FHWA Nondestructive Evaluation Program

STRATEGIC PLAN FOR FY 2019–2022

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FOREWORD

This strategic plan outlines the goals, objectives, and action items of the Federal Highway Administration (FHWA) Nondestructive Evaluation (NDE) Program for fiscal years 2019 to 2022. It is aligned with FHWA's and the U.S. Department of Transportation's goals, objectives, related program initiatives, and performance measures. The information presented in this strategic plan highlights the significance of a partnership between FHWA; other Federal, State, and local Government agencies; industry; and academia in advancing the state of practice in NDE. Advancements in sensing, information, and robotic technologies complement the current state of practice for condition assessment of highway-infrastructure assets. This document charts a path toward more fully realizing the potential of NDE technologies to support more effective management of highway-infrastructure condition.

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Director, Office of Infrastructure
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Front cover photo: iStock.com/Chombosan.

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<tr><td colspan="4">16. Abstract
This strategic plan outlines the Federal Highway Administration's (FHWA's) Nondestructive Evaluation (NDE) Program's strategic framework (i.e., goals, objectives, and strategies) for the allocation of FHWA resources. This framework is aligned with FHWA's and the U.S. Department of Transportation's other strategic plans.[1,2] Through internal and external discussions with stakeholders, three strategic goals and objectives were identified: stakeholders, technology, and implementation. Fifteen strategies were identified to support these goals and objectives. This document presents these objectives, strategies, action items, and a more complete description of how they will be used to guide the actions of the FHWA NDE Program.</td></tr>
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LIST OF ABBREVIATIONS

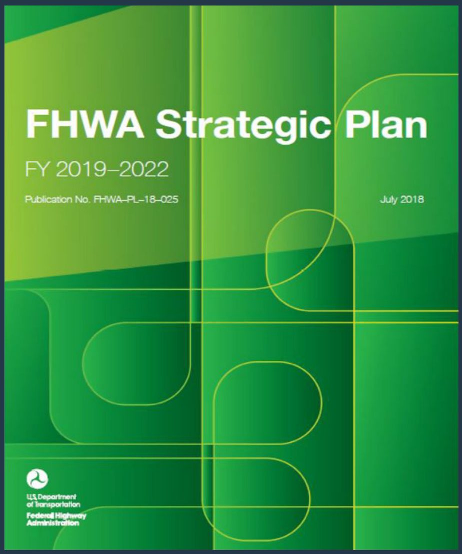
AASHTO	American Association of State Highway and Transportation Officials
AI	action item
AR	augmented reality
ASNT	American Society of Nondestructive Testing
AV	autonomous vehicle
DL	deep learning
DOT	department of transportation
FHWA	Federal Highway Administration
FWD	falling weight deflectometer
FY	fiscal year
GPR	ground penetrating radar
HOP	Office of Operations
HRDO	Office of Operations Research and Development
IC	intelligent compaction
ITS/JPO	Intelligent Transportation Systems/Joint Program Office
MAP-21	Moving Ahead for Progress in the 21st Century Act
ML	machine learning
NSBA	National Steel Bridge Alliance
NDE	nondestructive evaluation
NDT	nondestructive testing
NTIS	National Tunnel Inspection Standard
QA	quality assurance
ROI	return on investment
SG	strategic goal
SHM	structural health monitoring
SHRP2	second Strategic Highway Research Program
SO	strategic objective
TRL	technology readiness level
UAS	Unmanned Aerial Systems
USDOT	United States Department of Transportation
VI	visual inspection

Source: iStock.com/Just_Super.

OVERVIEW

This strategic plan outlines the goals and objectives of the Federal Highway Administration (FHWA) Nondestructive Evaluation Program from fiscal years (FYs) 2019 to 2022. This plan adopts FHWA's and the U.S. Department of Transportation's (USDOT's) goals, and its objectives, related program initiatives, and performance measures are aligned with those of FHWA's (figure 1) and USDOT's (figure 2) other strategic plans.[1,2]

FIGURE 1. PHOTO. COVER OF FHWA STRATEGIC PLAN FY 2019–2022.[1]



Source: FHWA.

FIGURE 2. PHOTO. COVER OF U.S. DEPARTMENT OF TRANSPORTATION STRATEGIC PLAN FOR FY 2018–2022.[2]

Source: FHWA.

INTRODUCTION

In the United States, the current inspection program and management tools for maintaining the safety of highway infrastructure—2.7 million miles of paved roads; 615,000 bridges; and 470 tunnels—are among the best in the world.(3–5)

The highway system provides a high level of safety and security for the traveling public and rapid response in case of public emergencies, and it ensures a high level of national security. The extreme diversity of bridge, pavement, and tunnel structures in the inventory; the widely varying conditions under which they operate; the lack of data needed to fully characterize condition and understand their performance; and limited resources, however, are challenges that asset owners and decisionmakers must overcome to more effectively manage the highway system. In addition, the engineered components of structures have aged and deteriorated, and many have exhausted their capacity to meet ever-expanding operational demands, particularly in urban areas and along major freight routes.

Asset owners, in recent years, have worked toward implementing an asset-management plan and performance-based management in maintaining, preserving, and managing the highway system. Essential components of this approach are having reliable and quantitative information regarding the physical condition of structures and a greater understanding of their deterioration processes. Quantitative information can be obtained by using advanced sensing technologies as a complementary means to the current state of practice for condition assessment of structures (visual inspection (VI) and manual sounding techniques).

Advancements in sensing, information, and robotic technologies have impacted nearly all industries (i.e., medical, aerospace, military, etc.), but they are just beginning to reach the domain of highway infrastructure. Asset owners are gaining more confidence in the added value of using a nondestructive-evaluation (NDE) technologies,

Source: iStock.com/Andrey Suslov.

which can be credited to the findings of a number of national projects (e.g., the second Strategic Highway Research Program (SHRP2)) and close collaboration and cooperation among asset owners, researchers, technology providers, and policy makers.

While many technologies offer potential benefits in a quantitative infrastructure asset-management plan, their use presents challenges. To date, some promising NDE technologies have not been packaged, integrated, and delivered in a manner that is cost effective for asset owners to use on a routine basis. Manual data collection using NDE technologies is a costly and time-consuming process because the collected data are still in raw form, and the interpretation process used to derive the needed information requires extensive expertise. More effective and near-real-time approaches to data analysis, interpretation, and visualization are needed. The application of these technologies is also hindered by the absence of recognized standards and guidelines.

Given this background, it is important to recognize that effectively introducing NDE technologies within the highway-infrastructure domain is not a basic research challenge. Rather, it requires a problem-focused research approach that emphasizes understanding the problem; technology integration and development; and partnerships across Government, academia, and industry sectors. To date, key application scenarios and performance requirements (in terms of reliability, sensitivity, accuracy, benefits, etc.) are not fully defined in the realm of highway infrastructure. Lack of performance-based requirements for technologies introduces significant uncertainty into investment decisions, especially those related to which technologies should be targeted for commercialization, the ultimate size of the market for such technologies, the level of investment that may be justified, and a reasonable estimate of return on investment (ROI). Therefore, a direct link between technologies, application scenarios, and the resulting benefit (related to cost) is necessary. Without linking NDE to tangible benefits, such as cost savings or reduced resource allocation, it is difficult to justify investment in it. In addition, despite many research papers and technical reports on NDE, no documentation has a high-level discussion of the technologies and their applications geared toward making the business case for their use.

