TR NEWS

July–August 2022

NUMBER 340

New Technologies in Highway Construction

PLUS

Cyberphysical Systems

Augmented Reality

From Paper to E-Ticketing

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TR NEWS

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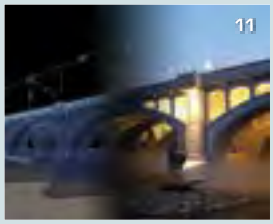

COVER Digital technology is the driving force behind highway construction innovations. The ability to see in 3-D via enhanced modeling technology is arming construction project designers with the means to produce more precise plans, manage materials, and track and organize data. Such technology is only part of the innovations in use now or just down the road in highway construction. (iStock)

ALSO IN THIS ISSUE

TRB COVID-19 Resources

Agencies and organizations can use TRB publications and online resources for useful and timely information to help address issues related to the COVID-19 pandemic. To read about TRB's current research and activities, and for a list of relevant publications, visit www.nationalacademies.org/trb/blog/transportation-in-the-face-of-communicable-disease.

Coming Next Issue

The September–October 2022 issue of *TR News* features a variety of perspectives on decarbonizing transportation. This theme issue is unique in that authors present thought-provoking discussions—some reflecting decidedly strong opinions—on a controversial subject. One author presents ideas on how growth in transportation electrification may increase energy to power grids while furthering decarbonization. Another author poses the challenge California faces in its efforts to reduce greenhouse gases by getting drivers off the roads. Other authors outline the research needed to support carbon reduction in aviation. All give readers a lot to consider as we move toward a zero-emissions future.


PxHere

Plugged in and powering up, an electric vehicle will soon be back on the road. Such vehicles have a role to play in the quest to reduce the transportation industry's carbon footprint.

The *TR News* Editorial Board thanks Waseem Dekelbab, TRB, for his work assembling and developing this issue.

TR NEWS
features articles on innovative and timely research and development activities in all modes of transportation. Brief news items of interest to the transportation community are also included, along with profiles of transportation professionals, meeting announcements, summaries of new publications, and news of Transportation Research Board activities.

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NEW TECHNOLOGIES IN HIGHWAY CONSTRUCTION

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Drones that aid in bridge maintenance. Smart roads that help control traffic. Electronic ticketing that offers more precise construction project management. All are among the new technologies that are driving highway construction into the future.

Let's cast our minds back nearly three decades ago when *TR News 176* (January–February 1995) was published as a special issue titled *Automation and Robotics in Highway Design, Construction, and Maintenance*, in which the realized and perceived benefits of automation were discussed. A notable remark about the future of highways stressed the need for a change to improve performance and the importance of supporting breakthrough research. Fast-forward to the present and *TR News 340* (July–August 2022) again reports on new highway-related construction technologies. But, why now?

It would not be an overstatement to say that the United States' highway construction industry, essentially, is tied to the nation's economic growth. Three forces propel the future of the highway construction industry: the weight of the past, the push of the present, and the pull of the future (*1*).

Long-standing challenges that include lagging productivity, workforce concerns,

and slow innovation and digitization characterize the past of the highway construction industry.

The push of the present is represented by trends that are driving change. One such trend is the strong growth supported by the 2021 Infrastructure Investment and Jobs Act, which includes $110 billion in funding to revitalize U.S. bridges, roads, and other major highway construction and maintenance projects.

Ohio DOT

Making last-minute checks, Ohio Department of Transportation (DOT) flight operations manager David Gallagher prepares to inspect nearby Veterans' Glass City Skyway Bridge in Toledo. Among an arsenal of new technology, drones can reach tight spots and capture data with far more ease, speed, accuracy, and safety than traditional hands-on inspections.

Additional current trends include the need to

- Address aging infrastructure, as well as the long-term benefits of yet-to-be-realized technology that would improve efficiency, cost less, and save time;
- Boost the number of technology solutions providers;
- Focus on labor shortages due to a reduced inflow of younger workers and resignations of existing workers; and
- Provide greater emphasis on diversity, equity, and inclusion.

The question then arises: What will the future of the highway construction industry look like? An image of that future that has been at the forefront of construction companies' conversations is that of technology reinventing the industry. Specifically, how can digital twins and cyberphysical systems support highway systems? How can new digitization tools, such as augmented reality and drones, enhance project delivery? And how can electronic ticketing of materials and building information modeling be leveraged for jobsite management? To underpin future success, state transportation agencies and contractors need new strategies to reinvent their business-as-usual processes to keep up with high demand and increased project complexity. These strategies must incorporate the digital and information technology revolution that the highway construction industry has been witnessing.

The question then arises: What will the future of the highway construction industry look like?

In this *TR News* issue, transportation professionals discuss these and other digitization tools, as well as the role of COVID-19 in driving industry reinvention by transforming data into future actions in highway construction.

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VOLUNTEER VOICES

"Sometimes life events—such as having a new baby, moving cross-country, or not having a sponsor—have interfered with in-person attendance at TRB Annual Meetings. In these cases, online access to the papers and presentations—posted a month after the meetings and now accessible by contacting their authors—has been invaluable. I use this resource throughout the year, and it is like being at the Annual Meeting every day!

—JANE GOULD
Principal, WAVA
Tiburon, California

Cyberphysical Systems

Innovative Applications for Highways

iStock

NAZILA ROOFIGARI-ESFAHAN

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Powered by innovation and technology, modern cities evolve into smart cities through a coordinated network of computer-based and physical components such as cloud storage, wireless Internet, GPS, and roadway sensors. Such cyberphysical systems are becoming the heartbeat that keeps cities thriving.

Cyberphysical systems (CPSs) are engineered systems built from—and dependent upon—the seamless integration of computational and physical components. Computer-based algorithms control or monitor the physical and computational systems in this mechanism. Such systems permeate practical applications that become an integral part of many industries, including manufacturing, healthcare, agriculture, energy systems, smart infrastructure, and transportation.

In the 21st century, CPSs are expected to generate innovation and drive for economic productivity and growth comparable to the Internet revolution of the late 20th century. However, their widespread adoption is limited due to the short supply of educational and training programs to develop skilled workforces and large-scale testbeds, which are expected to be major challenges over the next decade.

CPSs are safe and interoperable. They are smart networked systems with distributed and deeply integrated cyber and physical components, including sensing, control, processing, computing, communication, and actuating elements capable of interacting with the physical world and human users in real time. CPSs' design and inception are built upon this simple mantra: Knowledge is power.

As the name implies, a CPS essentially involves the integration of two subsystems: the cyber subsystem and the physical subsystem. The cyber subsystem, in some sense, represents the overall central nervous system of the CPS. It provides the "smart" elements of the system that control and enhance the operation of the physical subsystem's components. This central control system entails the computational subsystem involving communication infrastructure and computational algorithms. The physical subsystem involves components particular to the application context. For example, in transportation systems, this could include the road infrastructure, traffic control devices, and vehicles

Ivan Radic, Flickr, CC BY 2.0

In recent years, cyclists' safety has accelerated to include a dedicated light signal in traffic control devices at busy intersections.

Andrew J. Loney

Taking wrong turns and getting lost occur less frequently, as long as drivers rely on GPS. Such intravehicular sensors provide data that not only direct motorists along their journey but also warn of traffic conditions and accidents ahead.

(e.g., connected–automated vehicles). In contrast, in robotics applications, it would include the robot's motor units, gearbox, and arms, as well as the environmental elements it interacts with. Sensors and actuators are physical data collection and measurement devices that act as the connectors between physical and cyber subsystems. Sensors collect data from physical components, and actuators automatically implement the actions dictated by the central computing system on the physical components. For example, intravehicular sensors such as GPS and inertial sensors collect data about a vehicle's real-time location, speed, and heading. Passive magnetic sensors, which are installed on roads, collect information about traffic conditions. The collected data are transferred to the computational center, and the decisions—traffic light cycle times—are communicated back through actuators. What distinguishes CPSs from other smart systems (such as the Internet of Things[1] and embedded systems) is the tight integration between the cyber and physical subsystems. That is, these subsystems must closely collaborate and coordinate seamlessly. This tight integration drives the main CPS properties, including adaptability, autonomy, efficiency, functionality, reliability, safety, and usability. However, the priority of these properties varies, depending on the application domain and available resources.

Technology Requirements for CPS Implementation

To establish a CPS, the targeted application's physical components to be "smartened" need to be identified. The components consist of the legacy system of the original physical system prior to cyber enablement. The physical elements in CPSs can include the electrical and mechanical components—as well as the physical space that interacts with these components—of a robotic or autonomous system. The cyber subsystem is a set of computational processes running on computing platforms superimposed on the physical space. These computational systems continuously observe and monitor the state of the physical elements and identify the changes, discrepancies (or both) from the planned state. The cyber subsystem involves software, data structures, databases and networks, and the processors and computational devices. The integration of the cyber and physical elements occurs at the cyber–physical bridge. This integration bridge is comprised of elements that are connected physically or wirelessly and are used to sense and collect data from physical components, conduct necessary analysis and control, enable information flow throughout the system, and roll back the decisions to the physical elements. The information communicated between physical space and cyberspace using sensors and actuators is achieved through wired or wireless networks based on the application. Such integration involves observation of physical components conducted by sensors. These sensors provide the physical-to-cyber link that converts observable and measurable physical quantities to data. They connect the physical world with the cyber world by converting real-world phenomena into signals that can be processed, stored, visualized, and acted upon in cyberspace. Such sensors can be integrated into many devices and used in numerous applications. The data retrieved through sensors are processed, interpreted, and fused to generate the required information of the physical subsystem—depending on the application—without losing its semantics. In contrast, the cyber-to-physical link occurs

[1] The Internet of Things is the network of data-connecting and data-exchanging physical objects, or "things", that are embedded with sensors, software, and other technology.

at the actuation interface. The control decisions and required actions are communicated back to the physical space through actuation control. Figure 1 shows a CPS framework for roadside work zone safety applications. A CPS can vary significantly in scale. It can be a small local system (such as a building management system) or a highly connected, complex, and large system integrated over several domains (such as a city-scale autonomous transportation system or a smart electric grid that spans a continent).

CPS concepts are related closely to many fields, including embedded systems, robotics, the Internet of Things, and big data. However, the real-time interactions of CPSs with the physical world distinguish them from conventional systems. As a result, the terms that follow should not be used interchangeably, as differences lie in their characteristics, scale, and intended applications.

- **Embedded Systems**: These systems focus on integrating cyberelements—such as processors and software—to purely electrical and mechanical systems for performing a specific task. The idea of CPS originated from generalization of the concept of embedded systems to multitask in real time through integrating distributed sensing, computation, control, and actuation over a communication network.
- **Robotics**: The robotics field focuses on the seamless integration of sensors, actuators, processors, and control to perform a task autonomously or semiautonomously. Although similar elements are present in robotics and CPS, the strong emphasis on distributed sensing, processing, control, actuation, and networking is a distinguishing feature of a CPS.
- **Internet of Things**: This system focuses on a dynamic communication network infrastructure with standard interoperable protocols that autonomously communicate data among entities with well-defined and unique identifiers. These entities include physical equipment, virtual elements, computing devices, and human users. While CPSs have roots in control, computer science, real-time systems, and sensor networks, the Internet of Things has roots in communication networks and wireless communication. In other words, the concept of the Internet of Things emphasizes networking and communication protocols, while CPSs add the aspects of control or regulation, computational power, and human interaction. As such, the Internet of Things is a subset of CPSs.
- **Big Data**: The field of big data focuses on the systematic analysis, storage, and visualization of a large volume of data. CPSs facilitate the systematic transformation of massive data into information, which makes the invisible patterns of degradations and inefficiencies visible and yields to optimal decision making. Although the big data field has applications in CPSs, its focus is limited in comparison to CPSs. For example, intravehicular and road sensors create an immense amount of data every second. The collected data are then transferred to and analyzed by the CPSs' computational center and are used for making decisions relative to traffic management.

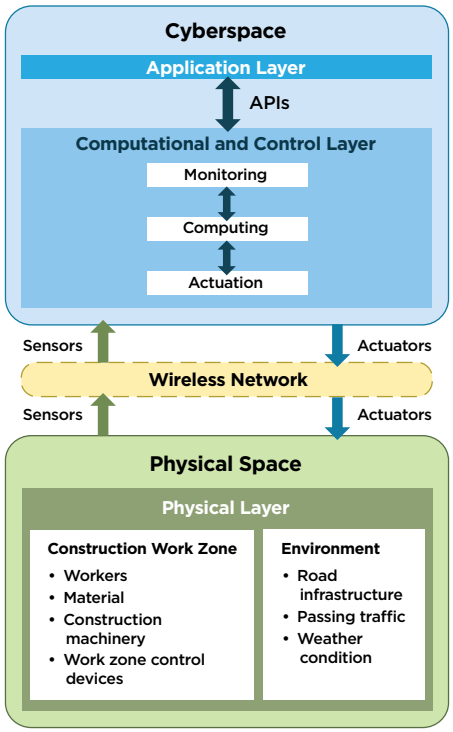

FIGURE 1 CPS framework for construction work zone safety applications (APIs = application programming interfaces).

Highway Versus Building Projects

The overarching goal of CPS implementation in construction is to enable rapid design and deployment of integrated computational and physical systems for different phases of the construction life cycle—from planning and design to construction and facility management. Although the general CPS requirements are the same, the details of the subsystem components and processes highly depend on the type of project, targeted application, and life-cycle phase. Similarly, the requirements for CPS implementation in highway (horizontal) projects are different from those for building (vertical) projects.

A comprehensive look at the current state of CPS implementation in construction indicates that most attention is paid to vertical projects, and few studies have been conducted on horizontal ones. Moreover, although the industry adopted CPSs at least a decade ago, implementation is in the initial stages. For example, in future CPS designs, decisions must be made to keep or remove the CPS components from the worksite.

When comparing applications, vertical and horizontal projects currently focus on the same three applications: machinery or resources monitoring, safety, and component tracking/progress monitoring. While vertical projects have a wider range of CPS implications (such as environmental purposes and temporary structures), horizontal construction has focused mainly on monitoring resources and safety issues. In both vertical and horizontal projects, CPS concerns are limited to addressing functionality issues and do not focus on the life-cycle assessment of the system.

The technology requirements for CPS implementation in these projects also are different. In vertical projects, accelerometers, gyroscopes, and proximity sensors are the

most important sensing devices. However, in horizontal projects, location sensors play a pivotal role because the nature of horizontal projects requires a comprehensive insight into the dynamic locations of the job site resources, including machinery and workers.

Communication means also are different due to the various environments surrounding these two types of projects. Highway work zone environments are open, dynamically changing locations, and the projects are short in duration. On the other hand, building project work sites are confined and static (i.e., the location of the project does not change over the life of the project, although the underlying processes change over time). Such projects usually take a relatively longer time to complete than do work zone projects. These differences in characteristics make CPS infrastructure easier to establish and more manageable to maintain for vertical projects compared with horizontal projects, leading to differences in the technologies used.

Oregon DOT, Flickr, CC BY 2.0

Despite placing peripheral safety barriers, an Oregon Department of Transportation (DOT) work crew cutting concrete on I-405 in Portland is still at risk of injury from nearby traffic. CPSs can automatically detect traffic and workers, alerting construction crews of danger and keeping them out of harm's way.

CPS Applications in Highway Construction Projects

Highway and roadway construction projects are characterized by their sequential, repetitive, and interrelated activities. Roadside work zones present imminent safety hazards for workers and passing motorists and are becoming increasingly dangerous, affecting both the construction and transportation industries. Traffic collisions have become the second most common cause of worker fatalities in the United States (*1*). As a result, the current application of CPSs in highway projects aims to address these issues as follows:

- **Progress Monitoring**: The unprecedented growth of data in construction work zones provides a unique opportunity to establish CPSs to automate and streamline monitoring using data collection, progress, and activity tracking and reporting. Such data are collected through different means, including unmanned ground and aerial vehicles, smartphones, fixed cameras, and other sensors. Automated ground robots and drones collect data and upload them to cloud systems. Reality models are generated, and activities are analyzed using state-of-the-art computer-vision techniques. The models are fused with building information models and project schedules to detect and track the progress in real time. To make the models actionable, the CPS generates visual analytics in the form of digital models, report dashboards, and weekly work plans to facilitate project control and decision making.
- **Safety Management**: Improving construction safety is a key concern due to the high rate of injuries and fatalities in the industry and the complex and unpredictable nature of the work. CPSs lead to extensive safety applications in construction, especially highway projects. These applications include controlling safety measures, visualizing construction work zones, detecting ongoing activities, and preventing contact collisions by issuing warnings to construction workers and equipment operators when there is a high probability of proximity to hazards. It is crucial to consider humans in the loop when designing CPSs to improve safety, particularly in highway work zones. Numerous employees and machines are working, moving, and interacting with each other in a complex and dynamic highway environment. Involving these essential resources in the CPS loop can make information acquisition more resilient. Including human workers in designing CPSs for construction is particularly beneficial to account for their lack of situational awareness and high mental workload while working. Human-factor involvement in construction CPSs can include incorporating aspects such as human intentions, behavior, presence, psychological

state, emotions, and actions, which help better understand the context and determine appropriate actions.

- **Traffic Management**: According to the National Institute of Standards and Technology, CPSs are expected to provide the foundation of our critical infrastructure, built on the basis of emerging and future smart services, and improve our quality of life in many areas (*2*). Transportation CPSs are highly dynamic, spanning spatial, temporal, and component dimensions. They operate in real time, with humans in the loop where safety is paramount. Various aspects of transportation CPSs have been investigated, such as Internet-connected smartphones that act as sensors with significant impacts in traffic monitoring (phone-to-system data flow) and traffic information provision (system-to-phone data flow). The social complexities of CPSs in transportation systems also are explored by examining travelers' decisions and behavior in a social context. Security of transportation CPS architectures, real-time control systems, and data management issues are other areas under consideration. At the same time, advanced technologies related to autonomous vehicles have been under development by several automobile manufacturers and other entities. Autonomous vehicles can operate without a human driver, using a variety of sensors such as GPS, lidar, radar, smart cameras, and terrain and map information. Another set of technologies is being developed to support connected vehicles, which can wirelessly communicate with surrounding vehicles and infrastructure. Autonomous vehicles that also can communicate with infrastructure and each other are often referred to as automated vehicles or connected and autonomous vehicles. It is highly likely that in the not-too-distant future, both types of vehicles will operate side by side in large numbers on U.S. highways, alongside conventional vehicles that do not have such capabilities. Given the extensive evolution of autonomous and connected vehicle technology, there is growing research on CPSs that investigates these advanced technologies, along with emerging issues related to security, verification, and autonomy, among others.

CPS Challenges

Major challenges facing innovation, development, and adoption of CPSs are classified into technological, educational, and legal.

TECHNOLOGICAL CHALLENGES

The technological challenges partly stem from the distinguishing features of CPSs, compared with classic systems. For example, technological advancements are required to develop distributed, interoperable, autonomous, and reliable systems that can protect the safety, privacy, dependability, and cybersecurity of CPSs. In addition, safety and reliability concerns are still the main barriers to adopting autonomous systems in different sectors. Cybersecurity is the most important technological challenge that must be addressed while designing CPSs, in view of the critical role that CPSs play in safety-critical systems such as defense and transportation. Considering the volume of data that CPSs will generate, gather, and process, it is appropriate to develop various mechanisms for protecting data privacy properly.

