for researchers and industry representatives who want to responsibly use these massive databases. Multistakeholder collaboration on privacy -preserving practices has the potential to transform transportation research and the broader scientific community. Such privacy-preserving practices can increase access to new data for solving complex questions about how people—drivers, cyclists, and pedestrians— can safely interact safely when traveling on the nation's roadways.

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. 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, they aimed to:

- 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 primitive and high-level behaviors and develop a statistical prediction model to link them.

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

- 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.

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 SHRP 2 NDS database using the continuous videos. The study aimed to make it easier for researchers to create smaller data subsets content from the over 1 million hours of video data that makes up the SHRP 2 NDS database. The research team developed and evaluated a series of deep neural network models (including convolutional neural network 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.

Completed EAR Program-Supported Research Projects

In the project **"SHRP 2 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 SHRP 2 NDS dataset. Once extracted, these data can be added into the SHRP 2 NDS time series, which includes radar and GPS data, or the roadway information database. 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 SHRP 2 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.

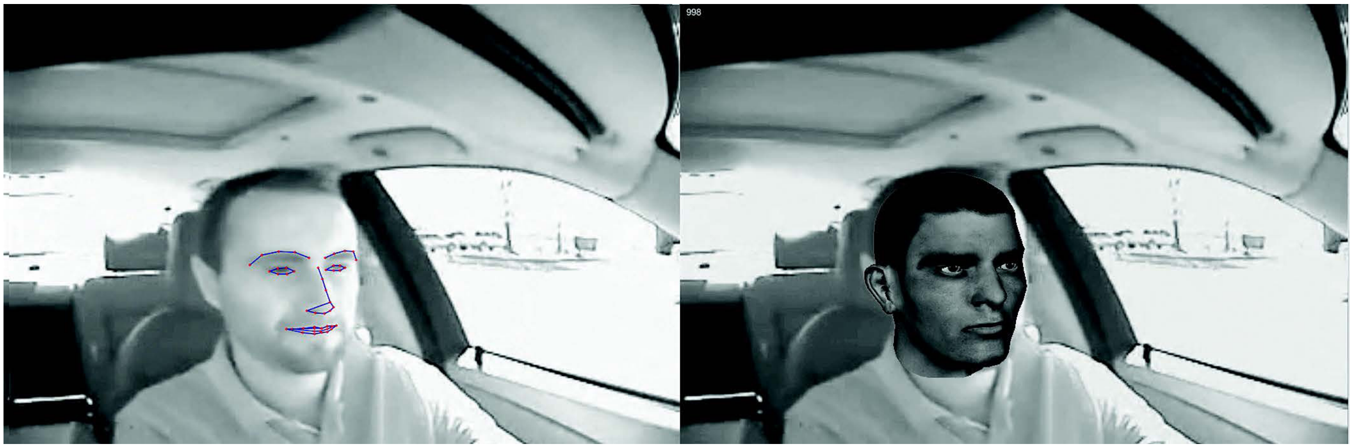
At Carnegie Mellon University, researchers in a study called **"Machine Learning for Automated Analysis of Large Volumes of Highway Video"** developed machine-learning tools to process and analyze the NDS data.[5] They developed learning algorithms that could separate important data from less important 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 state as well as their level 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"**).[6]

SRI International, in their 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 SHRP 2 data.[6] 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.[5]

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

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 as a way to develop an open-source software platform that could ultimately quantify driver distraction and engagement. The platform would enable feature extraction, behavior characterization, and visualization of SHRP 2 data.[6]

Because the amount of data is so vast, plenty of research opportunities still exist to analyze the SHRP 2 NDS data. FHWA seeks further studies that aid in analyzing video, creating privacy-compliant datasets, and refining data-security methods.



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

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 SHRP 2 NDS study, additional research can provide better insight not only into how and why crashes happen but also how and why drivers avoid crashes.[7] Other research areas within this general category include:

- 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 the development of 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 that 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 are able to understand the source of decisions.

Conclusion

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

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.

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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**

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