To overcome these challenges, the FHWA NDE Program will work with State departments of transportation (DOTs) and other stakeholders to develop national guidelines to assist with the deployment of NDE technologies for condition assessment. The FHWA NDE Program will also identify promising and proven NDE technologies for potential advancement through pooled-fund initiatives and Accelerating Market Readiness and/or Every Day Counts programs as well as work to advance technology readiness levels (TRLs) by improving data-collection, -analysis, and -interpretation methodologies and algorithms.[6] More speculative approaches to NDE-related challenges will be investigated through investments through the Exploratory Advanced Research Program.

MISSION

The mission of the FHWA NDE Program is to improve the performance and reduce the lifecycle cost of highway-infrastructure assets by providing comprehensive diagnosis- and prognosis-related infrastructure condition-assessment solutions in a timely and cost-effective manner.

Strategic Plan Framework

The four most important aspects of strategic plans are the identification of goals, objectives, strategies to achieve goals and objectives, and action items (AIs) to allocate resources.

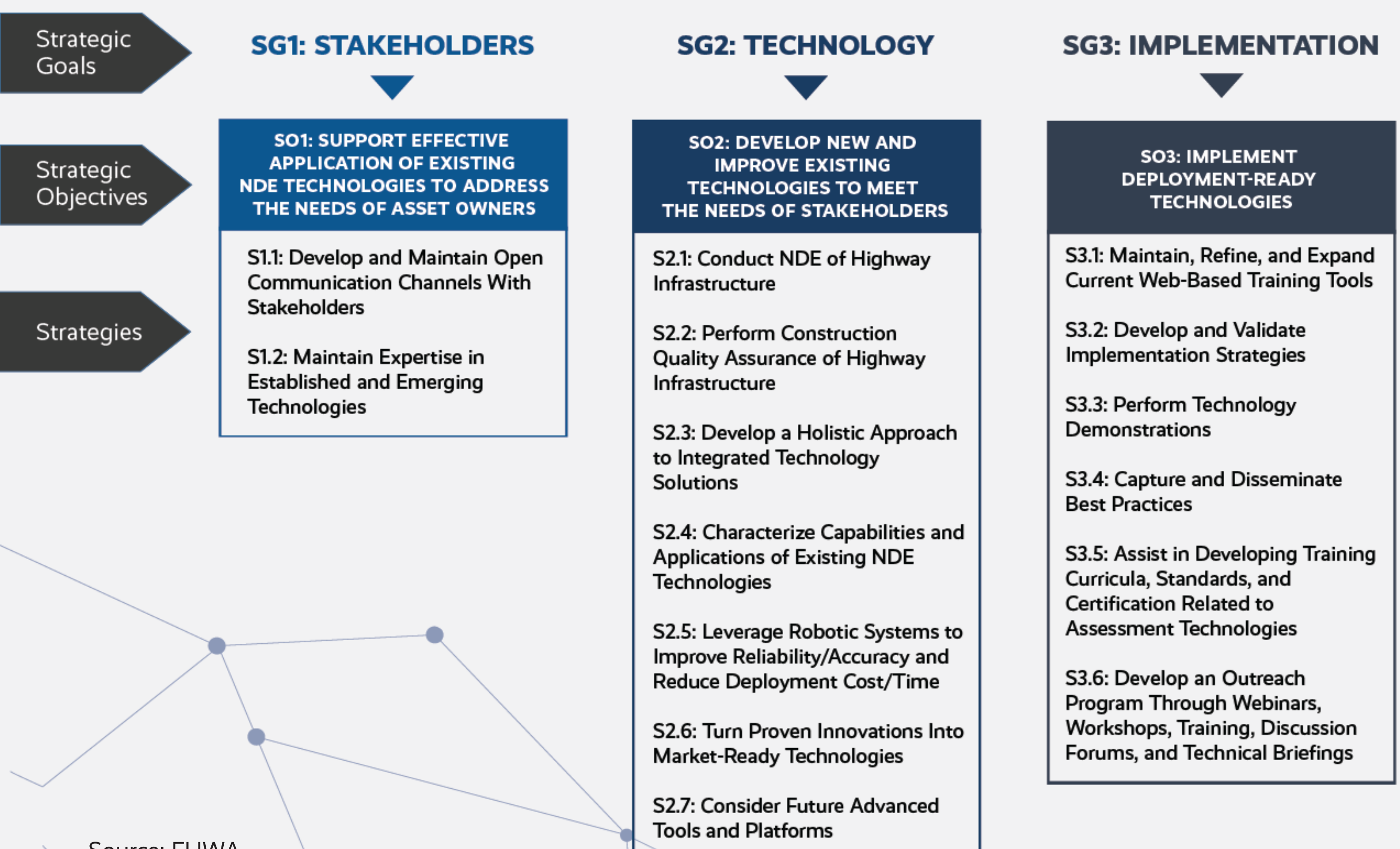
Strategic Goals, Objectives, and Strategies

Through internal and external discussions with stakeholders, the following three strategic goals (SGs) and strategic objectives (SOs) were identified:

- **Stakeholders**—Support effective application of existing NDE technologies in support of safe, cost-effective, timely, and well-founded highway-infrastructure inspection and management.
- **Technology**—Develop new technologies and improve the accuracy, reliability, and benefit of existing NDE technologies to meet the needs of stakeholders.
- **Implementation**—Accelerate the implementation of market-ready, customer-focused, accurate, reliable, and value-added NDE technologies.

Fifteen strategies were identified to obtain these three goals and objectives (figure 3). The following sections provide some additional discussion on these objectives, strategies, and AIs and a more complete description of how they will be used to guide the actions of the FHWA NDE Program.

FIGURE 3. GRAPHIC. OVERVIEW OF THE FHWA NDE PROGRAM'S SGS AND SOS.



Source: FHWA.

SO1: Support Effective Application of Existing NDE Technologies to Address the Needs of Asset Owners

While some existing and emerging technologies offer powerful alternatives to current practices, their effective implementation and further development demand multidisciplinary teams to integrate technology-specific expertise with sound structural-engineering heuristics. Table 1 provides a listing of internal and external stakeholders as well as a brief description of the envisioned role the FHWA NDE Program may play in their operation.

TABLE 1. STAKEHOLDERS AND THE FHWA NDE PROGRAM'S ROLE.

Stakeholders		FHWA NDE Program's Role
Internal	Headquarters	Support in policy and guidance development relating to NDE, SHM, and condition assessment
	Resource Center	Support in development of training and demonstration or deployment of tools and technologies
	Turner-Fairbank Highway Research Center	Support LTIP, structures, pavements, hydraulics, construction, and corrosion research programs
	Federal Lands Highway	Assist with NDE condition-assessment activities and deployment
	National Highway Institute	Assist in development of training modules
	Mobile asphalt and concrete trailers	Support in showcasing new NDE technologies, collaborate with the loan equipment program, and assist with workshops hosted by the mobile concrete/asphalt trailers
External	State transportation agencies and AASHTO	Provide technical assistance, and raise awareness of available tools
	Other Federal agencies: FAA, DOD, DOE, NASA, etc.	Provide technical assistance, potential collaboration, and information sharing
	Researchers	Provide access to available research data, validation specimens, sharing mutual information, sabbatical opportunities, and NRC fellows
	Industry	Access to validation specimens and sharing information
	Organization: ASNT, TRB, ASCE, ACI, NSBA, NRRA, NCC, etc.	Leadership roles in relevant conferences/special sessions, developing short courses/seminars

SHM = structural health monitoring; LTIP = long-term infrastructure performance; AASHTO = American Association of State Highway Transportation Officials; FAA = Federal Aviation Administration; DOD = Department of Defense; NASA = National Aeronautics and Space Administration; NRC = National Research Council; ASNT = American Society for Nondestructive Testing; TRB = Transportation Research Board; ASCE = American Society of Civil Engineers; ACI = American Concrete Institute; NSBA = National Steel Bridge Alliance; NRRA = National Road Research Alliance; NCC =North Coast Corridor.