The other contributing factors to technological challenges are the economic and scientific aspects. The benefits associated with CPS may not be quantifiable using current classical business models since, in many cases, they only contribute to facilitating the processes or providing services rather than resulting in a product. Thus, it is important to develop new business models and cost–benefit analysis tools to justify the investment in CPSs. Moreover, the transdisciplinary nature of the CPS means that innovations in this field require scientific contributions from several domains. Therefore, it would be useful to establish a body of knowledge with suitable breadth and depth from several domains to model, design, and implement CPSs. Finally, the sociotechnical aspect of CPSs plays a key role in their adoption in society, which demands special attention.

EDUCATIONAL CHALLENGES

The skilled workforce, knowledgeable experts, professionals, and educational trainers with a deep understanding of CPSs are in short supply. This condition is

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The need to protect online privacy, data, operations, and more makes cybersecurity the most important challenge in designing CPSs.

expected to remain as a major challenge to innovation, development, and adoption of CPSs, at least for the next decade. This is mainly because the field of CPSs requires the integration of knowledge from multiple areas of engineering—such as computer science; civil, mechanical, or electrical engineering; and systems engineering—with the right balance between theory and practice. The breadth and depth of knowledge required for the innovation and development of CPSs make education in this field challenging. Therefore, it would be helpful to design and implement new education and training systems based on CPS requirements. Another obstacle to providing the required education and training in CPSs is the lack of cyberphysical laboratories and testbeds in educational institutions and industry. Individuals in the CPS field need access to testbeds with different levels of complexity and integration of physical and cyber components so that they can develop relevant programming, simulation, and experimentation skills.

LEGAL CHALLENGES

The application of CPSs in different sectors demands different legislation and regulations concerning the following:

- Data privacy;
- System and user safety and security; and
- Liability, testing, and certification of CPSs.

Moreover, with the potential of CPSs spanning multiple states, provinces, and even continents, new legal standards and terms may be needed to specifically address CPS needs.

Conclusion

CPSs are critical elements of modern engineering system design. Their multidisciplinary roots have helped to spur interdisciplinary collaborations and results. Rich innovations exist at the intersection of traditionally siloed fields. When implemented correctly, CPSs improve the efficiency, flexibility, reliability, autonomy, and self-healing properties of systems while providing increased levels of situational awareness, robustness, resiliency, and interoperability. They enable better coordination, collaboration, and control of large and complex systems. They also provide opportunities for higher levels of connectivity and remote access. Finally, CPSs provide numerous opportunities for a skilled workforce to design, develop, and deliver new devices, systems, and services. As such, CPSs represent a paradigm shift in the way in which engineering systems are developed with regard to empirical and mathematical modeling, real-time computing, interaction with the physical world, and safety. As their technologies become intrinsic to the operation of smart societies, it will become imperative to address technological challenges and the shortage of an appropriately trained workforce.

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VOLUNTEER VOICES

"I attended my first TRB Annual Meeting in 1993 and, later that year, I interned at TRB in the Transit Cooperative Research Program (TCRP) at the Wisconsin Avenue offices. That experience cemented my affinity for a career in transportation because I recognized the critical role of research toward advancing society through industrial productivity and enhanced mobility and safety for citizens. After a stint in commercial logistics, I continued my graduate studies by pursuing a PhD in logistics. Today, I'm on the frontlines of education and research, preparing the next generation of business professionals for the rough-and-tumble world of logistics and supply chain management. Meanwhile, I also am advocating for cutting-edge research to help define mobility of people and movement of products throughout the remainder of this century. TRB has fostered my knowledge and stoked my passions for transportation-related inquiry and application."

—THOMAS GOLDSBY
Professor and Dee and Jimmy Haslam Chair in Logistics
University of Tennessee, Knoxville

PREPARING FOR DIGITAL TWINS

Pennsylvania DOT

FRANCESCA MAIER

The author is a principal at Fair Cape Consulting in Richland, Washington.

As advances in 3-D modeling technology make images like this one possible and traditional paper plans grow obsolete, how do we identify, organize, and track all of the data needed for each asset shown? Digital twins—virtual models of a physical object or system—may help agencies close the project development information gap and better organize data.

"Many state transportation organizations are searching for new technologies to provide quick and accurate collection, verification, and analysis of data to fill the void caused by reductions in staff and increases in work load" (*1*, p. 24). This sentence introduces an article, Laser Videodisc Technology Meets Changing Operational Demands, in *TR News 176*, a special theme issue on automation and robotics in highway design, construction, and maintenance. Unfortunately, many agencies still find themselves in this position today, a sobering 27 years after this issue's publication.

The *TR News* article describes how the Connecticut Department of Transportation (DOT) implemented a program to scan the highway system with multiple sensors and store the resulting data set on laser videodisc, which was current technology in the mid-1990s. It describes how users across the department eliminated the need for 80 percent of their data collection field trips, saving an estimated $1 million in labor and travel costs and 200,000 miles of vehicle travel. The cost savings estimated from using the system to inventory the state's signs alone were remarkable—from a cost of $1.3 million using manual methods to $0.5 million using the photolog.

The photolog vans collected images of the pavement and roadside, as well as geometric data, at a density of 100 data points per mile. The vans captured route numbers, direction of travel, roadway cross-slope, compass bearing, date, time, horizontal and vertical curvature, pavement roughness, grade, side friction, and vehicle speed. The information was stored digitally, and it was accessible. Agency staff could find the information for the road segment of interest easily. In 1994, Connecticut DOT produced a digital model, which was the first step toward creating a digital twin.

What Is a Digital Twin?

A digital twin is a virtual model of a physical object or system, and the bidirectional relationship between the

physical and virtual object is enabled through cyberphysical systems (smart networked systems with cyber and physical components that can interact with the physical world and human users in real time).[1] A digital twin is not a clone—which is a physical object—it is a virtual model. Imagine having access to Connecticut DOT's photolog and structured information about the entire transportation system. Imagine every signal, barrier, and bridge abutment represented with current, relevant, trustworthy information. The data evolve over time, from a variety of sources, capturing the complete asset history.

Digital twins analyze how the assets work together to provide insights on how to intervene to improve outcomes. Today, digital twins appear in places like manufacturing production lines. Sensors stream data to analytical models that monitor productivity and quality. The digital twins identify interventions in real-time to correct issues as they arise. Figure 1 shows how digital twins could be used for highway assets: Analytical models would use observation and sensor data from the physical asset, and they would produce visualizations and insights to support decision making. These decisions lead to interventions on the physical asset that result in the predicted or planned outcomes.

Digital twins would enable agencies to implement human-in-the-loop automation, a partially automated process that requires human input for higher order decisions. Sensors would automate repetitive tasks—like making and recording routine observations. Analytical models would conduct routine analyses of the sensor data, update dashboards, and trigger alerts when a decision needs to be made. Well-designed human-in-the-loop automation systems increase efficiency and safety. Currently, traffic operations centers are the closest to a digital twin implementation in the highway domain.

Assessing the Need for Digital Twins

In How to Tell the Difference Between a Model and a Digital Twin, the authors argue that obfuscation and conflation of models with digital twins lead people to dismiss the entire concept as hype (*2*). Using validated predictive analytics, a digital twin triggers timely intervention and maximizes agency operations and safety benefits. For example, if a driver crashes into a sign, the incident responder scans a barcode on the damaged sign, which changes its status. The change in status triggers a workflow to add the sign's repair to the maintenance schedule. Speed sensors pick up the traffic slow-down, which creates an alert in the traffic operations center. Someone in the traffic operations center accesses a nearby camera feed, verifies the situation, and revises the variable speed limits in the corridor. Traffic continues moving at a safe speed until the incident is cleared.

It is harder to conceive of a digital twin application beyond safety and operations. The pace of change for highway assets is glacial compared to the industries where digital twins currently bring value. Highway assets undergo changes due to time, weather, incidents, and renewal activities that manifest as maintenance or construction projects. The largest changes occur during construction, but these are also the most controlled.

Asset stewards could use digital twins to forecast conditions under cross-asset allocation scenarios to inform how to program maintenance and renewal actions. It is not clear, however, that a more sophisticated approach to programming maintenance and renewal activities using digital twins would bring more than marginal benefits; time scales and analytics are simply not that precise.

For now, we cannot build a business case for digital twins based on timely intervention. There are, however, many benefits to gain by pursuing a digital twin–ready model of the transportation system. Such a digital model would consolidate cross-functional asset information, resolving issues with interdisciplinary coordination.

Cross-Functional Digital Models

Many agencies use contemporary sensors, like mobile lidar and GPSs, to consolidate asset data collection. This routine collection

[1] See Cyberphysical Systems: Innovative Applications for Highways, Page 5.

FIGURE 1 Potential applications of digital twins for highways and bridges. (Courtesy of Francesca Maier)

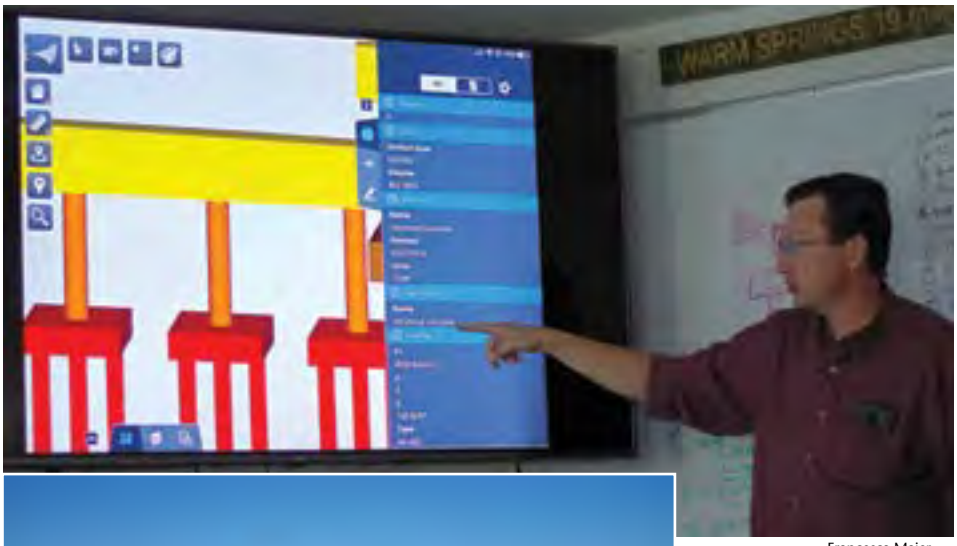
of asset inventory information provides a snapshot of the visible assets in the transportation system. In addition to inventory information, users need to know the condition of the assets, which often cannot be determined using automation. Condition information can be captured during inspections, or it can be inferred from asset history.

Every department that interacts with an asset documents part of its history. This leads to fragmented asset information that is time-consuming to collect, verify, and analyze when users need it. In the 27 years since the publication of *TR News 176*, little progress has been made toward consolidating asset histories and making data easily accessible to users.

Digital project delivery has created a new impetus to close the project development information gap in asset histories by creating, storing, and sharing digital asset information collected during construction. The pursuit of digital twins could benefit agencies because of how the information is organized: by asset. There is a one-to-one correspondence between the assets that are constructed, paid for, and delivered to asset stewards who maintain and operate them. By organizing agency data around the asset, agencies can consolidate asset histories and provide quick access to complete information that has been verified by the asset's data steward.

Digital Project Delivery Information

Over the past decade, designers and contractors have started making extensive use of 3-D engineered models of pavement and bridge assets. Designers have deprecated their 3-D models onto 2-D plan sheets that contractors use to create their own 3-D models. Skipping the step of deprecating 3-D models to 2-D plan sheets would create efficiencies for both designers and contractors, but a lack of interoperability of 3-D models has been a barrier to implementation. By extending the open data standard for construction information exchange (ISO 16739: Industry Foundation Classes) to infrastructure assets, the industry is rapidly making strides to overcome this challenge.[2]



Francesca Maier

Francesca Maier

A bridge engineer (*top*) points to a data field for a footing element in a 3-D model that is part of a plans-free bridge pilot project for the State Route 36 bridge over Interstate 80, west of Salt Lake City, Utah. The new State Route 36 bridge, built using the 3-D model shown above, is visible (*left*) while under construction in 2019, and the old bridge is still in use to its right.

There is a focus on replacing 2-D plan sheets with 3-D models as the medium for contract documents. This means as-built records need to be in a digital, or 3-D model–based, format. Many state transportation agencies have begun to pilot a plans-free, 3-D model–based method to deliver roadway and bridge information for construction projects.

Liberated from the need to create plan sheets, designers would have time to embed asset information as attributes in the design model. In addition to 3-D models, contractors would benefit from digital information that is searchable and includes tabular data, such as reinforcement schedules that are structured as spreadsheets. Some agencies are starting to update their design processes to create asset information and extract the as-designed information in a format compatible with the asset inventory.

So far, sharing 3-D models for construction has worked well because designers and contractors have access to the modeling software, the skill sets relate to their core job functions, and their involvement is limited to the construction project life cycle. Inspectors have a foot in both worlds—performing project-related functions and capturing asset histories needed over the life cycle of the asset. However, modeling skill sets do not relate directly to construction management and inspection, making it challenging to develop and sustain these skill sets. As

[2] ISO 16739-1:2018, Industry Foundation Classes (IFC) for Data Sharing in the Construction and Facility Management Industries—Part 1: Data Schema, can be found at https://www.iso.org/standard/70303.html.

plan sets entirely give way to 3-D models, there is a scramble to find a solution that works well for inspectors.

Closing the Project Delivery Information Gap

Despite two decades of sounding the alarm about workforce challenges, inspectors continue to be asked to do more things with increasingly complicated data and technology. The problem is not digital technology *per se*. Construction management and inspection workflows, such as those created with AASHTOWare Project Suite, have been digitized for a while. The issue is an unmet need to deliver the contract document information in a way that is compatible with digital inspection and construction management workflows, tools, and skill sets.

As early as 2003, a National Cooperative Highway Research Program (NCHRP) synthesis report documented issues with maintaining the construction workforce within state transportation agencies (*3*). The challenges associated with keeping a workforce with the necessary skills and institutional knowledge to get the job done safely and effectively are worse now. In this battle, technology often has been less of a blessing and more of a curse.

There are some notable exceptions, including mobile devices, PDF documents, and electronic tickets that track batching and delivery of construction materials. It is faster, easier, and cheaper to collaborate with electronic documents. Electronic document management works well for inspection and contract administration functions because it does not disrupt the processes and procedures from the "paper age." Agencies need more digital project delivery solutions that make it easier to recruit and maintain a skilled inspection workforce.

Preparing for digital twins creates an opportunity to design a solution that centers on the needs of construction managers and inspectors. Providing project information that is organized by asset makes it easier to document construction outcomes in a way that supports harvesting the important asset histories—like materials testing results—and delivering them to the asset data stewards. Switching to asset-focused information delivery helps by enabling better knowledge management.

Inspectors have to cross-reference a variety of data sources in the field. The plans indicate *what* to expect and *where* to expect it. The specifications provide the construction tolerances and acceptance factors. The payment system has the schedule of pay items and estimated quantities. Although the specifications and pay items usually match, their relationship to the plans can be complex and unrelated to how the work is constructed (Figure 2).

Using an asset-aligned, digital twin–ready approach to construction information management could be transformational for construction inspection workflows. Such a digital model would give inspectors a single access point to all the information they need. Inspectors would need less training on how to access and store information. Having a single point of entry to the digital record for each asset makes it easier to track items as they are accepted, avoiding duplicate inspections and even duplicate payments. Workflow automation could flag out-of-tolerance items as the inspection record is entered, or submit information to the asset data steward when work is accepted for payment.

A digital twin–ready model would connect a geospatial model of each individual asset to contextual information grouped into property sets. The geometric model of the asset would be geospatially located within the complete system. Designers and contractors need a detailed, 3-D geometric model that they would access via computer-aided design software. An inspector is primarily interested in the attributes and may only need a single coordinate point to locate the asset on a map interface. The interface could provide contextual menus and data tables for the type of asset and the current task. A "help button" could load a tutorial or walk the inspector through a task.

Outstanding Issues

Currently, the as-built recording responsibilities extend only to documenting deviations from the plans. From an asset-focused view, every asset undergoes changes during construction, resulting in assets that are retired, renewed, or commissioned. The actions performed on *all* assets during construction provide critical information—and context—for managing the assets. There is a need for someone to isolate the relevant information and deliver it to the asset data stewards.

There also is a need to evaluate the business processes and identify where to build in automation to extract and deliver asset information. Proceeding without automation would create an enormous burden on those who accept and commission or decommission those

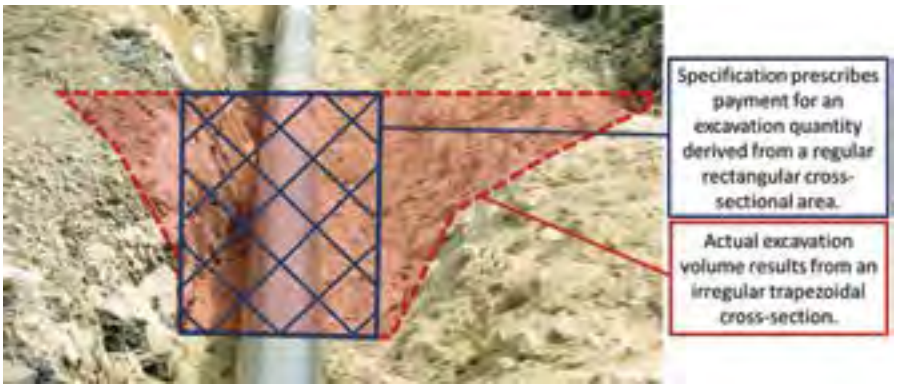


FIGURE 2 Excavation payments can be based on volumetric quantities that are unrelated to the actual work performed.

assets—they would need to document the changes accurately. Most construction is executed according to plans and specifications; the acceptance workflow could automate the transmittal of as-designed information to the asset data steward.

Nationwide, there is a need to coordinate data models for high-priority secondary assets like signs, barriers, pavement markings, walls, culverts, intelligent transportation system assets, and active transportation facilities. Agencies take many different approaches to track these assets, including maintenance management systems, asset management systems, and asset tracking spreadsheets. The processes and responsibilities for documenting the complete history of these assets still need to be defined. So, too, do the governance and stewardship responsibilities for the asset data. NCHRP Synthesis Project 20-05/Topic 54-06, "Ancillary Asset Data Stewardship and Data Models," will capture a snapshot of current practices.

Each asset life cycle needs to be mapped as a series of processes and actions that cause changes, and each change would have an associated set of properties. Some of these properties would

- Identify the asset,
- Describe its physical geometry,
- Describe its condition, and
- Contain parameters used to analyze the asset's performance.

Each property set would need a data steward, as well as processes and tools for capturing the information.

Users should only see the information that is relevant to their context, and they should use an interface with ergonomics that are appropriate for their work environment. There are many ergonomic challenges to accessing and capturing digital information on a construction site. These ergonomic requirements need to be defined carefully to accelerate the development of suitable tools for use at construction sites.

Courtesy of Adrien Patané

This inspector is holding an ergonomically friendly 3-D model viewer, developed for use at a construction site. It is important that the small device does not take up the user's full field of view because situational awareness is critical for an individual's safety on an active construction site. If the device is too distracting, the individual could be in danger.

What's Needed Next?

Building a comprehensive business architecture that captures the complete histories of all assets is an enormous task. The first step is prioritization: Which assets—and which actions—are most important? The next step is defining the information requirements for documenting those actions. What data fields are needed? What are the acceptance tolerances? How precise does the asset's location need to be? What construction acceptance information is relevant for its management and operation?