S1.1: Develop and Maintain Open Communication Channels With Stakeholders

The FHWA NDE Program will continue to strengthen and maintain its relationships with all the stakeholders shown in table 1. Input from these groups is essential to the success of the FHWA NDE Program. Such input will be gathered by engaging relevant professional organizations and technical committees as well as participating in key national and international events, such as meetings of the American Association of State Highway and Transportation Officials (AASHTO) Committees on Bridges and Structures, Maintenance, Materials and Pavements, and Construction; the American Society of Nondestructive Testing (ASNT) Annual Conference; and the Transportation Research Board Annual Meeting; among others.

AI1.1

To maintain open communication with stakeholders, the FHWA NDE Program will organize annual workshops to discuss and identify stakeholders' needs and acquire input and feedback from asset owners, researchers, and industry representatives. The input obtained from these workshops will be used to support the FHWA NDE Program's goals and objectives, initiate research studies to address the asset owners' needs, and develop technical guidelines. Once the studies have been completed, the FHWA NDE Program, through an open-communication strategy, will present and discuss the findings with the asset owners, researchers, and industry representatives, as discussed in AI3.6.

S1.2: Maintain Expertise in Established and Emerging Technologies

To be the go-to entity for NDE-technology support for stakeholders, it is imperative that the NDE Lab maintain and grow its in-house expertise and obtain an inventory of state-of-the-art tools, technologies, and validation specimens.[(7)] It is also essential to perform detailed multiphysics mathematical modeling and simulation in parallel to experimental testing to extend understanding of experimental data. Maintaining in-house expertise and state-of-the-art tools and technologies allows the NDE Lab to be a resource for FHWA's infrastructure programs.

AI1.2

One approach to growing in-house expertise that has been proven successful is the use of National Research Council fellowships to attract and bring high-quality postdoctoral researchers to the lab. In addition, the NDE Lab will pursue offering summer and sabbatical opportunities for interested faculty members. Growing in-house expertise will serve to disseminate the vision and capabilities of the FHWA NDE Program within the academic community, which is imperative to generating a pipeline of talent. In addition, these external resources will be expected to publish in refereed journals and assume leadership positions within relevant technical committees.

SO2: Develop New and Improve Existing Technologies to Meet the Needs of Stakeholders

Although basic technological advancements (e.g., in the areas of sensing, simulation, robotics, big data, augmented reality (AR), virtual reality, and materials technology) are becoming quite mature in other industries, their adaption to meet the needs of highway-infrastructure asset owners is lagging. The adaptation and integration of existing technologies and development of new technologies to meet the challenges associated with infrastructure assets are addressed by this SO. This adaptation requires that the technologies be packaged and delivered in such a manner as to cost-effectively meet the needs of asset owners. Achieving this goal requires both an understanding of the technologies themselves as well as the constraints, costs, and performance requirements (in terms of reliability, sensitivity, accuracy, benefits, etc.) associated with different applications. The FHWA NDE Program should have the credibility and expertise to meet this objective.

S2.1: NDE of Highway Infrastructure

State DOTs and other agencies are working to preserve and rehabilitate roadways (e.g., bridges, tunnels, and pavements), keeping them safe and efficient for the public. Infrastructure deterioration, such as cracking, often initiates beneath the surface, where it cannot be seen (especially in early stages). Structure evaluation is the first step in making good preservation and rehabilitation decisions. Destructive methods for evaluating a structure can be time consuming and expensive to State DOTs. NDE technologies detect the location and severity of defects before problems appear on the surface.

AI2.1

The FHWA NDE Program will conduct a series of studies to identify promising NDE technologies for evaluating pavement, bridge, and tunnel structures; deploy the selected technologies; and develop guidelines and protocols to successfully implement these technologies.

S2.2: Construction Quality Assurance of Highway Infrastructure

To date, State DOTs routinely accept highway construction based on quality-assurance (QA) procedures. These QA requirements consider, in most cases, Federal regulations for construction QA procedures (23 CFR, Part 637 subpart B); FHWA recommendations on developing QA programs; and AASHTO recommendations for QA.[8–10] Several studies have identified potential advantages of incorporating nondestructive-testing (NDT) technologies into the QA process for highway-construction inspection. Some examples of these NDT technologies are nuclear density gauges, electromagnetic density gauges and intelligent compaction (IC). NDT technologies can assess product properties and uniformity in real time as construction progresses; identify potential defects during construction, allowing for quick corrective actions; and inspection or testing at a higher sampling frequency to supplement coring and other destructive testing. Therefore, NDT technologies have the potential to improve construction quality and available data for State DOTs to use in the acceptance process while lowering testing and inspection costs and time. In addition, NDT technologies enhance the QA process by covering the entire pavement surface rather than using a small number of samples for acceptance. Using NDT technologies can greatly reduce lane closures, traffic interruptions from construction zones, and the possibility of accidental collisions. While many NDT technologies have been explored for several years, the transition from research and forensic investigations to QA has been somewhat limited because of the complexity of such methods, variability between NDT and destructive measurements, or lack of required training by QA technicians and agency inspectors. Standardized test methods and procedures (e.g., AASHTO standards) are needed before these types of technologies can be implemented by State DOTs.

AI2.2

To obtain a more performance-based measure of construction quality and uniformity, the FHWA NDE Program will carry out projects to develop and deploy more robust NDT technologies and standards to provide consistent, reliable, and objective measurements of density. In addition, straightforward and practical QA procedures are needed to convert the in-situ measurements to more quantitative measures of construction quality.

S2.3: Develop a Holistic Approach to Integrated Technology Solutions

Currently, development and implementation efforts tend to focus on single, isolated technologies. Although there have been some success stories with this approach, the true potential of technology lies in its integration across modalities (data collection, processing, visualization, interpretation, etc.), spatial scales (from material-level or NDE through system-level or structural health monitoring (SHM) approaches), and goals (from diagnosis to prognosis to treatment).

FIGURE 4. GRAPHIC. ENVISIONED TECHNOLOGY INTEGRATION.

TOOL AND TECHNOLOGY

- Reliability of damage detection
- Quantification of return on investment
- Improved speed and resolution
- Fully automated data collection and analysis

DATA

- Fusion of disparate technologies to improve detection and diagnosis
- Improved probability data analysis and interpretation strategies
- Intuitive visualization platforms to permit use by practitioners

INFORMATION

- Artificial intelligence strategies to develop and refine prognosis strategies
- Big data approaches to performance forecasting NDE integrated into asset-management process
- Development of reliable estimation of service life and required interventions

Source: FHWA.

To date, technologies have traditionally been fragmented across these dimensions, which greatly limits their effectiveness. Figure 4 provides a vision for a coordinated research program that focuses on integrating different technologies by leveraging the emerging fields of data fusion, big data, advanced visualization (inclusive of AR and virtual reality), and artificial intelligence.

AI2.3

The FHWA NDE Program will work with State DOTs and other stakeholders to develop new data-analysis, -interpretation, and -visualization approaches for more reliable and intuitive data interpretation and extracting useful information from the collected data.

S2.4: Characterization of Capabilities and Applications of Existing NDE Technologies

Currently, research approach to NDE is technology focused. However, the fact is that asset owners and end-users have specific problems with their infrastructure assets that need to be solved. Therefore, a problem-focused research approach that identifies and fully characterizes their needs, identifies technologies applicable to meeting those needs, and characterizes and specifies the technology capabilities is required. This problem-focused approach enables the quantification of the added value and ROI of each technology to support decisions.

Recently, as part of the Moving Ahead for Progress in the 21st Century Act (MAP-21) and the Fixing America's Surface Transportation Act, requirements for asset owners to develop data-driven asset-management programs have been introduced.[11,12] As NDE technologies become more reliable, deterioration can be identified at earlier stages and at smaller scales. Such early identification will enable timely asset-management decisions.

AI2.4

The FHWA NDE Program will work with State DOTs and other stakeholders to identify state-of-the-practice NDE technologies, develop a problem-focused approach to demonstrate and document the added value of NDE technologies to complement infrastructure inspection, highlight best practices, and document successful case studies. The FHWA NDE Program will develop standards for consideration by AASHTO and an FHWA guideline for application of NDE technologies. The FHWA NDE Program will also initiate studies to investigate how NDE technologies can be integrated into asset-management processes to enable more effective management of infrastructure assets and inform timely asset-management decisions. Upon the completion of these studies, the FHWA NDE Program will provide input on integration of NDE technologies into asset-management and inspection processes for FHWA's policy consideration.

S2.5: Leverage Robotic Systems to Improve Reliability and Accuracy and Reduce Deployment Cost and Time

Robotic platforms, including but not limited to Unmanned Aerial Systems (UAS), offer the potential to reduce the cost and time required for NDE data collection and improve the safety and efficiency of infrastructure inspection work.

AI2.5

The FHWA NDE Program will work to identify pairings of deployment-ready technologies with robotic platforms, including but not limited to UAS, to achieve the envisioned cost and time reductions and improve the safety and efficiency of inspection work. The FHWA NDE Program will objectively assess the capabilities and limitations of available and proven sensors for UAS. The FHWA NDE Program will explore expanding UAS capabilities to perform VIs and will assess the minimum UAS standards for supplementing VI and further implementation of UAS in the National Steel Bridge Alliance (NSBA) and National Tunnel Inspection Standard (NTIS).[13] Upon the completion of these studies, the FHWA NDE Program will provide input on the use of UAS for VI and its potential integration with the NSBA and NTIS for FHWA's policy consideration.

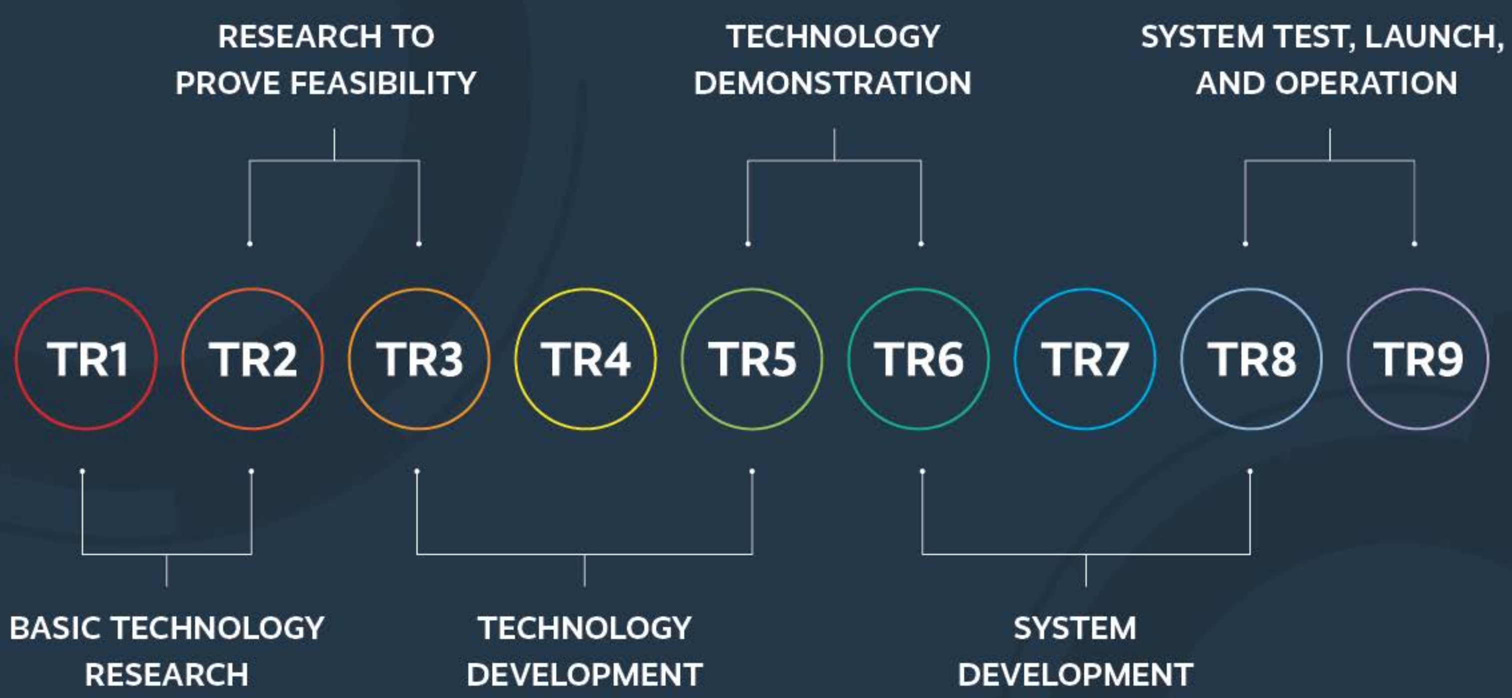
S2.6: Turn Proven Innovations Into Market-Ready Technologies

Many research programs support basic technology research that is federally funded by entities such as the Department of Defense and the National Science Foundation. However, none of those programs have aimed at moving technologies from the proof-of-concept phase to the commercialization phase, in which they could be implemented by asset owners. In addition, research by State transportation departments, the National Cooperative Highway Research Program, and SHRP2, in the realm of technology, primarily focuses on technology implementation. As a result, many promising technologies get stuck between the programs aimed at fundamental development activities and those focused on implementation. Therefore, there is a critical need to turn research products into proven technologies and demonstrated practices, identify the market forces that will influence successful technology and innovation deployment, and plan and deliver effective communication to promote rapid adoption of proven, market-ready technologies and innovations.

AI2.6

The FHWA NDE Program will work with FHWA's Center for Accelerating Innovation to identify proven and promising innovative research products and will work with technology developers to help them understand what is needed to turn those research products into market-ready technologies. Using the TRLs defined by the National Aeronautics and Space Administration (figure 5), the FHWA NDE Program will primarily focus on moving technologies from TRLs 5 and 6 to TRLs 7 and 8, where either industry or other research programs may support continued development and commercialization.[6]

FIGURE 5. GRAPHIC. TRLS.



Source: FHWA.

Source: iStock.com/monsitj.

S2.7: Future Advanced Tools and Platforms

Sensor technologies play a vital role in the function of autonomous vehicles (AVs), but the reality is that AVs struggle to navigate on faded or undetectable lane markings (i.e., due to snow coverage) and poor signage.

> *AI2.7*
>
> The FHWA NDE Program will coordinate with the Office of Operations Research and Development (HRDO), Intelligent Transportation Systems/Joint Program Office (ITS/JPO), and Office of Operations (HOP) to explore promising sensors that could assist AVs in navigating roadway geometries.