Defining the business and information architecture is a necessary next step in solving the bigger workforce challenges. Once the essential data model is documented, the workflows and governance structures to maintain quality need to be developed, and data need to be made accessible after they are collected. If the data architecture is published as a consensus standard, then vendors can bring products to market.

Published by the International Organization for Standardization, ISO 19650 is a global standard for the organization and digitization of information about buildings and civil engineering projects.[3] ISO 19650 describes how to establish two information models: one for projects and another for assets. Preparing for digital twins demands a fundamental shift away from *only* using project-focused organization for project development information. ISO 19650 provides a rigorous approach to isolating the asset information that has value over an asset's life cycle so that it can be extracted, ideally using automation.

Last, but not least, the industry will need to embrace the use of rigorous, standardized metadata (data that describe other data) on all project data. Metadata can be used to aggregate information from many sources over the asset life cycle, including future data sets not yet imagined.

There may not be clear beneficial uses of digital twins for highways and bridges yet, but there will be, and it is important to start preparing now. Having a complete digital model of assets and their histories will bring vast benefits through better knowledge management.

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[3] ISO 19650-1:2018, Organization and Digitization of Information about Buildings and Civil Engineering Works, Including Building Information Modelling (BIM)—Information Management Using Building Information Modelling—Part 1: Concepts and Principles, can be found at https://www.iso.org/standard/68078.html.

Augmented Reality

Existing Capabilities and Future Opportunities

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Augmented reality is changing how we look at the world around us and how we interface with devices that can aid human observation, quantification, recording, and maintenance tasks. It also is helping inspectors do their jobs more accurately—and quickly.

During the last decade, augmented reality has moved from research and gaming to business and industry—including infrastructure engineering and construction. Augmented reality mixes reality and virtual information in the field, which brings new opportunities to the infrastructure industry. This technology figures prominently in the future of social media and will bring virtual reality and augmented reality technologies together. It is timely to understand the following:

- Where and when augmented reality was designed, developed, and offered in its early days;
- What augmented reality is and why it is here to stay;
- What augmented reality hardware and software is available;
- What current applications exist in areas related to the infrastructure side of human–infrastructure interfaces; and
- Which gaps recognized from preliminary results are being investigated.

The Early Days of Augmented Reality

The engineering community started adopting head-mounted augmented reality devices in the 1960s (*1*). These early holographic experiences had limited resolution, brightness, and field of view. The following three decades focused on addressing visualization problems and, in 1997, a survey summarized the technology's development challenges (*2*). In the last two decades, augmented reality ecosystems have matured enough to generate applications for infrastructure, especially in the areas of construction and inspection.

What Is Augmented Reality?

In essence, augmented reality superimposes digital or computer-generated

content over the existing real-world environment (*3*). This technology integrates virtual objects with real objects in real time (*2*). The concepts of augmented reality and virtual reality are related, and the exploration of the two definitions together makes it easier to understand both concepts (*4*). While virtual reality leads the transformation from the real world to a new virtual world by blocking users' view from the physical environment, augmented reality enhances human experience of the real world by overlaying virtual information upon imagery of the physical environment. In the last decade, the augmented reality industry introduced lightweight devices, including a see-through headset that enabled eye tracking, hand gestures, voice commands, and mapping capabilities (*5*). These abilities enable this technology to be used in a wide range of activities in the infrastructure engineering industry.

Augmented Reality Hardware and Software

Augmented reality hardware is classifiable into three main categories: stationary, handheld portable, and head-mounted device (*6*). Table 1 compares the advantages and disadvantages of different hardware. Although the cost of today's headsets are high and computational limitations remain, powerful, affordable headsets will become available in the near future (*6*). After overcoming inherent limitations, headsets will provide considerable benefits for human–computer–infrastructure interactions and will surpass handheld or stationary devices (*7*).

Two creation platforms—Unreal and Unity—are used to develop applications for headsets with integrated computing capabilities. Although Unreal is a new engine for creating augmented reality tools, master application designers traditionally developed sophisticated applications using the Unity game engine platform (*8*).

Augmented reality developers use the C Sharp programming language, and the main contribution of researchers is the programming of new applications in response to requests from infrastructure owners or managers. In this context, conventional programming skills may not be sufficient to develop new applications that infrastructure owners require because of C Sharp limitations for Unity projects. Augmented reality applications and packages on different systems also need to be compatible and updated regularly.

Augmented Reality Applications

SMART MANAGEMENT OF INFRASTRUCTURE

Even as early as the 1990s, early augmented reality systems used during construction could find rebar located inside structures and overlaid 3-D frames (*9*). These prototypes identified challenges related to field implementation in real structures and the areas of additional research for implementation. Technical advancements in the last decade have enabled new uses of augmented reality to enhance infrastructure projects, such as

- Simulating designed structures before their construction,
- Providing virtual site visits,
- Offering effective means for online interaction,
- Developing new teaching strategies (*10*), and
- Evaluating the dimensional and geometric positions of physical objects (*11*).

The following section summarizes current advances in augmented reality research conducted in the context of the smart

TABLE 1 Types of Augmented Reality Hardware

Augmented Reality Hardware	Stationary	Handheld Portable	Head-Mounted Device
Devices	**PCs and Servers**	**Smartphones and Tablets**	**Augmented Reality Headset**
Hardware Configuration			
Advantages	High-Processing Capacity	Mobility and Low Cost	Mobility, Hands-Free Capability, and 3-D Image Projection
Disadvantages	2-D Screen and Low Mobility	2-D Screen, Requires Hand Support	High-Cost, Low-Processing Capacity, and Limited Field of View

management of infrastructure. The applications discussed are not all-inclusive, but they present a summary of the most recent capabilities intended to transform the interfaces between humans in the field and the infrastructure they manage.

TIME MACHINE MEASURE APPLICATION

The time machine measure application enables humans to save and restore a virtual representation of physical objects in the real-world environment over time. The augmented reality user can measure and track changes in a physical object based on color-coded virtual representations of the real environment recorded at specific times. The user is aware of both the status of reality and the damage pattern progression over time, which is applicable to structural health monitoring. The application can inform inspectors of changes that may not be obvious to the human eye—or memory—as well as changes that go unnoticed. As shown in Figure 1, augmented reality provides a way of recording changes to the real structure over time that was not previously possible (*12*).

FIGURE 1 The time machine measure app shows the movement of the structure. (Courtesy of Elijah Wyckoff)

INTEGRATED SENSORS

Augmented reality headsets are capable of connecting to sensors and displaying sensor data in real time (*13*). This implementation overlays sensor measurements in real time. The first augmented reality headset with integrated sensors was developed and supported by the U.S. Air Force Research Laboratory and the New Mexico Consortium, a nonprofit corporation to facilitate research and comprised of three New Mexico universities. Augmented reality developers programmed an algorithm calculating and showing the reference-free sensor displacement to the user in real time (Figure 2a) (*14*). Another application was created to plot live vibration levels in an augmented reality headset (*15*). The headset, which was connected to a smart sensor over Wi-Fi, sent acceleration values that were plotted and visible in the user's view (Figure 2b). This allows the

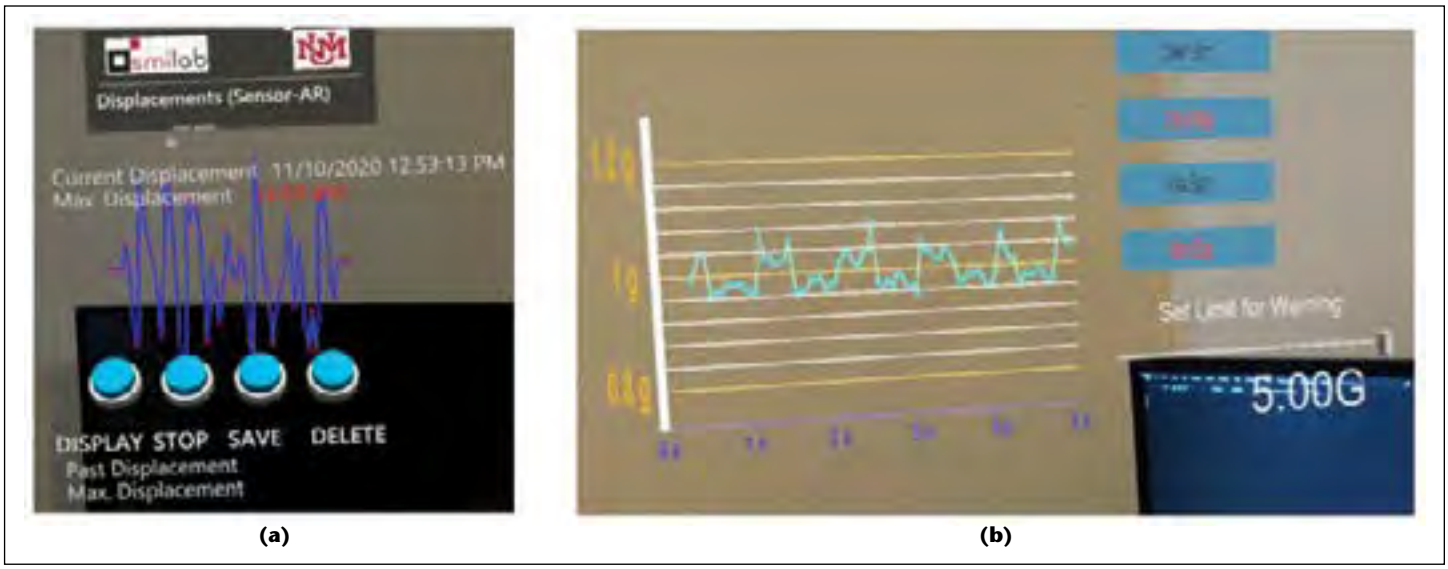

FIGURE 2 Sensor data visualization in augmented reality reveals (*a*) displacements and (*b*) accelerations. (Courtesy of Elijah Wyckoff)

human to maintain awareness of the real response of the dynamic structure while also monitoring data to make informed decisions.

ROBOT CONTROL

Robot automation with augmented reality technology is being implemented for sensor placement and feedback. By designating an augmented reality application for robot arm control, an interface that includes the camera view from the robot's perspective was developed, as were commands for sensor pick-and-place sequences, as demonstrated in Figure 3. Mode shapes and finite element models also can be included in the interface to inform the human of expected results and the correct location for sensor placement (*16*). These capabilities are particularly beneficial for the construction of hard-to-access parts of structures where traditional construction methods are costly and time consuming. Robots can be used to inspect infrastructure in places where human safety may be at risk. The U.S. Department of Transportation University Transportation Consortium of South–Central States (Tran-SET), a collaborative partnership including nine major institutions and two community colleges in five states (Arkansas, Louisiana, New Mexico, Oklahoma, and Texas), has supported several projects that implement technology for the construction and maintenance of infrastructure. Brutus is a robot that can test the properties of mechanical surfaces using multiple taps. Operating Brutus frees the augmented reality user from a handheld controller.

HUMAN–INFRASTRUCTURE INTERFACES

The Transportation Research Board (TRB) is supporting projects related to augmented reality and prioritizing the exploration of human–machine interfaces to advance the integration of computer vision with augmented reality and improve inspectors' perception in the field. These Innovations Deserving Exploratory Analysis (IDEA) projects[1] include

- National Cooperative Highway Research Program (NCHRP) Project 20-30/IDEA 223, "Fatigue Crack Inspection Using Computer Vision and Augmented Reality" and
- Rail Safety IDEA Project 43, "Augmenting Reality for Safer Inspections of Railroad Infrastructure and Operations".

With the support of TRB, researchers recently developed various advanced human–structure interface algorithms and provided their connections with augmented reality for a multidisciplinary effort involving the FRA on a Class I railroad project in which augmented reality aided industry collaborators inspecting a railroad bridge in Chicago, Illinois (*17*). This new approach has the potential to transform bridge inspections.

DETECTING FATIGUE CRACKS

Fatigue cracks in steel structures are significant because they are miniscule—which makes them hard to identify—and they propagate rapidly. Fatigue crack detector augmented reality software enables inspectors to find these cracks by analyzing the parts of the steel structure prone to cracking and showing the crack's location to inspectors in close to real time. The menu for this software, shown in Figure 4, provides a virtual view developed for steel fatigue crack detection. In collaboration with the University of Kansas and the University of New Mexico, a new approach used innovative software

[1] For more about NCHRP Project 20-30/IDEA 223, see https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=5057. For more about Rail Safety IDEA Project 43, see https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=5081.

FIGURE 3 A robot arm controlled by augmented reality places a sensor box on a structure. (Courtesy of Elijah Wyckoff.)

FIGURE 4 An augmented reality steel crack detection tool places a red mark—the virtual indicator—to show a crack's location in the steel structure's joint. The fatigue crack detection software also displays a virtual menu to facilitate field inspection.

developed to integrate computer vision in augmented reality so that inspectors could find fatigue cracks while wearing a headset. This research was developed as part of NCHRP Project 20-30/IDEA 223.

CHARACTERIZING CONCRETE CRACKS

Several studies integrated image processing for concrete crack detection and human inspection using the augmented reality platform. In these studies, headsets were connected to stationary devices via physical connections or the Internet. Image processing was performed in the stationary processing devices, and the processed images were sent to an augmented reality headset for localization and visualization (in which the headset locates the crack and shows the location to the user). Recently, Tran-SET and the New Mexico Department of Transportation funded a project at the University of New Mexico aimed at creating augmented reality crack detection and characterization tools for real-world inspections. This study eliminated the dependence of augmented reality crack characterization methods on external processors. The technology's software addresses one of the challenges in image-based crack detection methodologies: locating cracks in the field from images of the detected cracks on a computer screen. Augmented reality headsets can be used to transform these manual tasks to an automatic process and to project the computer analysis results in front of the user's eyes in real time.

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Bridge inspectors in New Mexico compared crack measurement methods to explore the practicality of using augmented reality for bridge management. Using existing methods, inspectors measured crack width at a given location with a thin, handheld plastic gauge and visual observation. Using advances in the technology, inspectors can put on an augmented reality headset to examine a given area of the surface through augmented eyes.

The Future

Successful integration of human–infrastructure interfaces already has been achieved in a variety of structural contexts that include, but are not limited to

- Structural quantification (such as length, area, and size measurement),
- Visualization of quantification results or external processor data such as sensor data,
- New interfaces with mechanical tools controlled and managed by humans observing augmented reality virtual quantities overlaid on relevant physical objects, and
- Real-time artificial intelligence implementation with augmented reality that offers potential empowerment of infrastructure operators and inspectors.

Although augmented reality has many benefits for structural inspection and assists inspectors in improving their inspection quality, there are still some issues that must be addressed in future research. The most significant of these involve head-mounted devices because they have limited analysis capacity, insufficient battery capacity, and are heavy enough that they may cause fatigue for inspectors performing lengthy inspections.

The future of augmented reality for enabling a new infrastructure industry, changing workforce management strategies, and even developing new infrastructure policies corresponds to future technological advances in software and hardware, such as

- Decreasing headset weight, potentially by separating batteries and computational units from head-mounted devices;
- Advancing holographic lenses so that they provide a better blend of virtual objects with real elements and eventually improve the visualization experience;
- Enhancing lenses or enabling higher contrast to permit more efficient data capture in the field (the impaired view from current headsets in direct sunlight is a barrier to application);
- Increasing the headsets' field of view to permit the user to have a better experience in the field, while not losing awareness of reality; and
- Increasing the head-mounted device's analysis capacity and improving the technology to provide faster analysis, gain independence from external processors, determine relative displacement, and solve registration problems that occur when unregistered files in useful libraries make those libraries undeployable in augmented reality headsets.

Further augmented reality integration with infrastructure depends on technical advances in its hardware and software and the early teaming of researchers and infrastructure stakeholders to identify gaps for

implementation and suggest priorities for bridging those gaps. Both entry-level and experienced members of the workforce can benefit from a new work environment that will improve their quality of life, as well as advance their profession.

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VOLUNTEER VOICES

"If I could go back in time, I would change two things that would have fundamentally altered American transportation. First, I would plan the Interstate system and other long-distance routes to go toward and around our cities, rather than carving through them. This approach would be less destructive and far less expensive to taxpayers. Second, I would change how we develop our cities and suburbs. The current widespread adoption of single-use zoning separates all the different types of land uses. This requires extensive parking lots and more driving and makes walking and biking more difficult and dangerous. In contrast, establishing zoning rules based on New Urbanism concepts allows for development that mixes land-use types and a public space design that is attractive and compact and, therefore, walkable. We would all have to drive far less than we do in today's suburbs, which would lessen public expenditures in wide roads."

—BRENT SWEGER
Quality Assurance Branch Manager
Kentucky Transportation Cabinet, Frankfort

Digital Eyes in the Skies

Machine Learning for Uncrewed Aerial Missions

Courtesy of Utah DOT

PAUL WHEELER AND BHARATHWAJ SANKARAN

Wheeler is director of aerial innovation for Research and Innovation Solutions in Advisory Services at WSP USA in Salt Lake City, Utah, and Sankaran is a highway project development data scientist in Advisory Services at WSP USA in Austin, Texas.

Uncrewed aircraft systems (UASs) have many applications as that "eye in the sky." Aircraft aided by multiple rotors that can achieve vertical takeoff and landing—and can hover—are well suited to structural analysis of transportation assets such as signs, mile markers, lighting, or other road features. It is important for a UAS to be maneuverable enough to pinpoint small items, such as individual rivets on a sign or bolts that have loosened over time.

Uncrewed aircraft systems (UASs) have seen a considerable surge in use in the transportation sector because they provide the ability to collect high-quality digital data that cater to a variety of applications across an asset life cycle—from project planning to construction monitoring and operations and maintenance. Advances in sensing and positioning technologies, coupled with increased cost-effectiveness and new regulations that promote the safe integration of UASs in commercial airspace, have catalyzed the increased interest in UAS applications shown by transportation agencies.

Integral to the success of a UAS mission is preflight planning, safe and efficient flight control, and the ability to process large data sets collected by UASs using algorithms that perform efficiently at scale. This article highlights two case examples related to using machine learning–based approaches for autonomous flight control and structural data collection and analysis.

System Requirements

Defining a system plan for a UAS mission involves identifying the sensors, platforms, ground controls, and other payloads that provide opportunities for large-scale data collection and application of machine-learning methods. Equipment selection often depends on mission objectives, availability of trained pilots, and compliance with other specific criteria included in a state department of transportation's UAS operations manual. Based on the information provided by several transportation agencies, a multirotor type of aircraft with vertical takeoff, landing, and hovering capabilities is preferred. In addition, the aircraft should incorporate at least a high-resolution video and still photo camera [minimum 12 megapixel (MP) capability, with 38 MP and a 1-inch sensor more desirable], with enhancements such as forward-looking infrared cameras for detailed element-level inspection.

Other major attributes to consider

while selecting the system include

- Stability against wind and magnetic interference,
- Safe operation inside a confined space,
- A 360-degree gimbal to stabilize sensors and payloads mounted on the UAS,
- Obstacle avoidance systems,
- A flight duration of at least 25 minutes, and
- Desirable horizontal and vertical accuracy based on the needs of the mission.

The expediency and risk involved in a particular UAS mission will determine the type of ground control systems to be deployed. Aircraft manufacturers offer varying levels of pilot dependence for controlling the parameters of the flight mission—such as climb rate and altitude—ranging from direct to autonomous control. Another important aspect is understanding the positional accuracy of the derivative data set. Depending on the objectives of the mission, this step would involve deploying GPS equipment onboard the UAS and establishing accurate ground control points using a total station (a location where ground-based surveying equipment is used for high-accuracy angular and distance measurements) to enhance data accuracy (*1*).

Case Example: Flight Controls

UAS flights with conventional flight controllers onboard can face challenges when flying near bridges or other obstacles because of environmental factors such as wind, magnetic interference, variable payloads, signal obstructions, or wherever GPS signals do not penetrate or exist (*2*, *3*). In contrast, machine learning methods [a type of artificial intelligence (AI) that allows software applications to become more accurate at predicting outcomes without being explicitly programmed to do so] are data driven and can enable dynamic responses to obstacles. They also can auto-adjust flight parameters as needed. In particular, reinforcement learning, a subset of machine learning methods, is gaining significance in the area of autonomous flight control. Generally, reinforcement learning comprises an agent and an environment. It involves training the agent by successfully rewarding its desired behaviors (based on its action in the environment) and penalizing—undesired actions. Through continuous training with hundreds of data samples (potentially available from similar aircraft or previous missions), the agent learns to perceive the environment, takes actions, analyzes the results of its actions produced in various states, and gets rewarded or penalized—depending on its ability to maintain the overall goal (Figure 1). In the case of UASs, the action could include changing the speed of propellers or adjusting the climb rate or altitude. The goal may include an optimal trajectory to maintain overall stability (*4*).

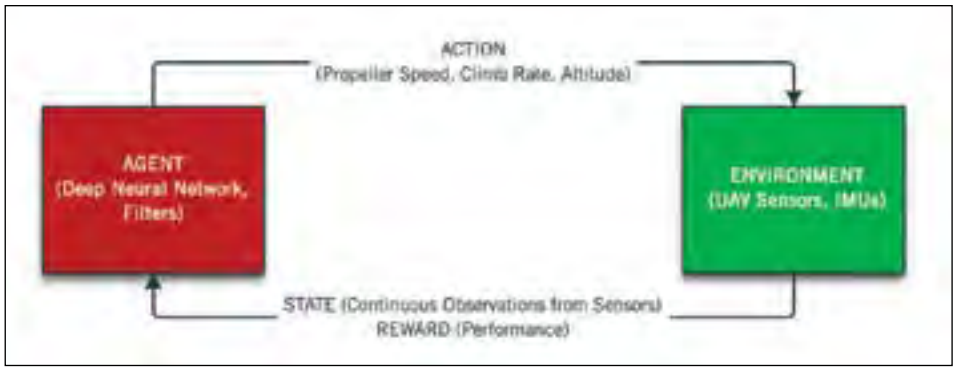

FIGURE 1 Conceptual depiction of reinforcement learning approach for UAS AI flight control (UAV = uncrewed aerial vehicle; IMUs = inertial measurement units).

Modern UAS manufacturers install controllers that rely on reinforcement learning–based algorithms to create accurate offline models that act as baseline controllers. These algorithms also provide "online learning" for fine-tuning and real-time adaptation. The marketplace also includes instances where vendors are developing lighter algorithms that can run computations onboard, an effort named "edge artificial intelligence" (*3*). Furthermore, some state-of-the-art platforms that enable total autonomy of the control system also rely on lighter sensors (such as visual cameras) that make the mission agile and cost-effective. Multiple navigation cameras (4,000 MP and above) with a high field of vision (200 degrees or more) enable a 360-degree view of the scene and adaptive control of navigation parameters for smooth and safe flight operations (*5*).

Case Example: Data Processing for Overhead Structures

For overhead sign inspections, UASs can provide the ability to inspect from the sides of roadways without impeding traffic. Furthermore, UASs allow the team to inspect from a safe location, reducing the risk to workers and vehicles. The Utah Department of Transportation (DOT) reported savings of more than $100,000 on the SR-201 and I-80 inspection project (Figure 2, Page 24), while increasing productivity from two signs per day to more than 16 signs by using UASs (*6*). While data collection using UASs is efficient, manually reviewing images can be a time-consuming process. Advances in machine learning have opened up new possibilities to significantly increase data processing productivity and eliminate inconsistencies and ambiguities between collections.

The Utah DOT project used a drone that could be equipped with a 30x optical zoom camera and a 1/2.8-inch, 2.13 MP sensor to capture the fine details needed to assess welds, rivets, bolts, and the structure's overall condition. Flights occurred over the sides of the roadway to prevent the aircraft from flying directly over traffic. This reduced the need for

FIGURE 2 **At Utah DOT, the benefits of using UASs on sign inspections near Salt Lake City included financial savings and increased productivity.**

traffic control devices. The UAS took photos on the front and back sides of the signs from multiple angles to capture necessary details. Once the data collection was complete, a structural engineer performed a manual image review with the software company to label the data. Then, what are known as convolutional neural network (CNN) AI algorithms were used with the labeled data sets so the algorithms could learn from the data.

In this particular use case, CNNs were used to analyze the large data sets common in image processing for object detection, feature extraction, and segmentation. The technique used in the study has been implemented using a region-based CNN (R-CNN) approach that incorporates a search algorithm to select regions from images before feeding them into the neural network. The detection is solved as a regression problem with the probability of the object class in the regions being the primary output (*7*).

This approach allowed for the rapid identification of missing rivets (Figure 3) and provided consistency among data collections, which can increase productivity.

What Are the Results?

Incorporating machine learning techniques into UAS operations can improve data collection efficiency. It also can improve the subsequent quality of the deliverables derived from the data. In this case example, implementing a machine learning algorithm increased the speed of inspection and provided the ability to accurately predict missing rivets at scale.

Insights from this prediction also could be integrated into other analytic approaches to provide an improved understanding of when components may fail (*8*). These tools could be expanded beyond overhead signs to multiple structures to understand not just missing hardware but also to indicate where there may be fundamental weak points—such as crack growth or delamination—and to help prevent failures. Since machine learning models can improve continuously by using new data samples, over time they could enhance accuracy and eliminate

FIGURE 3 **Missing rivets were detected using AI. (Courtesy of Scopito ApS)**

Courtesy of Utah DOT

The drone that took this photo of an overhead sign element near Salt Lake City, Utah, was able to perform a detailed structural inspection and capture imagery showing the condition of the bolts.

potential inconsistencies associated with findings from different inspection teams. Thus, machine learning may increase the chances of identifying failures before they become critical safety issues. Ultimately, this could improve the safety of the transportation system as a whole.

Conclusions and Future Frontiers

UAS technology merged with AI is dynamically changing inspection techniques. Significant savings in costs and productivity are appearing across organizations, driving a new revolution in data collection. AASHTO found that nearly all state DOTs have incorporated UASs into their operations (*9*). As adoption increases and additional data are collected, a rich data pool is being created to train the AI models. The Utah DOT project was a first for evaluating the potential for using machine learning for overhead sign inspections at DOTs, and more research is needed to determine what efficiencies can be gained over time.

Nonetheless, these initial results are promising. As this technology advances, it could bring new insights and opportunities to design, construction, maintenance, and asset management that could improve the safety of the transportation system and ultimately save lives while reducing impacts to the traveling public.

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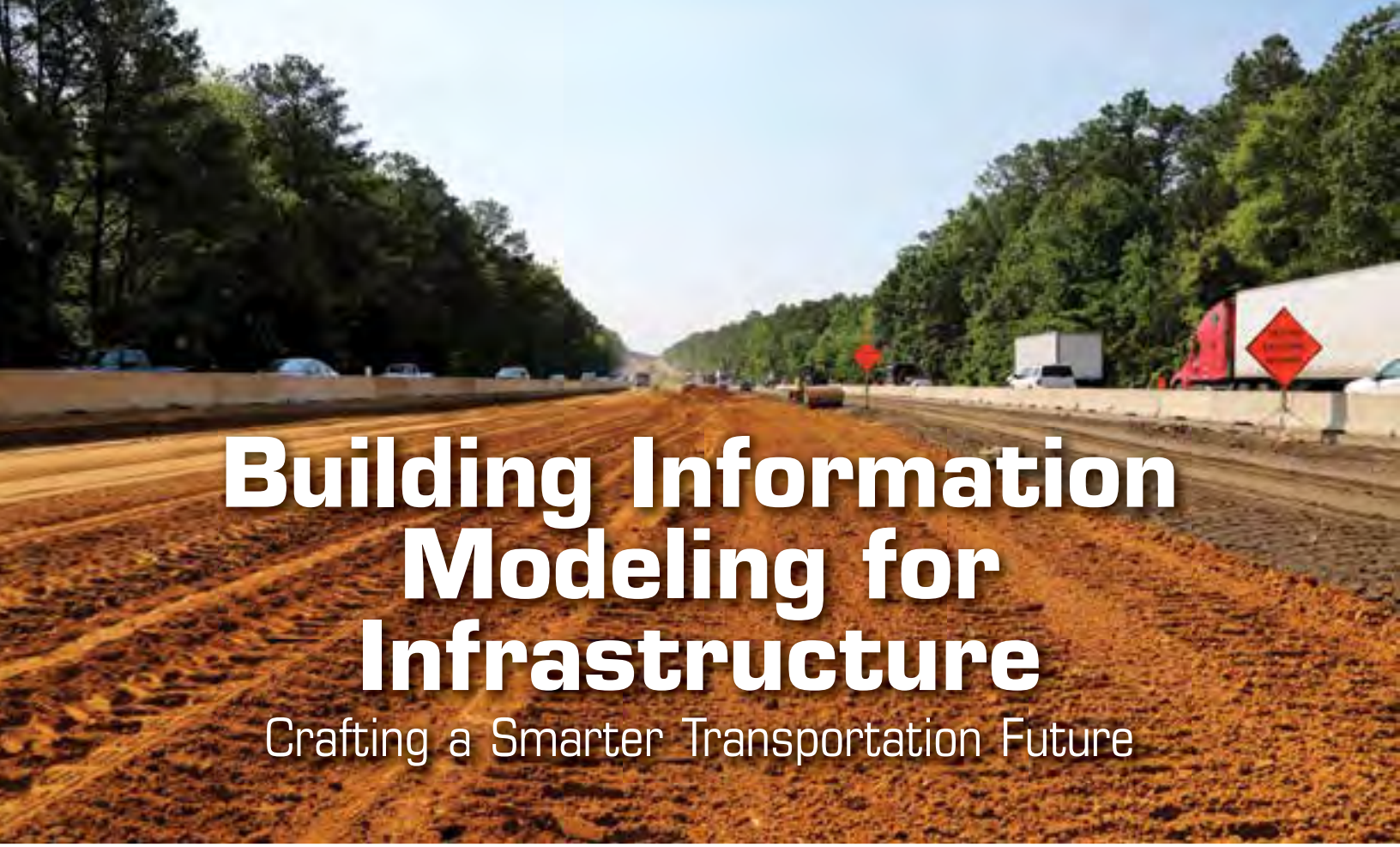
VOLUNTEER VOICES

"I have been attending the TRB Annual Meeting since 2013. The technical sessions have contributed immensely to my knowledge and skills, with which I have consequently contributed to the quality of life and safety in my country, Ghana. Thanks to the founders and organizers!

—MAGNUS QUARSHIE
CEO, Delin Consult Limited
Accra, Ghana



Building Information Modeling for Infrastructure

Crafting a Smarter Transportation Future

ALEXA MITCHELL

The author is a transportation building information modeling program planner at HDR in Phoenix, Arizona.

Traditionally, determining the tons of soil needed for roadwork projects—such as this widening project along I-64 in Virginia—called for highway designers to plan on paper and with basic computer software. However, such tasks become easier and more collaborative when planning with 3-D building information models, digital tools that follow the life of the project.

With the passage of the Infrastructure Investment and Jobs Act in 2021, transportation agencies across the United States find themselves on the cusp of a transformative period in the nation's infrastructure history. Billions of dollars are now being put to work on transit upgrades, transportation systems for roads and bridges, and much more. With this infusion of funding comes a need to work smarter and more efficiently. However, many public agencies do not have the staff needed to design and manage a sudden massive surge in projects. One solution could be a greater emphasis on the use of building information modeling (BIM) in transportation.

Already standard in the vertical building industry, BIM is fast becoming the way to deliver transportation projects, as well. No longer a futuristic vision or the sole domain of early adopters, this collaborative process for creating intelligent 3-D models already has shown its benefit to infrastructure owners. At least five states have completed projects using the 3-D model as a legal document (MALD) approach, and four others are currently working on MALD pilot projects. For many other states, the technology is part of regular design practice.

As the industry continues this shift from paper to 3-D models and digital delivery, much has been made of the impact on design and the benefits that can be captured in that process. This shift also has profound implications for construction, requiring new training for workers, new workflows for accessing designs, and new contract and procurement language. So, why should the industry accept this disruptive innovation? While challenges to its full adoption still exist, BIM offers a long-term value proposition that should be explored.

Benefits

COLLABORATION AMONG DISCIPLINES

While most people believe BIM is about creating 3-D models for visualization

purposes, a key value lies in calculating repetitive quantities and coordinating work across disciplines. Much of this work is critical but may not require a creative or innovative eye.

For example, BIM provides great efficiencies during design when compiling and checking earthwork quantities. Without BIM, a team would have to use representative cross-sections to quantify cut-and-fill material amounts for each corridor, a time-consuming process that can take up to two weeks on a large, complex project with multiple corridors. However, with BIM, the same process could take as little as two days. When design teams work in a collaborative BIM environment, they can reference each other's 3-D designs to identify potential conflicts. This type of 3-D coordination can save an owner a significant portion of the construction contract value due to avoidance of change orders (*1*).

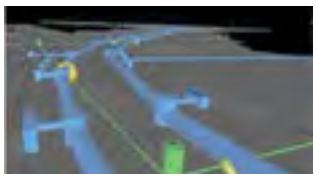
Massachusetts DOT

Hoisting up and over, a Massachusetts DOT crew installs a prefabricated span of an I-95 overpass. Some 3-D models allow construction contractors to schedule materials delivery, anticipating what they will need and when they will need it.

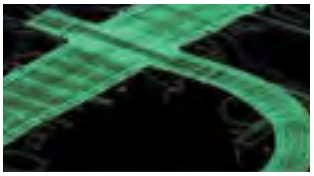
IMPROVED BIDS FOR CONTRACTORS

BIM also benefits contractors by increasing efficiency. Contractors can reuse models created during design; they do not have to make their own for key parts of a project and, therefore, can prepare bids more efficiently. Contractors also can grasp design intent much better when using 3-D models over 2-D representations, providing critical perspective as projects enter construction. Mobile apps can even provide contractors with the opportunity to see these digital models while in the field (Figure 1).

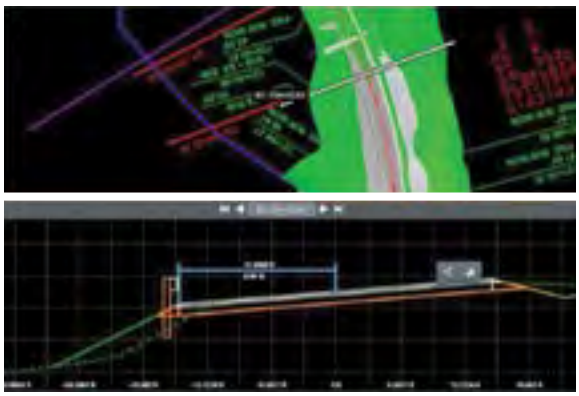
Additionally, contractors can use some 3-D models—depending on the level of detail—for fabrication, safety reviews, and construction simulations. Contractors can connect these models to their schedule and the materials needed at certain milestones to see a sequence of events virtually. This ability provides an improved understanding of the materials they will need to order and when they need to order them, making the 3-D model a good estimating and scheduling tool for procurement and delivery of construction materials.



Underground Utility Models
(a)



Triangulated Surfaces (DTMs)
(b)



Cross-Section View
(c)

FIGURE 1 A mobile app view of typical 3-D geometry on a project showing (*a*) underground utility models, (*b*) triangulated surfaces, and (*c*) a cross-section view (DTMs = digital terrain models).

ASSET INFORMATION CAPTURE

Another important benefit of BIM that is often overlooked is the opportunity to capture information about the assets to document the as-built environment digitally. This digital as-built model provides a representation of the physical asset at the end of construction. It contains both geometric (i.e., size and dimensions) and nongeometric information about objects in the project, such as location, material properties, and condition ratings. This model can provide valuable information for future maintenance and reference.

Challenges

As transportation agencies, designers, and contractors adjust to this new digital environment, a few specific considerations are needed while working toward BIM adoption.

WORKFORCE EDUCATION

There is much confusion about BIM and its benefits, and there is a great need for developing educational programs to help all stakeholders understand how to apply BIM methods to different types of projects consistently. As BIM deliverables become more common, construction staff can benefit from training in the new technology and software and in how to find the information they need to complete the job. One persistent roadblock has been incompatibility between software that designers and contractors commonly use. The good news is that this challenge will be addressed as new Industry Foundation Classes (IFC) file formats and open data standards[1] endorsed by AASHTO and the American Road and Transportation Builders Association are adopted.[2]

[1] For details about the adoption of IFCs, see https://highways.transportation.org/wp-content/uploads/sites/46/2019/10/Administrative-Resolution-AR-1-19-Adoption-of-Industry-Foundation-Classes-IFC-Schema-as-the-Standard-Data-Schema-for-the-Exchange-of-Electronic-Engineering-Data.pdf.

[2] See the American Railroad and Transportation Builders Association digital construction policy statement at https://www.artba.org/wp-content/uploads/2022/02/Digital-Construction-Policy-Statement.pdf.

Bruce Hull, Ohio DOT

Mouse clicks and concentration bring Ohio DOT staff up to speed during technology training. Lack of a trained workforce is a major impediment to the widespread adoption of 3-D building information modeling, a challenge that the construction industry is working to overcome.

LIFE-CYCLE INFORMATION AND DATA NEEDS

Stakeholders throughout a project need correct information to do their jobs well. Models can be packed with information, but designers, contractors, construction management teams, and asset owners all need to know how to find the specific information they require (Figure 2). They also need know how to provide information in the correct format to aid other teams. Standardized information-sharing methods are needed to ensure that each group has a complete picture of the information those elsewhere in the project life cycle require. At the most basic policy level, agencies cannot set requirements if they do not know what they need to ask for.

For example, in work with the Utah Department of Transportation (DOT) on its 3-D modeling pilot programs, one major area of feedback from contractors was a lack of consistency in the models. Contractors knew that all the information they needed for construction would be in the model, but where that information was, how it was presented, and how it needed to be accessed varied, depending on the designer who created the model.