SO3: Implement Deployment-Ready Technologies

The current practice for infrastructure inspection is VI for surface defects and use of tactile methods, such as sounding with a hammer or chain, to detect subsurface delamination. While more sophisticated NDE technologies offer powerful alternatives to the current practice, their effective implementation and deployment demand multidisciplinary teams to integrate technology-specific expertise with sound structural engineering heuristics. One of the barriers to the implementation of technology in the transportation industry is a lack of technical knowledge related to the proper use of existing technologies. The FHWA NDE Program will assist in developing training tools, implementation strategies, and best-practice guidance, and then transferring such tools, strategies, and guidance to asset owners and consulting engineers who will ultimately be tasked with implementation. The FHWA NDE Program will work with FHWA offices, namely the Office of Technical Services and Office of Infrastructure, to support effective deployment.

S3.1: Maintain, Refine, and Expand Current Web-Based Training Tools

To date, the FHWA NDE Program has developed two Web-based training and information tools that are receiving an increasing amount of attention among asset owners and consultants. The primary goal of these tools is to improve awareness of available NDE technologies, provide an intuitive understanding of how they work, and link them to specific benefits that they may provide asset owners. The first tool, NDE Web Manual, is a problem-focused approach that presents a structured framework of all available NDE technologies, inclusive of their capabilities, operating principles, and the types of materials and applications for which they may be used.[14] The second and more recent addition is the NDE Virtual Laboratory that provides a more hands-on experience to users and walks them through numerous technologies—from interactive laboratory portals to detailed descriptions of case studies.

AI3.1

Given the success of these tools, the FHWA NDE Program will continue to invest in refining, improving, and expanding its scope to include a host of NDE technologies for different types of highway infrastructure and technologies beyond NDE, namely SHM.

S3.2: Develop and Validate Implementation Strategies

To introduce technology in highway infrastructure in a comprehensive manner, it is first necessary to develop and refine sound implementation strategies. As these strategies are being validated and maturing, stakeholders may begin to see practical approaches to technology adoption that will have tangible benefits to their current operations.

AI3.2

The FHWA NDE Program will assist the FHWA Program Office and Resource Center to develop sound implementation strategies for deployment-ready technologies and help disseminate such strategies through a series of guidelines and technical manuals.

S3.3: Perform Technology Demonstrations

With the pace of technology innovation, the landscape of available technologies is expected to evolve quickly in the next 5–10 yr. It is important to make stakeholders aware of new technologies in a timely and practical manner.

AI3.3

The FHWA NDE Program will regularly organize and carry out technology demonstrations in coordination with the FHWA Program Office and Resource Center. These demonstrations will be identified as either responsive to asset-owner needs (in cases of deployment-ready technologies) or in need of feedback (in cases of new technologies at various stages of development). The FHWA NDE Program anticipates that these demonstrations will present opportunities to bring stakeholders together from Government, academia, and industry backgrounds to continue to build and strengthen a community practice.

S3.4: Capture and Disseminate Best Practices

Advances in NDE technologies have shown significant promise to the highway-infrastructure community for obtaining necessary information through those technologies. However, the current practice of applying NDE technologies by asset owners is not documented. NDE practices vary significantly from State to State. Some States use NDE technologies on an as-needed basis to augment VI, while other States rely only on VI and sounding methods.

AI3.4

The FHWA NDE Program will conduct a synthesis study to document NDE technologies currently in use by State DOTs from all available sources and will prepare a concise and documented report. This synthesis report will document best practices and problems with how asset owners use NDE technologies to inspect and manage infrastructure assets.

S3.5: Assist in Developing Training Curricula, Standards, and Certification Related to Assessment Technologies

Standards, specifications, and recommended best practices are needed to support technology use. Additionally, training curricula leading to certification are needed to define and enforce minimum standards in the application of technology.

AI3.5

The FHWA NDE Program will develop proposed standards for consideration by AASHTO. Additionally, this program will support development of FHWA guidance that reflects the program's research findings and AASHTO standards. Additionally, the FHWA NDE Program will support relevant professional societies, including the National Highway Institute and ASNT, by preparing and reviewing training materials for the application of NDE technologies in pavements and bridges and defining workforce qualifications. Not only does the certification process lead to a formalization of best practices, but it will also help standardize the industry, which will enhance confidence and will accelerate the implementation of NDE technologies.

S3.6: Develop an Outreach Program Through Webinars, Workshops, Training, a Discussion Forum, and Technical Briefings

A lack of familiarity with proper uses of NDE technologies is a significant barrier to their implementation in the highway-infrastructure sector. Overcoming this challenge requires the development of training tools and technical briefings and sharing them with stakeholders. There is also a need to identify lead State adopters and create a discussion forum where State DOTs could share information and experiences and provide feedback, which would provide a centralized system for each State DOT to view and learn from one another.

AI3.6

The FHWA NDE Program will transfer knowledge acquired from the strategies and AIs to stakeholders through webinars, workshops, peer exchanges, one-pagers, and technical briefings that employ NDE technologies to complement VIs and assist in developing reliable asset-management strategies. The FHWA NDE Program will also create a discussion forum or clearinghouse where State DOTs can share their knowledge and experiences and provide feedback that other States can access and use to learn. The FHWA NDE Program will coordinate with other FHWA programs to develop an expanded social media presence to better engage stakeholders.

CONTEXT—OVERVIEW OF THE *FHWA NONDESTRUCTIVE EVALUATION PROGRAM STRATEGIC PLAN FOR FY 2019–2022*

For the sake of brevity, the following sections present selected SGs, SOs, and strategies that were identified through USDOT and FHWA strategic-planning processes that are relevant to the future direction of the FHWA NDE Program.

SGs

FHWA and USDOT recently published their strategic plans for 2018 through 2022.[1,2] The following four key SGs were identified in both strategic plans:

- **Safety**—Reduce transportation-related fatalities and serious injuries across the transportation system.
- **Infrastructure**—Invest in infrastructure to ensure safety, mobility, and accessibility for road users and stimulate economic growth, productivity, and competitiveness for workers and businesses.
- **Innovation**—Lead in the development and deployment of innovative practices and technologies that improve the safety and performance of the Nation's transportation system.

- **Accountability**—Serve the Nation with reduced regulatory burden and greater efficiency, effectiveness, and accountability.

Related SOs and Strategies

The FHWA strategic plan identifies a series of SOs to support the key SGs of safety, infrastructure, innovation, and accountability.(1) Although aspects of the FHWA NDE Program may touch on the safety and accountability SGs, the program's primary mission is most closely related to the infrastructure and innovation SGs. Of interest for the FHWA NDE Program are the following four SOs that correspond to the infrastructure and innovation SGs:

- **SO2**—Improve program and project decisionmaking by using a data-driven approach, asset-management principles, and a performance-based program that will lead to better conditions and more efficient operations.
- **SO3**—Increase mobility of freight and people and reliability by building effective partnerships and encouraging targeted investments.
- **SO4**—Enhance the safety and performance of the Nation's transportation system through research and accelerating development and deployment of promising innovative technologies and practices.
- **SO6**—Transform the workforce and resource-management approach to ensure FHWA is properly structured, skilled, and equipped to deliver outstanding customer service to its partners and the traveling public.

Table 2 shows how SGs and implementation strategies were mapped from FHWA to the FHWA NDE Program.

TABLE 2. MAPPING OF SGS AND IMPLEMENTATION STRATEGIES FROM FHWA TO THE FHWA NDE PROGRAM.