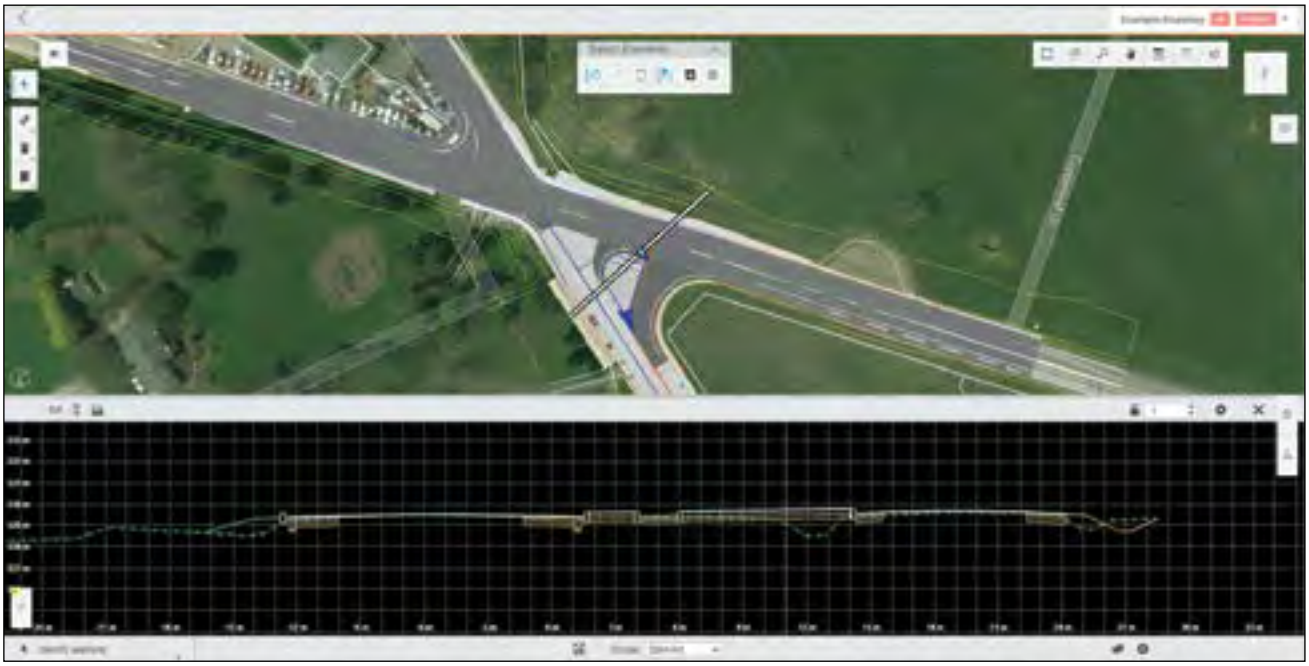


FIGURE 2 Screenshot of an example project model. (Courtesy of Pennsylvania DOT)

MODEL-DEVELOPMENT STANDARDS

As more transportation system owners require 3-D model–based deliverables, it is important to establish a consistent, repeatable, and reproducible process. Organizational modeling standards and information requirements are often needed to be clear about what should be modeled and to what level of detail.

The challenge is exemplified by Utah DOT's experience creating the nation's first model-development standards manual, which specifies what should be included in the design and what should be left out (*2*). For example, do designers need to model topsoil as a part of projects? There is no wrong answer, as long as the contractor knows consistently one way or the other. However, if topsoil modeling is left out of the calculation, contractors will need to know so they can account for it in their estimates and construction plans.

This challenge of consistency is being addressed on a national level by industry associations. The AASHTO Joint Technical Committee on Electronic Engineering Standards[3] and the American Council of Engineering Companies are working on making recommendations for a national framework that can be adopted by all state DOTs.[4]

CONSTRUCTION SPECIFICATIONS

Many construction specifications were written for how projects were built decades ago and do not take into account how technology has changed and is being used in the industry. In some cases, these specifications can force contractors to move away from using a model created in design, not because it is more efficient to do so but solely to satisfy the rules and norms of a different era. Particularly, when it comes to materials and methods, existing specifications can lack the necessary flexibility to take advantage of new efficiencies. As transportation agencies move forward with digital delivery, updating construction specifications will be a critical step for overcoming this challenge. A transition to performance-based specifications, with flexibility to use multiple approaches and technologies, may be necessary.

[3] Find out more about the committee's work at https://design.transportation.org/technical-committees/electronic-engineering-data/.

[4] Learn more about the collaboration between the two committees at https://portal.ct.gov/-/media/DOT/documents/AEC/IHEEP/National-JTCEESACEC-Collaboration-on-LOD-Framework.pdf.

Plan Now, Avoid Problems Later

While still evolving and growing, BIM is here to stay. This shift will have major impacts and benefits for the highway construction industry across project delivery phases—from design all the way through asset management. Now is the time for highway agencies to create or review strategic plans that will guide them as they set goals and objectives, establish expectations and timelines, and plan and identify investment needs for specific activities related to digital delivery. Making the right decisions at the beginning of this transition and putting the right foundation in place will result in important benefits for years to come.

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VOLUNTEER VOICES

"I fell into the transportation community by happenstance when the end of the Cold War dried up my original plans. Fortunately, I had contacts from a summer internship at my state department of transportation, and they had a mentoring program for engineers that allowed me to find a niche that matched my interests. I stayed in transportation because there is so much room for one person to make a difference. We operate on a shoestring budget in transportation, so there are few of us and big money isn't what drew us here. TRB has played a large role in that for me because it allows me to interact with colleagues outside my own state.

—GREGORY T. GIAIMO
Transportation Engineer IV, Ohio Department of Transportation
Columbus

E-Ticketing

The Fast Lane in Highway Construction Technology

Kathryn Weisner, FHWA

ROY STURGILL AND GABRIEL B. DADI

Sturgill is an assistant professor in the Civil, Construction, and Environmental Engineering Department at Iowa State University in Ames. Dadi is the W.L. Raymond and R.E. Shaver Chair associate professor of civil engineering at the University of Kentucky in Lexington.

Prepping for installation of 48-inch reinforced concrete pipes, a Maryland State Highway Administration inspector uses a mobile device to gain real-time access to an e-ticket database. Such tools improve project efficiency and reduce the use of paper tickets, as well as the frustration, clutter, and potential errors that come with them.

The electronic construction (e-construction) initiative has been evolving for decades. Its premise to improve the efficiency of construction processes with paperless systems eventually led to including e-ticketing in Round 6 of FHWA's Every Day Counts (EDC-6) Program.

Paper tickets are often a source of frustration and clutter in highway construction offices. This source documentation has traditionally supported record retention requirements for payments to contractors and had to be maintained for years. Pilot approaches to e-tickets occurred sporadically; total elimination of paper seemed daunting, since it involved an assortment of stakeholders, including suppliers, contractors, and state departments of transportation (DOTs).

However, Iowa DOT's drive for safety improvement really put e-ticketing on the map when a department construction technician died after being struck by a concrete truck. By nature of the technology, e-ticketing provided needed physical distance between inspection staff and delivery vehicles and equipment, thus improving safety while providing process efficiency.

What Is E-Ticketing?

FHWA defines e-ticketing as

A paperless process for creating, sharing, tracking, documenting, and archiving materials information, accessible in real time via mobile devices, [that] provides all stakeholders with an electronic means to verify materials deliveries while enhancing safety, streamlining inspections, and improving contract administration procedures.

E-ticketing has many forms but typically entails exportable and digitalized source data. AASHTO prepared a provisional specification for e-ticketing that notes source data such as contract, project, source, and mix design identification; material code; ticket number; and loading and weight details. Numerous applications have been developed that portray e-ticketing, including one of several Iowa DOT interfaces (Figure 1).

Scale Tickets

Project# Search Project Name

Ticket#:	240601
Date/Time:	Dec 01 2017 01:29 PM
Asset Name:	504049
Scale Asset Name:	504049
FW Known:	Yes
Source:	Cosmonaut Plant
Weighmaster:	--
Project Name:	Vera Appartments
Phase Code:	--
Material Name:	SP 9.5 C
Void:	0
Net Tons:	21.66
Gross Tons:	34.51
Free Form 1:	--
Temperature:	--
Waste Tons:	0.0
Project Number:	Vera
Cumulative Tons:	169.9

FIGURE 1 Iowa DOT e-ticketing interface. (Source: Iowa DOT)

Forms of E-Ticketing Implementation

Within the confines of FHWA's definition, there is some flexibility in what is considered an e-ticket. While this definition continues to evolve, the recognized spectrum of approaches to implement e-ticketing solutions has become constricted. A ticket being transferred or communicated as an image is no longer considered an e-ticket. A true e-ticket must be a digitalized form with either readable cells or electronic data that can be transferred or analyzed by end-user applications. This is an important consideration for state DOTs when choosing e-ticketing solutions.

More advanced uses of e-ticketing consist of solutions that are either integrated with other systems or that involve automated information flow. Some state DOTs also have implemented e-ticketing, along with supplementary or complementary intelligent construction technologies. These technologies include paver-mounted thermal profilers, GPS, intelligent compaction, dielectric profile systems, and more. To emphasize this point, there has been an effort to incorporate e-ticketing into Veta data management and analysis software that geospatially stores data sourced from intelligent compaction and other intelligent construction technologies (Figure 2). As these systems merge, AASHTO has begun to develop standards to improve uniformity.

Implementation of e-ticketing can occur through various vendor- or in-house–developed solutions and may be used for a variety of materials or components. The implementation of an e-ticketing solution usually begins with a host of initial decisions, such as which materials or components it will include; which features are necessary (like GPS hauler tracking); and how it will be procured.

Benefits and Uses of E-Ticketing

The benefits of e-ticketing include improvements but are not limited to

- Safety,
- Communication and data exchange,
- Material tracking and verification, and
- Future forensic investigation of materials.

Any e-ticketing solution that does not require field staff to climb equipment or trucks to retrieve tickets results in safety benefits that are difficult to quantify. The typical form of receiving an e-ticket involves field staff with mobile devices

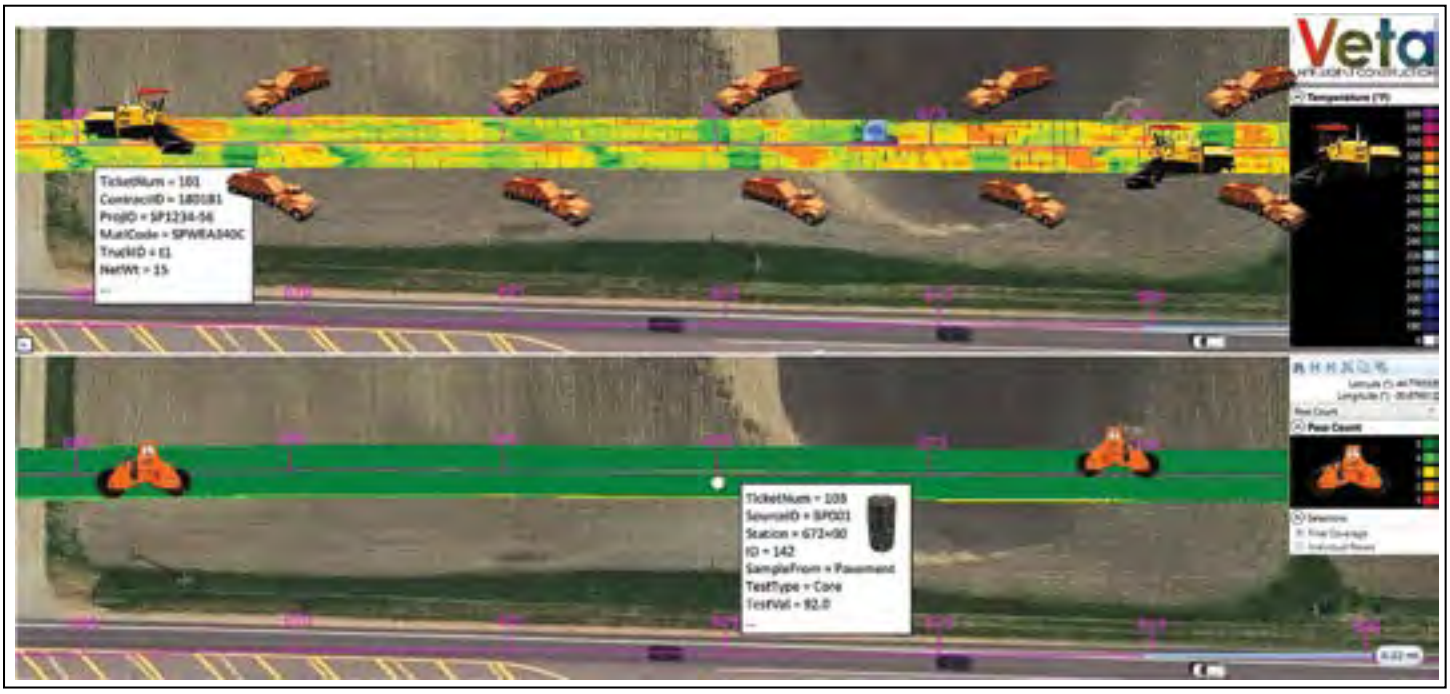

FIGURE 2 E-ticketing interface within Veta.

being able to first recognize a truck onsite through license numbers or other identification and then locate ticket information electronically according to that identifier. A deeper level of integration after simply receiving the ticket can lead to additional benefits. For instance, if the e-ticketing solution is tied into a state DOT's construction management system, field staff can provide material notes or even testing information regarding material delivered. Some systems include geospatial tracking of the hauler and can show the location of material placement. This location information, coupled with material formulas or other information, could equip state DOTs with powerful forensic opportunities.

Another possible benefit would be tying the solution to contract payment systems. Field staff and engineers can process payments quickly and easily. Beyond the time savings, data quality also can be improved. As a result, the elimination of lost tickets leads to a seamless and accurate data exchange.

While the noted benefits are largely those of the state DOT, one of the standout elements of e-ticketing is the benefits to all stakeholders. Solutions with geospatial tracking allow paving contractors to determine when the next load of asphalt or concrete will arrive. This is a critical benefit for asphalt pavers who may be able to avoid paving stoppages and improve pavement quality. Further, many of the e-ticketing solutions also act as fleet management systems. These systems provide opportunities to suppliers and haulers to build efficiencies and savings into their approaches by balancing truck numbers and production.

Challenges in Using E-Ticketing

The challenges of implementing e-ticketing often include

- Connectivity issues,
- Cost and procurement,
- Liability concerns, and
- User buy-in.

As with many IT solutions, the lack of reliable connectivity and cellular coverage presents issues. Many vendor solutions maintain data until connectivity is restored, but projects in locations without service will typically need to revert to paper tickets unless other solutions—such as cellular boosters, wireless connections, or satellite connections—can be implemented. Procurement has largely been left to the contractor stakeholders, leading to multiple vendor-provided solutions. Having multiple applications and field staff trained in their use presents a challenge, leading to a new range of vendors to provide more agnostic interfaces that accept data across multiple vendors.

E-ticketing also is not without its technology expense to other stakeholders. Suppliers must have accessible systems. Therefore, implementing e-ticketing has resulted in equipment upgrades. State DOTs have been cognizant that equipment upgrades for small suppliers are cost prohibitive and have typically implemented e-ticketing strategically. Other challenges from stakeholders have involved geospatial tracking of haulers; there have been liability-related concerns (e.g., known speed or weight violations), and haulers believing their competitive advantages could be compromised. Further concerns of data security from all stakeholders also have been an implementation challenge.

COVID-19 Pandemic and E-Ticketing Use

While the challenges caused many state DOTs to avoid rushing into e-ticketing implementation, the COVID-19 pandemic led to rapid implementation of various forms of e-tickets. Many state DOTs went to touchless construction management approaches, with paper tickets being one of the most common shared points of contact. Due to the pandemic, e-ticketing forms included pictures or other image forms of paper tickets shared by either e-mail or vendor-supplied solutions. While state DOTs needed a quick e-ticketing solution to compensate for the pandemic environment, these static images did not meet the true definition of an e-ticket. Therefore, many state DOTs are now revisiting true e-ticketing solutions.

Which State DOTs Use E-Ticketing?

Some of the first states piloting e-ticketing approaches include Iowa, Kentucky, Alabama, Pennsylvania, Florida, Minnesota, and Utah. A desire to determine which state DOT was implementing e-ticketing led to the creation of the *National Cooperative Highway Research Program (NCHRP) Synthesis 545: Electronic Ticketing of Materials for Construction Management*, a 2019 survey that revealed the use of e-ticketing in 10 states (*1*). A 2020 survey by the National Asphalt Paving Association—conducted after COVID-19 had caused severe effects—indicated that 24 state DOTs were using e-ticketing (*2*). Figure 3 shows the state of practice from

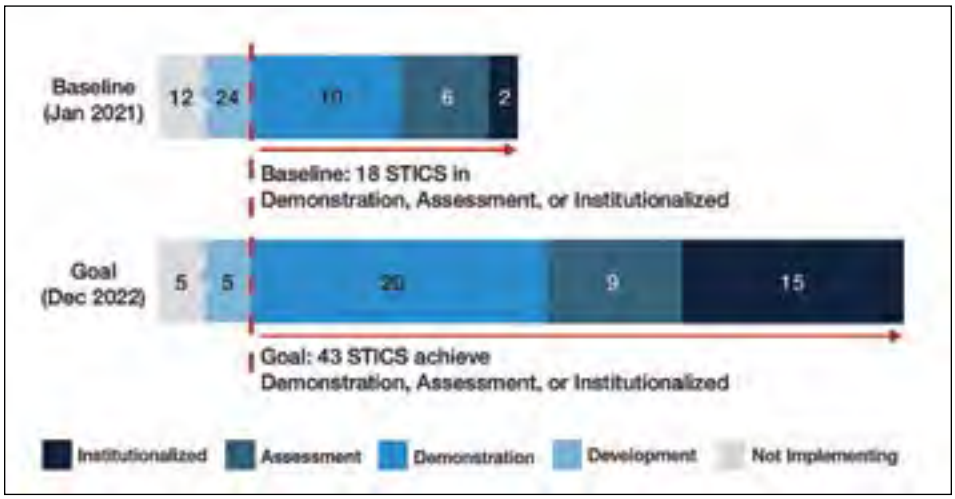

FIGURE 3 FHWA EDC-6 e-ticketing status. (Source: FHWA)

FHWA's EDC-6 as of January 2021, as well as the goal for December 2022.

How Does the Future Look for E-Ticketing?

With many states having some experience with e-ticketing, the future seems promising. While numerous challenges exist, the benefits of e-ticketing make it one of the most appealing recent technology solutions for highway construction. More standardization protocols need to be developed as the variety of e-ticketing solutions increases. AASHTO standardization of e-ticketing—as part of a material data management system—will guide much of its future implementation (Figure 4). Many states need to evolve through levels of e-ticketing before achieving a fully integrated system of material-related data collection with automated workflows.