FHWA SG	FHWA SO	SG1		SG2							SG3					
		NDE S1.1	NDE S1.2	NDE S2.1	NDE S2.2	NDE S2.3	NDE S2.4	NDE S2.5	NDE S2.6	NDE S2.7	NDE S3.1	NDE S3.2	NDE S3.3	NDE S3.4	NDE S3.5	NDE S3.6
Infrastructure	#2	—	—	•	•	•	•	•	•	•	•	•	•	•	—	—
Infrastructure	#3	•	—	—	—	—	—	—	—	—	•	•	•	•	•	•
Innovation	#4	—	—	—	—	•	—	•	•	•	—	—	—	—	—	—
Accountability	#6	—	•	—	—	—	—	—	—	—	—	•	—	—	•	—

•Applicable.
—Not applicable.

FHWA NDE PROGRAM POTENTIAL PROJECTS

NEAR-TERM PROJECTS

The following sections provide abstracts for the high- and medium-priority projects that have been identified through one-on-one discussions with internal and external stakeholders in various venues. These projects will allow the FHWA NDE Program to provide the most significant benefits to stakeholders in the near-term future. These projects primarily focus on improving the value of existing technologies to stakeholders in the realm of highway-infrastructure assessment. The focus on these primary areas was derived from recent stakeholder engagement activities and offers the FHWA NDE Program the opportunity to not only reinforce its position as a trusted partner to asset owners, but also to make a significant near-term impact on how customer agencies view and deploy NDE technologies.

Topic 1: Highway-Infrastructure Condition Assessment

Project 1—Evaluation of Pavement Foundations Using NDE Technologies

Priority: High

Abstract: One pavement rehabilitation option is placing an overlay over an existing structure. However, an overlay might not be the best option if the condition of the foundation is poor (e.g., contaminated base, decompaction, significant variability in foundation support). Doing so can result in poor rehabilitation performance. To assess a pavement foundation at the time of rehabilitation, highway agencies are using falling-weight-deflectometer (FWD) and ground-penetrating-radar (GPR) NDE technologies in tandem. FWDs are used to measure a pavement foundation's moduli values with inputs of GPR measurements. However, FWDs and GPR have some limitations (e.g., dielectric constant properties of layers are typically assumed based on published values in literature but can vary with moisture content at the time of testing, material type, and curing time), and therefore, is not a proper way of evaluating or quantifying the condition of pavement foundation.

Through a series of laboratory and field testing, this study will identify promising NDE technologies to evaluate pavement foundations and develop guidelines for using such technologies.

Project 2—Uniformity and QA of Pavement Foundations at the Time of Construction

Priority: High

Abstract: Stakeholders have shown a lot of interest in using NDE technologies to evaluate conditions of pavement structures. Ensuring the uniformity and quality of a pavement foundation at the time of construction is critical for avoiding costly future problems. NDT methods are an excellent tool for evaluating quality and uniformity of a pavement foundation in the QA of new construction. IC may have the potential to monitor the uniformity and stiffness of a pavement foundation during its compaction. Continuous monitoring of quality during construction can help build better quality and long-lasting pavements.

This study will investigate the application of IC in foundation quality control at the time of construction, establish a correlation between IC's measurements and foundation quality or uniformity, and develop guidelines for the use of IC in QA.

Project 3—Evaluation of Tunnel Linings Using NDE Technologies

Priority: High

Abstract: Many tunnel-ceiling incidents, in the United States and around the world, illustrate that timely detection and remediation of problems within tunnel linings are central to ensuring road-user safety. With the aggressive environmental conditions in which tunnels exist, structural problems could lead to rapid deterioration and unexpected tunnel failures, which in turn, could cause serious injuries and even fatalities. Tunnel inspections are required by MAP-21 and the published NTIS.[11,13] Periodic condition assessment of tunnel structures is key to determining the appropriate schedule of maintenance and/or rehabilitation activities needed to remedy structural and safety problems. NDE technologies can benefit a tunnel-inspection program by providing information on conditions behind tunnel walls and linings. NDE technologies may provide a cost-effective means to examine a structure in more detail and provide independent verification of defects identified by VI. Nonetheless, further information and guidance are needed to support appropriate NDE-technology selection, deployment, and interpretation. High-speed NDE technologies that would minimize the disruption of ongoing traffic are also needed.

This comprehensive study will identify promising NDE technologies for evaluating the condition of various types of tunnel linings and tunnel-lining finishes, such as tile. The selected technologies will be deployed, and related guidelines and protocols will be developed to successfully implement these technologies.

Topic 2: Buried Utilities

Project 1—NDE Technologies for Detecting and Locating Buried Utilities

Priority: High

Abstract: Extensive arrays of utility networks, which are vital to society's daily life, are buried underneath the ground's surface. Highway renewal projects and expanding or replacing sections of a road-network depend on the availability of accurate buried-utility records and information to support effective planning, design, and delivery of renewal work. In addition, buried utilities have a limited service life, and assessing their condition throughout their lifecycles is crucial to avoiding potential catastrophic failure due to their deterioration. Thousands of excavations are carried out within the U.S. road network each year to relocate, install, or repair buried utility pipes and cables. Additionally, utilities are often exposed as roadway construction occurs in their vicinity. The precise location of existing buried utilities is mostly unknown to highway agencies. Not knowing the location of buried assets causes practical problems that increase costs and delay projects, but more importantly, it increases the risk of injury to project personnel and damage to utilities that can have ripple effects far beyond the project boundaries. The problems associated with inaccurately locating buried pipes and cables are serious and are rapidly worsening due to the increasing density of underground infrastructure in major urban areas. Buried-utility conflicts and relocations are two of the largest causes of project delays during road construction.

This study will investigate and document the reliability of existing and promising NDE technologies for mapping buried utilities and will identify and demonstrate innovative applications of existing NDE technologies for mapping buried utilities.

Topic 3: Bridging the Gap Between Research and Implementation

Project 1—Integrate NDE Technologies Into Asset Management

Priority: High

Abstract: Asset owners have worked toward implementing effective asset-management plans and performance-based management for their highway assets, including, but not limited to, bridges and tunnels. The primary goal of this study is to investigate how NDE technologies can be applied to improve highway asset management and inform timely asset-management decisions.

Project 2—Minimum Drone Standards for Supplementing VI

Priority: High

Abstract: NDE and VI of highway infrastructure are critical for evaluating existing material deficiencies and suitability for safe, continued service. However, access requirements in performing these inspections introduce various risks and can significantly increase costs. Inspection sites often require specialized access to areas of the bridge to perform a VI via equipment, such as under bridge inspection trucks, personal fall protection (safety harness and lanyard), ladders, scaffolding, inspection bucket trucks, catwalks, and rigging. Working in such environments is a safety risk to the worker performing the inspection and expands work zones and traffic detouring, which results in increased congestion and hazardous risks for the traveling public. UAS have the potential to improve the safety and efficiency of highway-infrastructure inspection by enabling the inspection to be conducted with workers safely on the ground. The NSBA defines several types of inspection, including initial, routine, comprehensive, damage, special, and underwater, as well as inspections of fracture-critical members. In general, fracture-critical members, elements in poor condition, and elements underwater require a hands-on inspection, and inspection of this type is not possible using solely UAS. The primary reason for this impossibility is that such inspections generally require direct contact or close inspection of elements of interest (to remove debris, clean rust, measure section loss, determine extent of deterioration through sounding, etc.), which currently cannot be performed by available UAS. Although expanding UAS capabilities to perform such inspections in the future is certainly possible, in the near term, the focus of the FHWA NDE Program will be on maximizing or identifying the benefits of existing technologies for asset owners. The primary goal of this study is to determine the minimum standards to establish a UAS program and procedures for supplementing VI and further implementation of UAS in bridge inspection to improve the NSBA and NTIS, particularly with regard to the safety and efficiency of inspection work.[13]