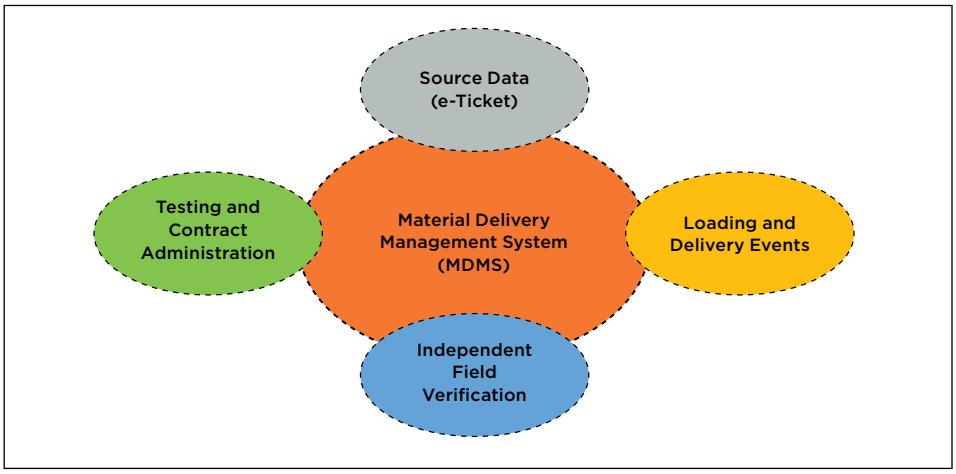

FIGURE 4 Minnesota DOT MDMS provisional practice standard. (Source: Minnesota DOT)

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ADDITIONAL RESOURCES

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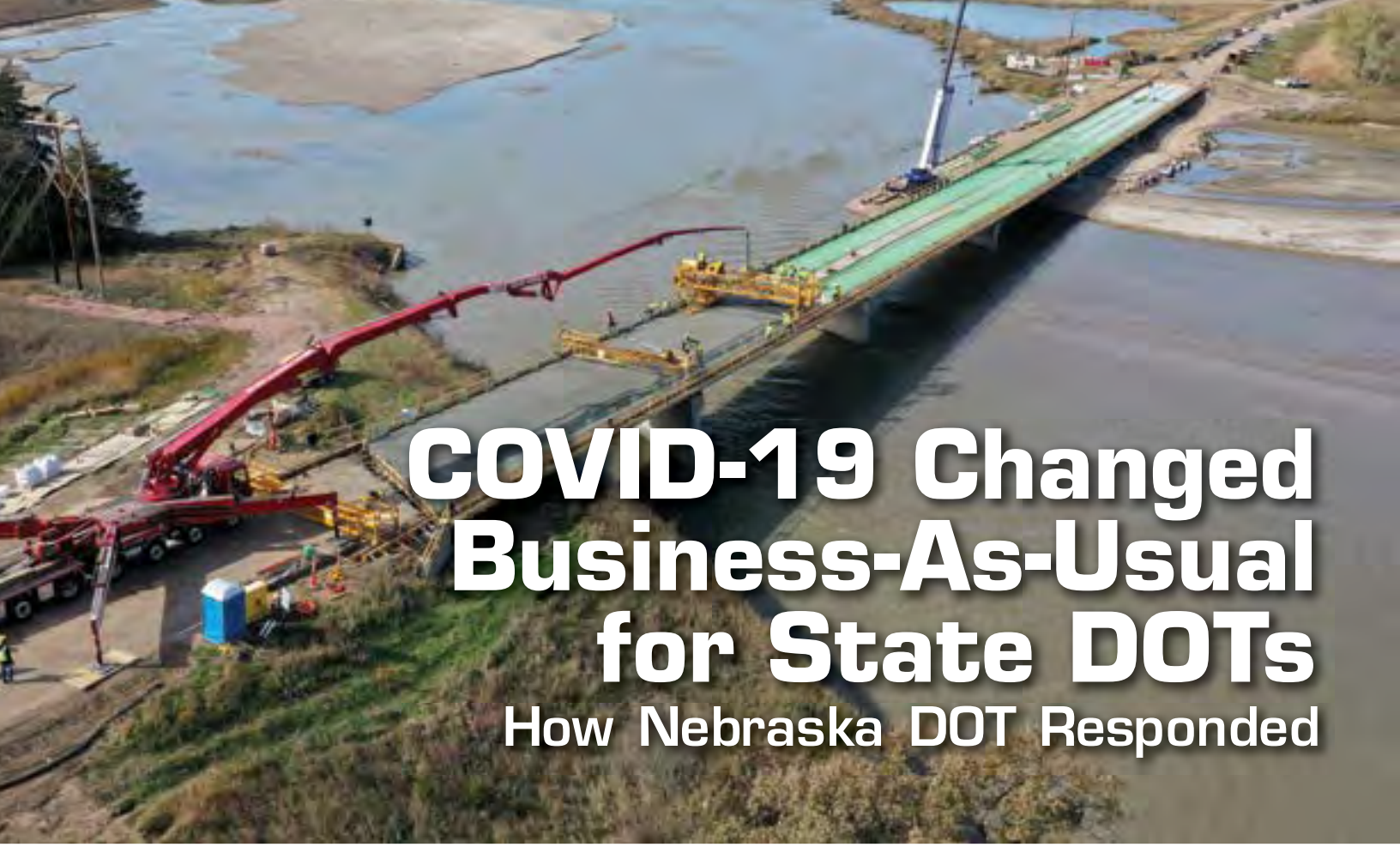
VOLUNTEER VOICES

"I was drawn to the transportation industry primarily because of my affinity for materials and pavement, as well as my flair for infrastructure systems engineering. I have been privileged to observe the beneficial transitioning from conventional practices to such fundamental yet innovative processes as the use of internal curing techniques, Markov chains for infrastructure condition evaluation and decision making, and nondestructive devices. More academics in engineering practice are bridging the gap between the industry and academia. Over the decades, TRB has provided the forum for us to conceptualize, initiate, and conduct research, as well as to have peer reviews of journal papers.

—BERNARD IGBAFEN IZEVBEKHAI
Research Operations Engineer
Minnesota Department of Transportation, Maplewood



COVID-19 Changed Business-As-Usual for State DOTs

How Nebraska DOT Responded

Nebraska DOT

LORRAINE LEGG

The author is assistant state construction engineer at the Nebraska Department of Transportation in Lincoln.

Hauling out the heavy equipment, Nebraska Department of Transportation (DOT) crews and its contractors sprang into action after a 2019 flood damaged the Niobrara River Bridge in Butte. The department's successful response to the historic flooding set the stage for an effective response to disruptions brought on by the COVID-19 pandemic.

The COVID-19 pandemic struck Nebraska just as the 2020 construction season was gearing up. Directed health measures (DHMs) requiring social distancing and quarantines tested the Nebraska Department of Transportation's (DOT's) abilities to adapt to unforeseen circumstances; a situation that is not new to the department. Almost a year before the pandemic, Nebraska experienced historic flooding that significantly damaged its transportation infrastructure. Nebraska DOT staff and partners quickly responded to the flooding and effectively reestablished vital transportation routes within northeast Nebraska. While Nebraska DOT faced a different type of challenge with DHMs, its response was similarly consistent and effective. The department leveraged existing technology to administer its highway construction program while complying with the DHMs.

COVID-19 pandemic–related DHMs motivated Nebraska DOT and its industry partners to adopt helpful technology more rapidly and comprehensively. The social-distancing environment required department divisions—and individuals who had resisted using existing software and electronic processes—to adopt such measures to fulfill their responsibilities.

Many manual processes that were converted to electronic are described in this article. There was no choice but to use these electronic processes to avoid close contact between personnel. In addition, many of Nebraska DOT's existing electronic and digital project delivery and construction processes improved during the COVID-19 pandemic. The department leveraged technology to stay connected with its staff, paving the way for its teams to remotely perform their work efficiently and effectively. These successful strategies and tools have carried forward to today, when many Nebraska DOT teams are offered a hybrid work schedule. They enjoy the flexibility of alternating between office and remote locations without losing productivity or communication.

Nebraska DOT

Positioned for accuracy, stationary survey equipment forms a base station—half of the set-up for real-time kinematic (RTK) surveying, which corrects common satellite navigation errors. Establishment of base stations allows contractors and field staff to use models for surveying during construction that facilitate social distancing.

Nebraska DOT

Collecting data on the I-80/I-76 Interchange in Ogallala, Nebraska, a surveyor operates a GPS survey rover—the freely moving half of two receivers used in RTK surveying. The state's GPS reference station network allows surveys to be conducted electronically, helping to minimize survey crews and reduce their exposure to each other.

Nebraska DOT has been slowly progressing toward implementing building information modeling for infrastructure, a larger set of digital practices. The department's response to DHM requirements demonstrates some of that progress. For example, roadway design staff were already using 3-D modeling software to produce project designs with models provided for information only. Contractors and field staff were able to use the models for surveying and construction to facilitate social distancing. The combination of GPS survey equipment, cell phones, and the state's GPS reference station network allowed for independent surveys to be conducted, equipment to be efficiently used, and staff to be effectively allocated to stay on schedule while maintaining social distancing.

Electronic submittal of final plans was being piloted when the pandemic hit; however, checking hard copy plans was still the norm. The remainder of the contract package—such as special provisions and calculations—also was submitted and checked as a hard copy. When it became apparent that remote reviews would be needed, Nebraska DOT staff found a solution that allowed all documents to be submitted and checked electronically. This solution became permanent because it provided effective coordination and efficient handoff of the contract package throughout the process.

Project bidding had been held in person from a conference room at Nebraska DOT headquarters. Staff began using online conferencing to livestream contract bidding and conform with DHM. Nebraska DOT was thereby able to fulfill its responsibility to conduct public bidding while providing industry partners the opportunity to hear bid results read publicly. Bidding attendance increased from a handful of Nebraska DOT staff and contractors to dozens of participants logging in to hear bid results. The department now posts bidding results online shortly after reading them. This change in procedures has improved customer service, and it will continue after the pandemic's effects have abated.

The e-construction initiatives that were already underway at Nebraska DOT helped the department manage its responsibilities during the COVID-19 pandemic. While some contractors were already executing contracts electronically, the health directives provided the impetus for Nebraska DOT to actively encourage greater use of this option. Today, almost all contractors execute their construction contracts electronically.

Further, change orders currently allow execution entirely via electronic means. The change order passes through Nebraska DOT and FHWA review using AASHTOWare, an electronic construction management system, and is forwarded to

the contractor electronically. This procedure has not only simplified the change order management process but also has significantly shortened the time between initiation and execution. During the height of the COVID-19 pandemic, the department was able to take advantage of the electronic process when staff were required to work remotely.

Nebraska DOT already uses an electronic construction management system; however, most of the inspection documentation work was being performed in the office. During the DHM, field staff could report project information directly from their respective vehicles using Wi-Fi hotspots and virtual private network (VPN) access with laptops or cell phones. Previously, acquisition of laptops or cell phones with Wi-Fi hotspots and VPN access had been restricted to select individuals who had an approved need, due to budgetary constraints and concerns about the potential loss of the device. During the worst of the COVID-19 pandemic, conducting daily responsibilities to meet the DHMs forced a change in culture that encouraged the use of Wi-Fi hotspots and VPN access throughout the organization. Nebraska DOT will continue to benefit from this change when it adopts the web-based version of AASHTOWare.

Lost load tickets from asphalt and concrete trucks and voluminous ticket retention requirements have long been a source of frustration. Rudimentary electronic ticketing (e-ticketing) processes were implemented due to the COVID-19 pandemic, since passing paper tickets back and forth was not recommended. Nebraska DOT field staff used various solutions with the contractor, some of which were initiated based on other projects. During the COVID-19 pandemic, the department used simplistic solutions such as e-mailing a photo of the ticket to the inspector and collecting all the paper tickets at the end of the day. These ticket collection solutions smoothed the way for Nebraska DOT to begin piloting projects with more sophisticated e-ticketing solutions.

Mobile devices—such as smartphones and laptops—also helped staff remain productive while maintaining social distancing. Electronic methods of communication provided a valuable variety of tools to Nebraska DOT. When in-person meetings were discouraged or prohibited, text messaging (including group texts), virtual meetings, and e-mail provided multiple communication options for project coordination and problem solving. Employees who had never participated in virtual meetings learned to schedule them. Virtual platforms continue to be an option for most meetings, allowing more staff across the state to attend.

Nebraska DOT's concern for its employees' well-being transformed the workplace because, in the end, staff were the most affected by the COVID-19 pandemic changes. The department provided equipment to employees, as needed, for remote work. Additional laptops were purchased to provide a remote work option to those employees who had previously used desktop systems. However, printers were not supplied to staff working remotely, which further encouraged the use of electronic methods of review and communication. Skepticism about productivity was replaced with confidence in staff's ability to produce while working remotely. Nebraska DOT experienced and recognized the benefits. Staff learned that the savings in commute time allowed for more flexibility in their personal lives, while increasing effectiveness during their established work hours. The department learned that allowing flexibility provides more job satisfaction, which ultimately results in invested employees. Nebraska DOT will likely change its computer refresh/update schedule to replace most desktops with laptops, which will provide for continued flexibility.

Nearly all state DOTs have been experiencing workforce retention and recruitment issues, which was evident before the pandemic. Nebraska DOT continues to allow remote work for many positions, recognizing that a flexible workplace with a hybrid remote work schedule can make employment at the department more appealing. The potential to diversify its workforce and attract more talent is greater now than it was before the COVID-19 pandemic.

Nebraska DOT learned valuable lessons from the pandemic. Typically, government agencies are not known for moving quickly. However, COVID-19 expedited movement. The department needed to provide for the safety of its employees and industry partners while delivering its program and projects for its customers. It learned to adjust and adapt rapidly to changing requirements. The success that Nebraska DOT has experienced in its strategies for delivering the construction program during the pandemic increased the agency's comfort level with perceived risks associated with technology innovations.

The COVID-19 pandemic required Nebraska DOT and its construction partners to think creatively. They see further possibilities for adopting technological advancements and expect that those will be realized more quickly. Nebraska DOT has confidence in its staff's quality and efficiency in accomplishing their work while leveraging technology. Although the COVID-19 pandemic experience has been devastating in many ways, the action Nebraska DOT took—and the resulting confidence in its abilities—has positively changed its organization's culture.

COVID-19 pandemic–related DHMs motivated Nebraska DOT and its industry partners to adopt helpful technology more rapidly and comprehensively.

Carmen E.L. Swanwick

Project Development Director, Utah Department of Transportation

Carmen E.L. Swanwick specializes in bridges. In a recent Washington State University presentation for Women's History Month, she described some of her favorite structures. There were classics like the Golden Gate and the Brooklyn Bridge, as well as modern marvels like West Virginia's New River Gorge Bridge, which reduced a 45-minute drive along winding Appalachian roads to a one-minute trip high above the gorge. Swanwick then drew attention to humble box culverts, pedestrian bridges, and bridges that hardly seem like bridges when driven over from one part of the highway to the next. Old or new, grandiose or simple, she describes these structures and the process of constructing them with respect and awe. "To design a bridge and see it constructed is an extremely rewarding experience," she notes.

After receiving her bachelor's and master's degrees in civil engineering from the University of Utah, Swanwick spent more than 15 years as a transportation engineering consultant with an emphasis in bridge design and design–build projects. During this time, she gained experience on large projects such as Utah's I-15 Reconstruction, New Mexico's Big I (the I-25 and I-40 Interchange), and Massachusetts' Route 3 North Transportation Improvement Project.

In 2009, the Utah Department of Transportation (DOT) offered Swanwick the position of chief structural engineer. "I was honored by this opportunity," admits Swanwick. "It is not every day that a consultant bridge engineer is asked to take such a leadership position within a state DOT." In this position, she was responsible for the Structures Design, Bridge Management, and Geotechnical Design divisions. In 2022, Swanwick became the project development director for Utah DOT, a role in which she leads the Central Construction, Central Preconstruction, Contracting Services, Central Materials and Pavements, Central Right of Way, and Structures divisions to support project delivery.

Swanwick has championed research throughout her career. "Research," she emphasizes, "plays a vital role in advancing the transportation industry." She concurrently is a member of the Transportation Research Board (TRB) Long-Term Infrastructure Program Committee and chairs the AASHTO Committee on Bridges and Structures. Swanwick also chairs two National Cooperative Highway Research Program (NCHRP) project panels—NCHRP Project 23-22, "AASHTO Committee on Bridges and Structures Strategic Plan, Operating Guidelines, and Research Roadmap Development," as well as NCHRP Project 20-123(10), "Alternative Project Delivery Methods: Assessing and Allocating Risk to Increase Competition."

"In today's world we need to think differently, and research will help us—as an industry—get there."

"Technology is advancing so fast in today's world," she cautions, "that, as an industry, we want to capitalize on these advancements." She points out unmanned aerial systems, robotics, and digital project delivery, as well as the continued use of accelerated bridge construction in which bridges or bridge components are constructed offsite and assembled on location. In 2017, Swanwick started Utah DOT's Unmanned Aerial Systems Program to supplement traditional bridge inspection data while allowing for improved safety and data collection efficiency. "Robotics is in the future of bridge building," she predicts, noting that technology already exists where "machines move the reinforcing bars, place them in the bridge deck, and then tie them together—and autonomous vehicles are coming to construction equipment, as well."

Swanwick recognizes digital project delivery as a major initiative for Utah DOT and AASHTO. "Think of moving away from a paper plan set to digital models," she suggests.

Swanwick is a prolific author on topics like accelerated bridge construction, rapid bridge replacement, and prefabricated bridge elements. "Accelerated bridge construction is extremely important," she emphasizes. "A get in–get out philosophy benefits the public by minimizing time spent in construction traffic but—most importantly—improves safety for workers and the public. In today's world," she adds, "we need to think differently, and research will help us—as an industry—get there."

Swanwick also has an urgent sense of the need for workforce development to counter critical transportation-sector workforce shortfalls. "States are faced with shrinking resources, outdated training, and an evolving difference in skill sets," she warns. An avid speaker, she encourages young adults—especially young women—to consider a future in transportation engineering. "I knew at a very young age that I wanted to build things," she admits, giving credit to those who supported her efforts and provided opportunities for her to reach her goals. In turn, she encourages women to enter engineering. "I warn them not to let anyone ever tell them that they can't do something, and I remind them that they can do anything they want—with dedication and hard work."

Quick to point out how bridges eliminate obstacles by making travel and commerce easier, Swanwick bridges obstacles to individual success by being an advocate for those considering the engineering field. "When a student approaches me after an event to ask more questions about how to get involved, I believe I make a difference—no matter how small."

INFLUENCER

Jennifer Rasmussen

Jennifer Rasmussen is a senior research engineer at Safe Roads Research and Development in Aurora, Ontario, Canada. She has been a friend and is now a member of the Standing Committee on Roadside Safety Design. She also has been a friend of 15 TRB committees, including the Young Members Coordinating Council, and has served as a panel member on a National Cooperative Highway Research Program project.

How did you first hear about and become involved in TRB?

In 2009, my colleagues at the Midwest Roadside Safety Facility at the University of Nebraska–Lincoln encouraged me to attend the TRB Annual Meeting, as it was one of the prominent conferences in roadside safety design. I was a graduate student and didn't understand the expanse of the roadside safety field. At my first Annual Meeting, I met so many other researchers, members of industry, and FHWA and AASHTO representatives, which really gave me a new perspective on the field. I continued to make connections, volunteered to help, and eventually became a member of the Committee on Roadside Safety Design.

How has TRB influenced your career so far?

After I attended my first Annual Meeting, I realized how much roadside safety design research was still needed. My perspective changed from wanting to be a structural engineer who designs buildings and bridges to one who could make a difference in the roadside safety design field. It is such a small, niche field, and the people within the roadside safety community are really the reason I ended up on this career path. With the connections I made through TRB and its network, I ended up in my current position with Safe Roads Research and Development, and I truly enjoy everything I do.

What was one of your most memorable TRB Annual Meeting moments?

The most memorable *surprises* for me were the first time I received a Best Paper Award from the Roadside Safety Design Committee in 2014, and then when I received a Volunteer of the Year Award from the committee this year. However, I think the networking and socializing with all of the other professionals in the field is what has been most important to me—and that happens every year that I get to attend in person.

Transportation Influencer highlights the journey of young professionals active in TRB. Have someone to nominate? Send an e-mail to TRNews@nas.edu.

Let's Hear from You!

In each issue, we pose a sometimes light and fun transportation-related question that allows you to share your thoughts with other readers. To answer, **click here** or e-mail us at **TRNews@nas.edu** and follow these simple steps:

1. In the subject line, include **"Volunteer Voices: [the question you're answering]"**;
2. Answer the question thoughtfully, but keep it brief—up to about 150 words;
3. Add whether you are a TRB member or volunteer, and list the committees you are involved with; and
4. Add TRNews@nas.edu to your contacts so we avoid your spam folder when we tell you you're going to be published.