Topic 4: Advanced Data Analysis, Interpretation, and Visualization Techniques to Improve Detection and Diagnosis

Project 1—Spatial and Temporal Probability-Based NDE Data Analysis

Priority: Medium

Abstract: The objective of this project is to establish the benefits of temporal (captured when NDE data are collected across multiple periods) and spatial data analyses over conventional approaches and develop protocols and guidance as to how such approaches may be implemented in practice. To date, the interpretation of NDE data is generally carried out in a point-by-point manner, which treats each data point in isolation and ignores its spatial context. Also, NDE technologies have been employed to capture snapshots of condition maps, and thus, all NDE data-analysis and -interpretation technologies focus exclusively on data collected during a single period. Over the last decade, several researchers have begun to conduct NDE analyses over multiple periods with the goal of not just capturing a snapshot of condition maps, but also tracking deterioration rate and how spatial patterns of deterioration evolve with time. This new approach to data collection essentially creates a time series of NDE data; however, current data-analysis and -interpretation approaches are only capable of dealing with NDE data as a snapshot. Under this project, researchers will explicitly examine and evaluate the use of temporal and spatial contexts to improve the overall reliability of results from NDE analyses.

For example, based on the current temporal NDE datasets, it appears that conditions generally stay constant or degrade at slow to moderate rates. In cases when condition improves over time, lower data quality or confidence may be assigned. Conversely, in areas where temporal relationships are within expected ranges, higher levels of data quality or confidence may be assigned. If an element's condition reaches a critical point, the deterioration progresses rapidly and condition changes at a higher rate. Only if this rate of change is consistent through the rest of the element or structure, higher data quality or confidence may be assigned.

For example, in a spatial context, low dominate frequencies are caused by the flexural vibration mode of delaminated concrete, which is consistent with an advanced stage of delamination, when using impact-echo methods. Given the spatial size of such advanced delamination, such data provide information about the condition of concrete in the vicinity of where the data were extracted. That is, such data also carry information about the size of the delamination (with larger delaminations resulting in lower dominate frequencies), which can be used to cross-validate other data points within this zone. If this cross checking bears out a spatial consistency within the data, then improved quality or confidence may be assigned, whereas if this cross checking results in inconsistencies, then lower quality or confidence may be assigned.

Project 2—Machine Learning–Based Infrastructure Condition Assessment

Priority: Medium

Abstract: Currently, there is a strong demand for condition assessment of a large population of highway infrastructure with various advanced NDE technologies and advanced processing techniques, which allow automated identification of hidden defects and damages. Artificial intelligence algorithms (e.g., machine learning (ML) and deep learning (DL)) have great potential to predict deterioration of highway infrastructure. ML is generally defined as a set of algorithms that are capable of parsing and learning from data and then applying what was learned to make informed decisions. For ML to work in practice, it is necessary for an analyst to provide feedback as to whether the resulting decisions are accurate. In contrast, DL, which is a subset of ML, does not require this feedback to improve decisions and can operate more autonomously. This benefit, while impressive, do come with some additional requirements, namely, access to much larger datasets. In either manifestation, the goal of these algorithms is to automatically process big data, identify patterns and relationships implicit within the data, and leverage these patterns and relationships to provide improved predictions. As such, both ML and DL appear highly compatible with NDE data analysis, which also aims to discern patterns and relationships from massive datasets. These methods can be used for multi-NDE data processing to automate infrastructure condition assessment. The general procedure involves collecting and preprocessing data, labeling or parsing data, defining appropriate learning model(s), training the model, and testing or evaluating the model on the new data (outside the training samples). The ultimate goal of this study is to establish how artificial intelligence (inclusive of ML and DL algorithms) can improve the reliability and quality of NDE data analysis for condition assessment of highway infrastructure. Of particular interest will be identifying the most suitable learning models and optimization methods to process NDE data and developing a framework to guide the implementation of such techniques to support reliable data interpretation.

Project 3—AR to Supplement and Improve Infrastructure Inspection

Priority: Medium

Abstract: To ensure safety and longevity of highway infrastructure, onsite VI, NDE, and SHM are used to assess performance and condition and quantify deterioration. VI techniques involve chain dragging or hammer sounding to detect deterioration, taking photographs, taking measurements with tape measures, and filling out forms or reports to document damage and repairs. In general, these approaches have two primary shortcomings. First, they tend to result in only sparse information about the state of the infrastructure. Second, they tend to operate without the context provided by previous inspection activities to allow inspectors to better assess changes in condition and estimate deterioration rates. In contrast to these approaches, NDE and SHM systems generally capture data with high spatial and/or temporal resolutions that can provide improved spatial coverage and quantitative estimates of changes and deterioration rates. However, the size of data captured by different technology components makes it difficult to assess and visualize any potential deterioration conditions in a combined, yet meaningful manner. AR tools offer a possible solution that mitigates these challenges. AR tools can be used to quickly and easily capture and allow inspectors to visualize high-resolution, full-field three-dimensional models (including data and metadata for VI, NDE, and SHM) of infrastructure's previously documented condition while they are on-site. In addition, the geometry-capture (e.g., LiDAR) data required to implement such approaches offer additional benefits, such as the ability to generate finite-element models that accurately reflect the condition and as-built geometry of the infrastructure at a given point in time. AR also facilitates sharing the infrastructure inspection notes between inspectors across time because it opens the possibility for including geotagged notes, photographs, and so forth created by various inspectors. The outcome can be incorporated and integrated into building information modeling and considered in further lifecycle management. The ultimate goals of this study are to establish a framework for incorporating AR within highway-infrastructure condition assessment practices and to validate the framework through a series of field deployments. This work will build off related work completed under the Infravation SeeBridge project.[15]

Project 4—Data Fusion Across Multiple NDE Modalities

Priority: High

Abstract: The objective of this project is to establish how fusing data from multiple NDE modalities can improve overall NDE data reliability. Recently, there has been increasing interest from stakeholders in deploying multiple NDE modalities to provide more reliable condition assessments. While this approach is to be commended as it recognizes that many NDE technologies are inherently complementary (i.e., one technology's shortcomings align with another technology's strengths), it is typically carried out in a qualitative and subjective manner. That is, each technique is generally processed and analyzed in isolation with the integration generally done through qualitative comparison of condition maps. Under this project, researchers will work further upstream within the processing and interpretation framework and look for opportunities to fuse the data to produce more reliable condition results. The FHWA NDE Program envisions that this integration will take one of two ways identifying reliable parameters to be used within the data-processing framework of each technique or providing a means for quantitative cross-validation of techniques to estimate data quality or confidence. An example of this first integration approach involves using cover depth, acquired from GPR, to define the bounds the dominant frequency, obtained by using an impact-echo method, that would constitute shallow, early-stage delamination. An example of the second type of integration would include using the spatial correlation between results from impact-echo methods and GPR to determine whether the delamination identified contains water, the presence which would likely indicate corrosion of the reinforcement.

Topic 5: Capture and Disseminate Best Practices

Project 1—Document Deployment-Ready NDE Technologies, Current Practices and Policies of State Highway Agencies, and Added Value and Asset Owner–Defined ROI for Applications of NDE

Priority: High

Abstract: Maintaining the Nation's infrastructure is a big task. Bridge, tunnel, and pavement structure–evaluation practices vary significantly from State to State. Some States use NDE technologies on an as-needed basis to augment VIs, while others rely on only VIs and sounding methods. In addition, as

NDE technologies are being deployed (although on a limited basis) to serve assessment and management goals related to highway structures, capturing the circumstances in which the use of NDE technologies add value, how various State highway agencies define ROI, and in particular, how they define and quantify the various costs (direct, user, etc.) and benefits (reduced uncertainty, improved forecasting, more efficient use of time and resources, etc.) associated with technology applications is necessary. The objective of this project is to document NDE technologies that are currently used in practice by State DOTs, identify NDE technologies that are mature enough for more widespread deployment and implementation, and quantify the added value and ROI (as asset owners define it) related to applications of NDE. Through this project, the FHWA NDE Program will identify and engage first adopters of NDE technologies and document how their decisions related to the deployment of NDE technologies are made (in particular, the goals and expectations they have for applying NDE). In addition, this project will track the actual deployment of NDE technologies, the results obtained, and ultimately the asset owner–defined ROI. This research will also provide examples of how ROI can be calculated.

This study will document deployment-ready NDE technologies and the strengths and limitations of those technologies from the perspectives of accuracy, precision, ease of use, speed and cost. Based on the results of this study, researchers will recommend or develop test procedures and protocols for different applications of those technologies. This information can be obtained by literature search and review (e.g., SHRP2) as well as through validation testing on developed test beds, real structures, or a full-scale infrastructure system in an accelerated testing facility. This study also documents best practices and potential problems and highlights how asset owners use NDE technologies to assist them with managing their infrastructure assets. This document will be a valuable source for practitioners and asset owners to deploy NDE technologies in managing infrastructure assets more effectively.

Topic 6: Future Advanced Tools and Platforms

Project 1—Exploring Sensor Technologies to Improve Capabilities of AVs

Priority: High

Abstract: Sensor technologies play a vital role in advanced tools and platforms, such as AVs. The aim of this project is to objectively assess the capabilities and limitations of available and proven sensors for AVs and to explore promising sensors that could assist AVs in navigating roadway geometries. Effort will be coordinated with HRDO, the ITS/JPO, and HOP.

Topic 7: Standards and Technical Guidance

Project 1—Develop NDE Standards for Consideration by AASHTO and FHWA Technical Guidance

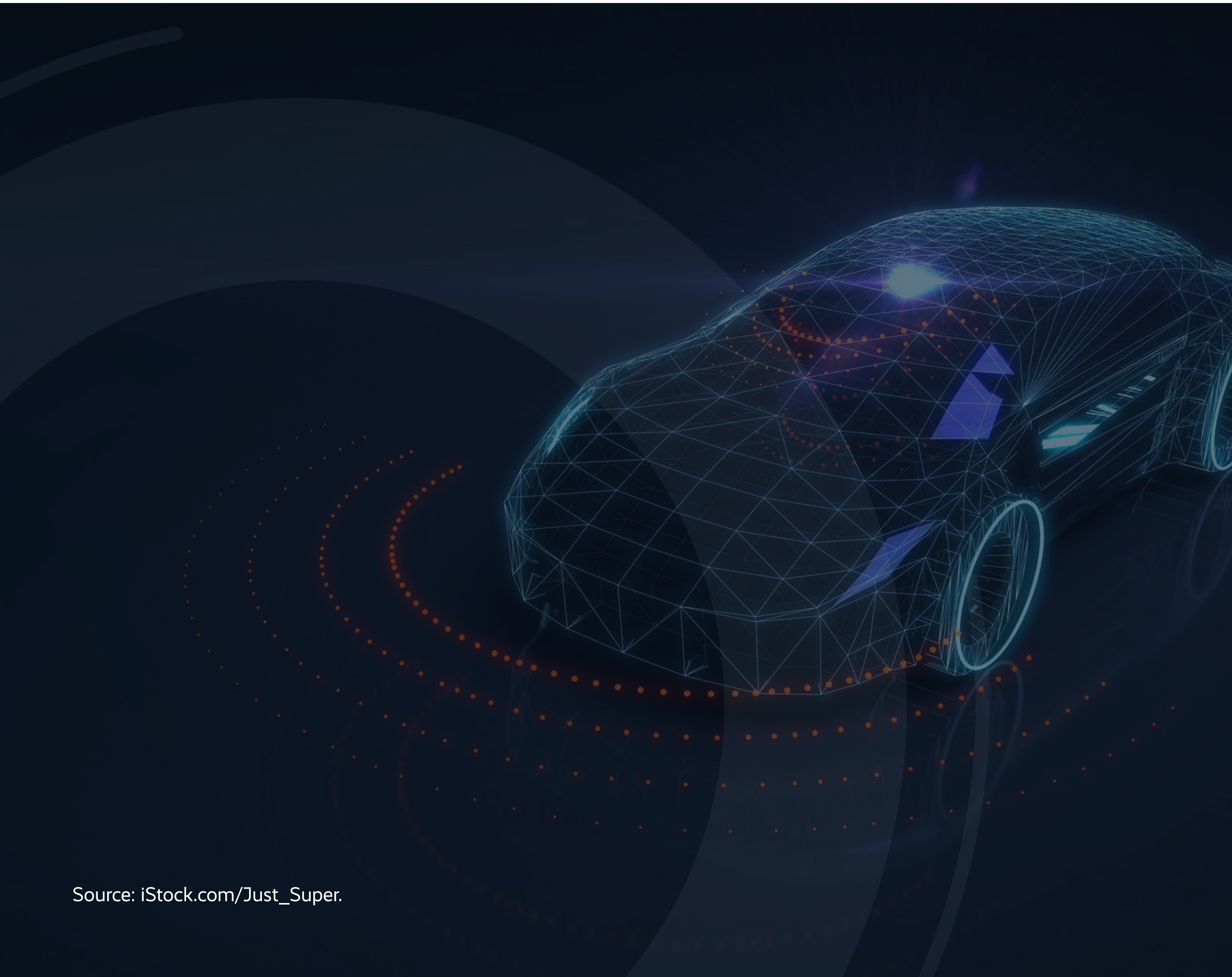
Abstract: The FHWA Long-Term Bridge Performance Program has released a set of data-collection protocols for testing in-service bridges with the goal of ensuring consistent data collection and reporting. Additionally, the American Concrete Institute, the American Society of Civil Engineers, and the Federal Institute for Materials Research and Testing in Germany have all developed similar protocols. The FHWA Mobile Concrete Trailer has developed one-pagers on NDE technologies and in-person trainings for the use of these technologies for pavement-structure evaluation. Some States also have their own NDE-technology specifications. However, no single set of standards and guidelines that identify the best practices for field data collection, analysis, and reporting with regard to NDE data exists. The objective of this project is to review and compile existing specifications and develop a single NDE standard for consideration by AASHTO as well as FHWA guidance to reflect the NDE Program's research findings and the AASHTO standard.

Project 2—Develop Technical References for the Use of SHM

Priority: High

Abstract: Documentation of successful SHM applications and tying specific SHM approaches to specific performance problems were among the more important needs identified in the recent NDE-SHM workshop, led by the FHWA NDE Program. The following are three possible forms of guidance:

- Web Manual—The current NDE Web Manual can be expanded to include SHM technologies and techniques. This format not only provides open access to all end users, but can also be updated frequently to include recent developments.[14]
- Case Studies—Detailed documentation of complete SHM case studies is important to provide tangible examples to end users. The inclusion of unsuccessful case studies (with successful case studies) is also valuable.
- Synthesis Report—The development of a synthesis report that documents domestic and international practices and policies related to SHM is necessary.



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