That's it! Like all *TR News* content, your response may be edited for grammar, length, and TRB style. When the issue with your quote is published, you'll get a PDF of the page featuring your response and photo.

Now that you have the details, here's the question:
How is your work or organization affected by the supply chain problem?

We Bring Different Perspectives

Founded in 2016, Latinos in Transit (LIT) was created to promote the advancement and development of Latinos and other minorities in transportation. Members come from across the United States and meet regularly to network, share information, and celebrate each other's professional development. After serving as vice president, in 2019 Alva Carrasco became LIT's second president.

In 2021, the Transportation Research Board (TRB) and LIT signed a memorandum of understanding that includes action items such as supporting each other's mentoring initiatives, identifying content for each other's newsletters and social media sites, and collaborating in each other's convening activities. Recently, Carrasco responded to questions on her new role and goals as president.

Your work at LIT is in addition to your day job. Where do you work, and what you do?
I work for WSP USA as the vice president/Transit and Rail West Region market lead. I am responsible for business development in the U.S. Southwest, and I also manage projects related to zero-emission bus fleet and facility transition plans for several transit agencies.

What are you most proud of accomplishing since being involved with LIT?
I have been a part of LIT since Day One. We started with the goal of encouraging Latinos to strive to become decision makers in the transportation industry, which was important to me after noticing how underrepresented we are in the industry. The importance of our mission has grown over the last two years while realizing that we really need to be part of the decision-making processes to address equity issues. We bring different perspectives that allow for making the best decisions for our community. I am proud of being part of the inaugural board and team that has helped LIT grow to where we are today. For instance, our reach now spans across the United States—and even abroad. We now have 24 member organizations ranging from small businesses to large public and private organizations and more than 1,400 followers on LinkedIn. We started with just 11.

Alva Carrasco (*above*), president of Latinos in Transit, shares her insights with Karen Febey, TRB senior report review officer.

What do you want to accomplish for the remainder of your tenure as president?
Before my term ends in December 2023, I have three main goals. First, I would like to reestablish the Leadership Summit, which we first held in 2019. This is a one-day conference that allows LIT members to network with top transit professionals. Second, I want to kick off an LIT scholarship program to award scholarships to minorities who are pursing transportation careers. Third, I want to launch a mentorship program for our members.

What is your view on how we can diversify the transportation industry?
My view of the transportation industry shifted during the pandemic. We all agree that more diversity is needed. As an industry, not only should we be looking for more women and people of color, but we also should be recruiting professionals from other industries—like social work, environmental justice, the medical community, higher education, and law enforcement—that can complement these goals. Doing so can broaden our equity lens.

What are some ways that you think TRB and LIT can most effectively collaborate?
There are a lot of cross-pollination opportunities. I would like TRB to be involved with LIT's next Leadership Summit later this year. At the 2022 TRB Annual Meeting, I was involved with TRB's Minority Student Fellows Program as a mentor, and I gave a presentation on LIT at their orientation session. I would like to continue supporting the fellows. I am excited to have TRB Senior Program Officer Mariela Garcia-Colberg on the LIT Board of Directors. I have already served as a point of contact for her when she has sought to identify diverse members on Transit Cooperative Research Program panels. I want to continue to serve as a resource for TRB to increase the diversity of its volunteers.

What do you like to do in your free time?
I love gardening and landscaping, which I will do at the new house I just moved into in Los Angeles. I also enjoy going to art installations, concerts, and music festivals, and spending time with my French bulldog, Louie.

To learn more about LIT, go to www.latinosintransit.org.

CONSENSUS STUDY REPORT

Retooling the Enforcement of Safety Regulations

MARK HUTCHINS

The author is a senior program officer at the Transportation Research Board at the National Academies of Sciences, Engineering, and Medicine in Washington, DC.

U.S. Navy Mass Communication Specialist 2nd Class John Paul Kotara II, Flickr, CC BY 2.0

Searching for the black box and wreckage from the missing U.S.-flagged merchant vessel *El Faro*, which was lost at sea after encountering Hurricane Joaquin east of San Salvador, the United States Naval Ship *Apache* retrieves and secures the towed pinger locator.

On October 1, 2015, the U.S. flag cargo ship *El Faro* sank during a hurricane en route to Puerto Rico from Florida, leading to the death of all 33 crew members. Following investigations, the National Transportation Safety Board and the U.S. Coast Guard's (USCG's) Marine Investigation Board identified a number of safety issues contributing to the tragedy. Most significant were the unsafe actions and decisions made by the ship's master and owner before and during the voyage. Investigations also revealed that verification of the vessel's compliance with applicable safety regulations was lacking, in part due to vague or misunderstood policies and procedures by the USCG and the American Bureau of Shipping (ABS). ABS was the classification society authorized to verify *El Faro*'s compliance with safety regulations on behalf of the USCG. In addition, ABS was responsible for certifying that *El Faro*'s owner had an effective safety management system (SMS). Post-accident audits of the company's SMS, however, revealed deficiencies sufficient to warrant the certificate's suspension, as well as evidence of substandard conditions among other vessels similar to *El Faro* that had been inspected by ABS on behalf of the USCG.

Classification societies are nongovernmental organizations that establish and apply technical standards for ships. Certification by a classification society confirms that the ship's design and construction meet the society's standards and is usually required for a ship owner to obtain marine insurance. In addition, classification societies often are authorized by maritime administrations to perform surveys of ships and audits of the ship owners' management systems to verify compliance with the safety requirements and other demands of international conventions. USCG has authorized seven recognized organizations (ROs) to provide verifications and certificates of compliance with international requirements (including those pertaining to SMS) that can be accepted by the USCG as evidence of compliance with safety, security, and environmental standards. The USCG uses this information to evaluate whether the ship merits a Certificate of Inspection and is fit for its intended route and service.

As an RO, ABS was authorized to conduct *El Faro*'s SMS review and certification on behalf of the USCG. Moreover, because *El Faro* was enrolled in the USCG's Alternate Compliance Program (ACP), ABS also was authorized to act on the USCG's behalf in verifying its compliance with many other applicable requirements. ABS and three other classification societies are authorized ROs that participate in this program. When conducting inspections of ACP-enrolled vessels, the ROs consult a "U.S. Supplement" to verify that the vessel complies with all applicable U.S. requirements that are not otherwise satisfied by international or classification society rules.

The compliance shortcomings of *El Faro* prompted investigators to take a closer look at the USCG's oversight of the delegations to ROs, and particularly those in the ACP. Subsequent findings of substandard vessels in the ACP fleet caused investigators to question the vigilance of RO surveyors in conducting inspections and the effectiveness of RO auditors in verifying SMS compliance. Investigators also pointed to the need for more vigilant USCG monitoring and oversight of ROs, including more thorough and better targeted vessel examinations, routine tracking of vessel compliance and safety levels, and more defined procedures for addressing poor performance. Inconsistent communication and coordination among RO surveyors and USCG inspectors were identified as possible factors contributing to these issues, which were exacerbated by incomplete and difficult-to-access records of vessel condition and compliance histories in the

USCG's Marine Information for Safety and Law Enforcement (MISLE) data system.[1] In finding that RO performance was not being monitored and lapses were not being investigated and resolved, investigators pointed to the USCG's failure to establish an organizational unit with direct responsibility for oversight of ROs and the ACP.

In response to these findings, the USCG acted promptly to create a new framework for RO oversight. Its foundation is a new organizational unit within USCG headquarters' Office of Commercial Vessel Compliance, the Flag State Control Division (CVC-4), dedicated to overseeing ROs and other third-party organizations having functions delegated by the USCG. CVC-4 has issued new policies, procedures, and guidance for marine inspectors in conducting vessel oversight examinations and making observations relevant to assessing the quality of RO surveys and audits. With this organizational and procedural framework in place, the USCG has taken additional steps to support the compliance verification work of marine inspectors and RO surveyors and auditors (Figure 1).

In October 2018, Congress passed the Hamm Alert Maritime Safety Act (as part of the Save Our Seas Act), formally mandating that the USCG carry out many of these oversight reforms that it was planning and starting to implement. The act also called for an independent assessment of their effectiveness and impact, which led the USCG to commission a study by an expert committee convened by the Transportation Research Board. *TRB Special Report 343: Strengthening U.S. Coast Guard Oversight and Support of Recognized Organizations: The Case of the Alternate Compliance Program* presents study findings. Having reviewed the USCG's response, the committee's overarching conclusion is that the USCG has put in place and proceeded to implement a well-conceived organizational and procedural framework for supporting and overseeing ROs and the ACP. While it is too early to assess fully the effectiveness of this new framework, important supportive elements that remain missing or incomplete suggest a potential impact that continues to be unfulfilled. To ensure an effective, long-term implementation of this framework, the USCG will need to make more pronounced and sustained progress in improving vessel records and data systems to support inspections and other compliance verification activity, as well as enable the development of more relevant metrics and risk-based methods for monitoring and assessing compliance and RO performance. It also will need to strengthen the relevant skills and competencies of its field inspectors and other marine safety personnel who support and oversee them while improving their ability to coordinate and communicate with ROs. The effective performance of the USCG and ROs' safety partnership requires positive support, in addition to vigilant monitoring and oversight. Qualities key to that support include an emphasis on cooperation, communication, transparency, and continuous learning.

For a full list of conclusions and recommendations, see TRB Special Report 343: Strengthening U.S. Coast Guard Oversight and Support of Recognized Organizations: The Case of the Alternate Compliance Program *at https://doi.org/10.17226/26450.*

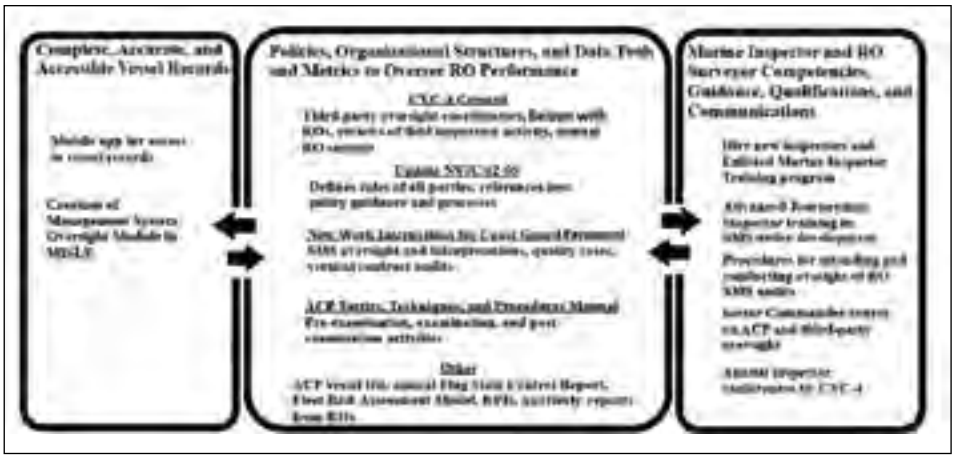


FIGURE 1 **USCG actions in response to findings and recommendations from *El Faro* investigations pertaining to the Alternate Compliance Program and third-party oversight (KPI = key indicator of performance; NVIC = Navigation and Vessel Inspection Circular).**

TRB Special Report 343 documents the independent assessment TRB performed to aid the USCG in improving safety through comprehensive organizational and procedural changes to address safety system inadequacies.

[1] MISLE contains data on vessels, facilities, USCG activities, information on individuals and organizations, and adjudication records. Access to MISLE is restricted due to privacy and security concerns related to the individual and law enforcement information contained in the database.

Experts Discuss COVID-19 Credentials for International Travel

NICOLE CERVENKA

The author is an associate program officer in the Policy and Global Affairs Division at the National Academies of Sciences, Engineering, and Medicine in Washington, DC.

The National Academies Board on Global Health—within the Health and Medicine Division—collaborated with the Policy and Global Affairs Division to convene a virtual workshop in August 2021 to explore effective, feasible, and secure ways to document and provide health information for safe international travel in an ethical and equitable way. Experts considered the use of COVID-19 travel credentials, denoting the traveler's vaccination, testing, and/or recovery status. This article includes highlights from the presentations during the workshop.[1]

PUBLIC HEALTH AND EPIDEMIOLOGY

Kathleen Neuzil, the Myron M. Levine Professor of Vaccinology and director of the Center for Vaccine Development and Global Health at the University of Maryland School of Medicine, discussed the public health impact of requiring vaccination or testing for travel. She explained that the goal of travel measures is to minimize the risks of increasing overall infections and introducing variants of concern in the destination country.

Angie Rasmussen, a virologist at the Vaccine and Infectious Disease Organization, explained that planes can be a fairly low-risk environment due to air filtration systems, spacing, and capacity limits. However, other parts of traveling can present a high risk for transmission: travel to and from the airport (e.g., public transport and ride shares), poorly ventilated environments, inability to physically distance, and poor mask use. Regarding mitigation measures, Rasmussen suggested that travel testing can be effective, but it depends on implementation, COVID-19 prevalence, and the interval between test and departure. She cautioned that symptom self-reporting can be difficult due to the wide range of potential symptoms, including none. Rasmussen further noted that temperature screening can be ineffective, given that transmission can occur before symptoms, some people never get a fever, and fever-inhibitor medications may mask fever.

Jonathan Cutrer, Flickr

Which regulations and laws apply to travelers in an international airport? It depends on *where*. This crowd in the Transportation Security Administration (TSA) security area at the Louis Armstrong New Orleans International Airport in Louisiana left state government jurisdiction when entering the TSA envelope and crossed into federal jurisdiction while within the security area. Once passengers leave the security area, they are again under state jurisdiction.

ACCURATE, SECURE, VERIFIABLE, AND USABLE DATA

Rebecca Coyle, executive director at the American Immunization Registry Association, conveyed that the purpose of a system of vaccination history for travelers is to provide a central repository for consolidating records and support the functions of immunization programs. She explained that immunization information systems can be leveraged for disease surveillance and that certain policies may affect interoperability and functionality, including authorized users, consent to opt in or out of policies, and mandates for reporting.

Josh Mandel, chief architect for Microsoft Healthcare and a lecturer in the

More information about the Board on Global Health is available at https://www.nationalacademies.org/bgh/board-on-global-health. Information about the Health and Medicine Division is available at https://www.nationalacademies.org/hmd/health-and-medicine-division. And information about the Policy and Global Affairs Division can be found at https://www.nationalacademies.org/pga/policy-and-global-affairs.

[1] The full report, *The Utility, Feasibility, Security, and Ethics of Verifiable COVID-19 Credentials for International Travel: Proceedings of a Workshop—in Brief*, is available at https://doi.org/10.17226/26409.

Harvard Medical School Department of Biomedical Informatics, mentioned that Microsoft is designing a platform for the consumer-driven sharing of vaccine credentials. He noted that the company has grappled with three main issues regarding how to ensure that

1. Individuals have access to their own data and cannot access data that they should not,
2. User data sharing is transparent, and
3. The platform and the health information system have no direct communication (no ping back of users' personal data to health care providers).

PRIVACY ISSUES AND LEGAL CONSIDERATIONS

Meryl Chertoff, executive director for the Georgetown University Project on State and Local Government Policy and Law and an adjunct professor of law at Georgetown University Law Center, explained that multiple federal authorities are involved in administering COVID-19 protocols. The Centers for Disease Control and Prevention is relying on private airlines to carry out regulations, and airports rely on the TSA and the FAA to create their own regulations, she added. This means that when travelers leave the TSA envelope, they are under state government jurisdiction. Legal questions remain about who is in charge, for example, on the issue of who has the authority to mandate quarantine.

According to Glenn Cohen, the James A. Attwood and Leslie Williams Professor of Law, deputy dean of Harvard Law School, and faculty director of the Petrie–Flom Center at Harvard, much of the debate about digital health passes for international travel is really about related but separate questions on whether mandating vaccination is justifiable and which exemptions should be permitted. On the issue of privacy, Cohen emphasized that the Health Insurance Portability and Accountability Act, or HIPAA, does not prohibit building a vaccine verification program or a system that stores the relevant information.

Ann Hartell, TRB

FACE TO FACE—Neil J. Pedersen, Transportation Research Board executive director, addresses members of the AASHTO Board of Directors at the AASHTO Spring Meeting in New Orleans, Louisiana, in May 2022. Pedersen was recognized by Shawn Wilson, the current AASHTO president, Secretary of the Louisiana Department of Transportation and Development, and vice chair of the TRB Executive Committee, who congratulated him upon the announcement of his retirement and invited him to say a few words. Pedersen will retire in the fall of 2022.

In Memoriam

Lester A. Hoel 1935–2022

Former Transportation Research Board (TRB) Executive Committee Chair, member of the National Academy of Engineering, and retired University of Virginia Professor Lester Hoel died in San Francisco, California, on April 19, 2022. Born to Norwegian immigrants, Hoel grew up in a Brooklyn, New York, tenement. From an early age, he embraced education, attending Brooklyn Technical High School, City College of New York, Polytechnic Institute of New York (now New York University), and the University of California, Berkeley, where he earned his PhD.

Hoel was the L.A. Lacy Distinguished Professor Emeritus of Engineering at the University of Virginia in Richmond, where he held the Hamilton Professorship in Civil Engineering from 1974 to 1999 and previously chaired the Civil Engineering Department. Prior to this, he was a professor of civil engineering and associate director of what was then the Transportation Research Institute at Carnegie Mellon University in Pittsburgh, Pennsylvania. In addition to being a member of the National Academy of Engineering, he was a distinguished member of the American Society of Civil Engineers, and a fellow of the Institute of Transportation Engineers.

Hoel had pivotal and longstanding leadership roles on TRB's oversight committees and reports from the National Academies. As Robert E. Skinner, Jr., TRB Executive Director from 1994 to 2015, noted, "Les Hoel was first and foremost a teacher."

A prolific author on transportation, Hoel is credited with 141 works in 398 publications in two languages and 4,097 library holdings. *Traffic and Highway Engineering*, of which he was coauthor, was released in 85 editions between 1988 and 2020.

Although he is best known for writing university textbooks, in 2010 he authored *I'll Have to Remember That: Ten Ideas for Living*, which summarizes 10 life lessons: five on what you must do yourself and five about the importance of other people in your life. The title, *I'll Have to Remember That*, was often spoken by Hoel's students, who appreciated the catchy phrase—a memorable last-minute takeaway—with which he would sum up each class.

Truly, Les Hoel taught a generation.

COOPERATIVE RESEARCH PROGRAMS NEWS

CARBON REMOVAL AND REDUCTION TO SUPPORT AIRPORT NET-ZERO GOALS

Mead and Hunt has received a $600,000, 20-month contract [Airport Cooperative Research Program (ACRP) Project 02-100] to develop a playbook to help airports understand and define how to reach the goal of net-zero carbon emissions by 2050. This research will provide foundational knowledge for airports to better understand carbon removal strategies—technology and nature-based—and their potential feasibility in an airport setting. The playbook will assist airports in selecting and customizing net-zero carbon strategies.

For further information, contact Marci Greenberger, TRB, at 202-334-1371 or MGreenberger@nas.edu.

MANAGING A FLIGHT DIVERSION WITH AN EMERGENCY RESPONSE

Aviation Innovation has received a $45,000, 12-month contract (ACRP Synthesis Project 11-03/Topic S04-26) to discover and describe current practices for handling diverted flights that involve an emergency response. The group also will provide information on practices to small hub, nonhub, and general aviation airports that may receive a diverted passenger flight and not have appropriate staff, resources, or equipment available. The synthesis created will describe and report on lessons learned, document case examples, create an example checklist, and outline any further research needed to close knowledge gaps.

For further information, contact Jordan Christensen, TRB, at 202-334-2317 or JChristensen@nas.edu.

Jan Rosolino, Unsplash

Research for *ACRP Synthesis 99: Emergency Working Groups at Airports*, revealed that although most flight diversions are gas-and-go with no deplaning of passengers, some diversions may impact airport operations or there may be a need for victim or family assistance. The flight diversion may be to an airport that does not typically handle the size or type of aircraft involved or the number of arriving aircraft, passengers, or both.

SAFE BEHAVIORS WITH HIGHWAY CONSTRUCTION AND MAINTENANCE CREWS

Blue Hardhat Consulting has received a $45,000, 18-month contract [National Cooperative Highway Research Program (NCHRP) Synthesis Project 20-05/Topic 53-02] to create a synthesis report that documents state department of transportation (DOT) practice regarding safety incentive and disincentive programs for state DOT highway construction and maintenance crews, related motivational techniques, and written policies or training to implement these programs. Information will be collected through a literature review, a survey of state DOTs, and follow-up interviews with selected agencies for the development of case examples.

For further information, contact Leslie Harwood, TRB, at 202-334-2312 or LHarwood@nas.edu.

Cathy Frye, Flickr, CC BY 2.0

Highway construction and maintenance are hazardous. Many state DOTs have unique limitations on financially incentivizing safe actions or using corrective actions to disincentivize unsafe behaviors.

STRATEGIC ISSUES AFFECTING HIGHWAY PRESERVATION, MAINTENANCE, AND RENEWAL

WSP USA has received a $279,999, 20-month contract [NCHRP Project 20-44(36)] to develop and conduct four virtual workshops for state DOT management and staff from Idaho, Utah, and Wyoming. The workshops are based on *NCHRP Report 750: Strategic Issues Facing Transportation, Volume 7—Preservation, Maintenance, and Renewal of Highway Infrastructure* and its appendices provided in *NCHRP Web-Only Document 272: Existing and Emerging Highway Infrastructure Preservation, Maintenance and Renewal Definitions, Practices, and Scenarios.* The workshop series is intended to share information on and promote adoption of emerging preservation, maintenance, and renewal practices and technologies.

For further information, contact Amir Hanna, TRB, 202-334-1432 or AHanna@nas.edu.

TELECOMMUTING, REMOTE WORK, AND HYBRID SCHEDULES

ICF has received a $150,000, 13-month contract [NCHRP Project 23-13(01)] to conduct a rapid review of recent state DOTs' experience with flexible work environments, synthesize this experience to identify successful practices and key considerations, and develop a template for managers and employees to assess their

Oregon DOT, Flickr, CC BY 2.0

Are employees less—or more—productive in flexible work environments? As agency leadership, managers, and employees consider longer term and wider adoption of flexible working environments, they must consider the benefits and risks for the agency, as well as for individual employees and their supervisors.

suitability for a flexible work environment. The template will be designed to inform decisions about remote work and modified work schedules for a wide range of state DOT job types.

For further information, contact Ann Hartell, TRB, at 202-334-2369 or AHartell@nas.edu.

IMPLEMENTING AND LEVERAGING MACHINE LEARNING

Old Dominion University Research Foundation has received a $350,000, 24-month contract (NCHRP Project 23-16) to advance the understanding and use of machine learning tools and techniques. This research will aid state DOTs by demonstrating machine learning feasibility and practicality in the context of transportation systems and fostering a better understanding of machine learning application opportunities, implementation processes, and data requirements. The project will identify needed skills, capabilities, resources, and organizational capacities; investigate existing transportation agency applications; provide cost, benefit, performance, and limitations considerations; and share machine learning frameworks, tools, guidance, and code for common use cases.

For further information, contact Sid Mohan, TRB, at 202-334-1249 or SMohan@nas.edu.

PLANNING FOR THE FUTURE OF INTERMODAL PASSENGER FACILITIES

Nelson\Nygaard Consulting Associates has received a $450,000, 18-month contract [Transit Cooperative Research Program (TCRP) Project D-21] to develop a guide and decision-making framework for stakeholders to plan, implement, and operate intermodal passenger facilities.

Improving multimodal, sustainable mobility requires intermodal collaboration, particularly to ensure that capital projects such as intermodal passenger facilities, effectively serve future community needs and address innovations in design, technology, and business models.

Recognizing the need for multimodal transportation research, ACRP, NCHRP, and TCRP jointly funded this research project.

For further information, contact Dianne Schwager, TRB, at 202-334-2969 or DSchwager@nas.edu.

MEMBERS *ON THE MOVE*

Rod Bliss, an NCHRP panel member, retired as fleet acquisitions manager for the Fleet Operations Division of the Texas Department of Transportation on June 30, 2022.

Marlon Boarnet, professor and chair of the Urban Planning and Spatial Analysis Department at the University of Southern California (USC) Sol Price School of Public Policy and a member of the Standing Committee on Economic Development and Land Use, was appointed director of USC's METRANS Transportation Consortium, effective July 1, 2022.

Steven Cliff, an ex officio member of the TRB Executive Committee and former NHTSA administrator, is the new executive officer of the California Air Resources Board.

Andrew Dawson, past chair of the TRB Committee on Aggregates and 2001 K.B. Woods awardee, retired in July from the University of Nottingham in England, where he has been associate professor emeritus.

Waseem Dekelbab, NCHRP associate program manager, has been promoted to NCHRP manager and CRP deputy director.

Erin Patricia Doherty joined *TR News* as an editor in May. Previously, she was a writer/editor for the Office of Communications and Public Information for the City of Alexandria, Virginia.

Melissa Foreman, an NCHRP and TCRP project panel member, is now an environmental protection specialist at the FAA. She previously worked at FTA.

Edward K. McDonald III joined TRB as an ACRP senior program officer in May. Previously, he was an aviation/aerospace consultant and chief value officer for J. T. Salem, a change management firm headquartered in Cleveland, Ohio.

Lori Sundstrom, NCHRP manager and CRP deputy director, retired on August 12, 2022, after more than 15 years at the National Academies and TRB.

Tod Yankee, a principal with Yankee and Associates in Freeport, Maine, is now an aviation strategy consultant for ICF, which is headquartered in Fairfax, Virginia.

Katherine Zeringue, an NCHRP project liaison, has joined NASA/Kennedy Space Center as the cultural resources manager. Previously, she was with the FRA.

Total Maximum Daily Load Development and Implementation
ASCE, 2022, 460 pp., $150; 978-0-7844-1594-8. Edited by Harry X. Zhang, Nigel W.T. Quinn, Deva K. Borah, and G. Padmanabhan.

This new manual of practice provides guidance to practitioners selecting analytical tools and models in the development of a total maximum daily load (TMDL) and its implementation plan. Included are detailed descriptions of a variety of watershed and receiving-water quality models that can be used, highlighting recent advances in TMDL analysis and modeling.

The Engineer's Project Delivery Method Primer: Uniform Definitions and Case Studies
Douglas D. Gransberg, Michael C. Loulakis, and Ghada M. Gad. ASCE, 2022, 412 pp., $110; 978-0-7844-1601-3.

To aid in understanding capital project delivery, procurement, and contracting, the authors bring clarity to the definitions and sometimes complex—and conflicting—terminology associated with project delivery methods. Provided is a comprehensive explanation of each delivery method, including the top three: design–bid–build, construction manager-at-risk, and design–build.

2022 Interim Revisions to Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals, 6th Edition
AASHTO, 2022, 56 pp., AASHTO member, $24; nonmember, $32; 978-1-56051-778-8.

These specifications are intended to serve as a standard and guide for the design, fabrication, and erection of highway signs, luminaires, and traffic signals. Structural supports are categorized as sign support structures, luminaire support structures, traffic signal support structures, and a combination of these structures.

Disruptive Emerging Transportation Technologies
ASCE, 2022, 344 pp., $110; 978-0-7844-1598-6. Edited by Heng Wei, Yinhai Wang, and Jianming Ma.

Emerging technologies such as the Internet of Things, 5th-generation wireless technologies, artificial intelligence, robotics, and connected and automated vehicles offer great potential to mitigate existing transportation issues. This book addresses the need for a fundamental understanding of relevant disruptive emerging technologies and their potential impact on smart transportation infrastructure and systems.

The titles in this section are not TRB publications. To order, contact the publisher listed.

TRB PUBLICATIONS

Transportation Research Record 2676
Issue 2

Included in this issue is research on understanding ridesplitting behavior, differences in near-crash risk by types of distraction, and nudging consumers toward greener air travel.

2022; 841 pp. For more information, visit http://journals.sagepub.com/home/trr.

Transportation Research Record 2676
Issue 3

The design of merging and diverging length at toll plazas, characteristics of heavy vehicle discretionary lane changing, data-driven air traffic flow management, modeling the demand for shared e-scooter services, ride-hailing behavior among millennials, and more are examined in this issue.

2022; 785 pp. For more information, visit http://journals.sagepub.com/home/trr.

SAGE is the publisher of the *Transportation Research Record: Journal of the Transportation Research Board* (TRR) series. To search for TRR articles, visit http://journals.sagepub.com/home/trr. To subscribe to the TRR, visit https://us.sagepub.com/en-us/nam/transportation-research-record/journal203503#subscribe.

Guidelines for Quantifying Benefits of Traffic Incident Management Strategies
NCHRP Research Report 981

This report offers information for evaluating traffic incident management programs, which can vary widely and may have different goals, guidelines, and methods applicable under a variety of data scenarios.

2022; 88 pp.; TRB affiliates, $57.75; TRB nonaffiliates, $77. Subscriber categories: operations and traffic management, planning and forecasting, safety and human factors.

Relationships Between the Fatigue Properties of Asphalt Binders and the Fatigue Performance of Asphalt Mixtures
NCHRP Research Report 982

Traffic-associated fatigue damage is one of the major distresses in which flexible pavements fail. This type of distress is the result of many thousands—or even millions—of wheel loads passing over a pavement. This report summarizes running selected binder fatigue tests and mixture fatigue tests and an evaluation of the results.

2022; 178 pp.; TRB affiliates, $73.50; TRB nonaffiliates, $98. Subscriber categories: materials, planning and forecasting.

Breaking Barriers: Alternative Approaches to Avoiding and Reducing Highway Traffic Noise Impacts
NCHRP Research Report 984

This report presents the results of a review of innovative strategies to avoid and reduce highway noise impacts. A practitioner's handbook to identify which of these innovative strategies may be appropriate for a highway project also is included.

2022; 166 pp.; TRB affiliates, $66; TRB nonaffiliates, $88. Subscriber categories: design, environment, highways.

Lighting Practices for Isolated Rural Intersections
NCHRP Synthesis 575

By gathering information and experiences from different agencies into a single document, this synthesis helps provide a foundation for transportation departments considering if, when, and where to install lighting at isolated rural intersections.

2022; 70 pp.; TRB affiliates, $51; TRB nonaffiliates, $68. Subscriber categories: design, highways, safety and human factors.

Use of Unmanned Aerial Systems for Highway Construction
NCHRP Synthesis 578

In the last decade, new technologies have transformed all stages of highway construction. This synthesis documents the use of unmanned aerial systems (UASs) by state departments of transportation (DOTs) during highway construction, identifies potential benefits and obstacles DOTs face when implementing UASs in highway construction projects, and identifies information gaps to be filled that could enable state DOTs to enhance the benefits of UASs for construction-related operations.

2022; 58 pp.; TRB affiliates, $49.50; TRB nonaffiliates, $66. Subscriber category: construction.

Primer and Framework for Considering an Airport Noise and Operations Monitoring System
ACRP Research Report 237

This comprehensive resource is designed to help airport industry practitioners assess the potential benefits and costs of acquiring, maintaining, and updating a noise and operations monitoring system or flight tracking tools without permanent noise monitors.

2022; 50 pp.; TRB affiliates, $46.50; TRB nonaffiliates, $62. Subscriber categories: aviation, environment.

Fare Capping: Balancing Revenue and Equity Impacts
TCRP Synthesis 160

This synthesis includes a review of the literature; a survey of 35 North American transit agencies that have recently considered implementing, are in the planning stages of implementing, or have implemented fare capping; and detailed case examples for five transit agencies that provide insight into fare capping motivations, program designs, implementations, and lessons learned.

2022; 150 pp.; TRB affiliates, $68.25; TRB nonaffiliates, $91. Subscriber categories: passenger transportation, policy, public transportation.

ADA Paratransit and Other Demand-Responsive Transportation Services in Small to Midsized Transit Agencies
TCRP Synthesis 161

Americans with Disabilities Act (ADA) paratransit demand continues to grow while resources are dwindling. Because of this, transit agencies continue to explore models to meet the demand more effectively. This synthesis explores paratransit delivery models for small and midsized systems and documents the way service and contract models are structured.

2022; 192 pp.; TRB affiliates, $73.50; TRB nonaffiliates, $98. Subscriber categories: administration and management, passenger transportation, public transportation.

To order the TRB titles described in Bookshelf, visit the TRB online bookstore, https://www.mytrb.org/MyTRB/Store, or contact the Business Office at 202-334-3213.

MEETINGS, WEBINARS, AND WORKSHOPS

September

6–9 **International Conference of the International Society for Intelligent Construction***
Guimaraes, Portugal
For more information, contact Nancy Whiting, TRB, at 571-217-2956 or NWhiting@nas.edu.

9 **TRB Webinar: Accelerating Decarbonization in the United States**
For more information, contact TRBwebinar@nas.edu.

12–16 **TRANSED: Mobility, Accessibility, and Demand Response Transportation Conference**
Online
For more information, contact Bill Anderson, TRB, at 202-334-2514 or WBAnderson@nas.edu.

19–21 **Conference on Scenario Planning in Transportation**
Washington, DC
For more information, contact Claire Randall, TRB, at 202-334-1391 or CRandall@nas.edu.

22 **TRB Webinar: Strategies to Improve the Quality of Pavement Condition Data**
For more information, contact TRBwebinar@nas.edu.

27–29 **SNAME Maritime Convention***
Houston, Texas
For more information, contact Scott Brotemarkle, TRB, at 202-334-2167 or SBrotemarkle@nas.edu.

October

27–28 **Criteria for Installing Automatic and Remote-Controlled Shutoff Valves on Existing Gas and Hazardous Liquid Transmission Pipelines (Meeting 6: Some sessions are open; others are closed.)**
Washington, DC
For more information, contact Tim Marflak, TRB, at 202-334-3213 or TMarflak@nas.edu.

Please contact TRB for up-to-date information on meeting cancellations or postponements. For Technical Activities meetings, visit https://www.TRB.org/calendar/calendar.aspx or e-mail TRBMeetings@nas.edu. For information on all other events or deadlines, inquire with the listed contact.

November

3–4 **10th International Symposium on Visualization in Transportation**
Washington, DC
For more information, contact Thomas Palmerlee, TRB, at 202-334-2030 or TPalmerlee@nas.edu.

15–17 **13th Annual Maritime Risk Symposium***
Lemont, Illinois
For more information, contact Scott Brotemarkle, TRB, at 202-334-2167 or SBrotemarkle@nas.edu.

December

12–14 **Advances in Materials and Pavement Performance Prediction***
Hong Kong
For more information, contact Nelson Gibson, TRB, at 202-334-2953 or NGibson@nas.edu.

*TRB is co-sponsor of the meeting.

To subscribe to the TRB E-Newsletter and keep up to date on upcoming activities, go to www.trb.org/Publications/PubsTRBENewsletter.aspx and click on "Subscribe."

VOLUNTEER VOICES

"I have always wanted to make a difference for the greater good through my work and family. Being involved with TRB through its committees, task forces, and panels has afforded me that opportunity to give back and contribute. Thank you for the opportunity to make a difference.

—SANDRA LARSON
Transportation Innovation Strategies Leader (Retired)
Stanley Consultants
Muscatine, Iowa

INFORMATION FOR CONTRIBUTORS TO TR NEWS

TR News welcomes the submission of articles for possible publication in the categories listed below. All articles submitted are subject to review by the Editorial Board and other reviewers to determine suitability for *TR News*; authors will be advised of acceptance of articles with or without revision. All articles accepted for publication are subject to editing for conciseness and appropriate language and style. Authors review and approve the edited version of the article before publication. All authors are asked to review our policy to prevent discrimination, harassment, and bullying behavior, available at https://www.nationalacademies.org/about/institutional-policies-and-procedures/policy-of-harrassment.

ARTICLES

FEATURES are timely articles of interest to transportation professionals, including administrators, planners, researchers, and practitioners in government, academia, and industry. Articles are encouraged on innovations and state-of-the-art practices pertaining to transportation research and development in all modes (highways and bridges, public transit, aviation, rail, marine, and others, such as pipelines, bicycles, pedestrians, etc.) and in all subject areas (planning and administration, design, materials and construction, facility maintenance, traffic control, safety, security, logistics, geology, law, environmental concerns, energy, technology, etc.). Manuscripts should be no longer than 3,000 words. Authors also should provide tables and graphics with corresponding captions (see Submission Requirements). Prospective authors are encouraged to submit a summary or outline of a proposed article for preliminary review.

MINIFEATURES are concise feature articles, typically 1,500 words in length. These can accompany feature articles as a supporting or related topic or can address a standalone topic.

SIDEBARS generally are embedded in a feature or minifeature article, going into additional detail on a topic addressed in the main article or highlighting important additional information related to that article. Sidebars are usually up to 750 words in length.

POINT OF VIEW is an occasional series of authored opinions on current transportation issues. Articles (1,000 to 2,000 words) may be submitted with appropriate, high-quality graphics, and are subject to review and editing.

RESEARCH PAYS OFF highlights research projects, studies, demonstrations, and improved methods or processes that provide innovative, cost-effective solutions to important transportation-related problems in all modes. Research Pays Off articles should describe cases in which the application of project findings has resulted in benefits to transportation agencies or to the public, or in which substantial benefits are expected. Articles (approximately 750 to 1,000 words) should delineate the problem, research, and benefits, and be accompanied by the logo of the agency or organization submitting the article, as well as one or two photos or graphics. Research Pays Off topics must be approved by the RPO Task Force; to submit a topic for consideration, contact Nancy Whiting at 202-334-2956 or nwhiting@nas.edu.

OTHER CONTENT

TRB HIGHLIGHTS are short (500- to 750-word) articles about TRB-specific news, initiatives, deliverables, or projects. Cooperative Research Programs project announcements and write-ups are welcomed, as are news from other divisions of the National Academies of Sciences, Engineering, and Medicine.

BOOKSHELF announces publications in the transportation field. Abstracts (100 to 200 words) should include title, author, publisher, address at which publication may be obtained, number of pages, price, Web link, and DOI or ISBN. Publishers are invited to submit copies of new publications for announcement (see contact information below).

SUBMISSION REQUIREMENTS:

- **Articles** submitted for possible publication in *TR News* and any correspondence on editorial matters should be sent to the *TR News* Editor, Cassandra Franklin-Barbajosa, cfranklin-barbajosa@nas.edu, 202-334-2278.
- Submit **graphic** elements—photos, illustrations, tables, and figures—to complement the text. Photos must be submitted as JPEG or TIFF files and must be at least 3 in. by 5 in. and 2 megabytes with a resolution of 300 dpi. Large photos (8 in. by 11 in. with a minimum of 4 megabytes at 300 dpi) are welcome for possible use as magazine cover images. A detailed caption must be supplied for each graphic element.

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