Transforming Transportation: Leveraging the Power of Artificial Intelligence, Digitalization, and Automation (2026)

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CONTRIBUTORS

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Transforming Transportation

Leveraging the Power of Artificial Intelligence, Digitalization, and Automation

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TRB TRANSPORTATION RESEARCH BOARD

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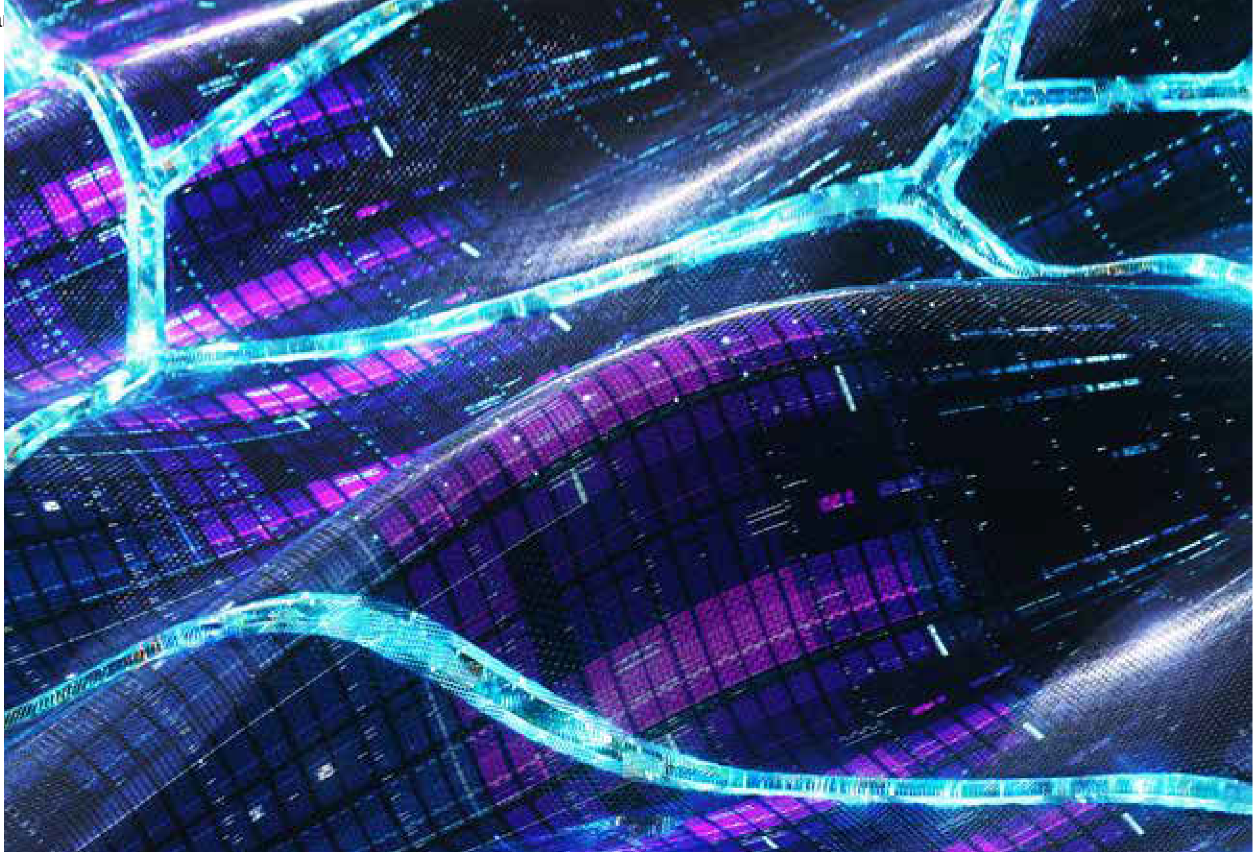


Introduction

Artificial intelligence (AI), digitalization, and advanced automation—including autonomous systems—are reshaping public-sector transportation agencies and their core mission to provide safe, reliable, and efficient mobility. As these technologies rapidly evolve, they will offer new ways to deliver this mission and change public expectations for transportation systems.[1] They will also reshape how public agencies work with the private sector, which is investing heavily in these technologies to accelerate their development and expand their capabilities. Although the pace of change and impact on specific transportation functions are uncertain, leveraging all three technologies and their synergies will be a major endeavor for transportation professionals and decision makers in the decades ahead.

This publication, which is a product of the Transportation Research Board (TRB) of the National Academies of Sciences, Engineering, and Medicine, examines how AI, digitalization, and advanced automation—including autonomous systems—are opening exciting new possibilities for transportation. Written by a subgroup of the TRB Executive Committee and endorsed by the committee as a whole, it aims to inspire and encourage TRB's participants and sponsors, as well as the broader community of transportation practitioners and researchers, to take an active role in exploring and advancing these possibilities to improve and potentially transform transportation.

AI, digitalization, and advanced automation are separate but closely connected technological fields. In the case of digitalization—which entails the use of data and digital tools and infrastructure to manage and monitor transportation systems and their construction, operation, and maintenance—its use and range of transportation applications have been expanding for years. However, when coupled with AI, its power, utility, and potential benefits are growing rapidly. AI is also accelerating the progress of advanced automation and autonomy, which are now developing rapidly across all transportation modes. While these technologies are moving into commercial and consumer markets across the broader economy, there is uncertainty about how quickly they will be deployed and scaled in transportation systems to bring about increasingly safer, reliable, and efficient mobility for people and goods.

Together, AI, digitalization, and advanced automation offer extraordinary opportunities to strengthen, reshape, and even transform the transportation enterprise, but in ways that will differ across modes and functions. Some opportunities may emerge quickly, such as from pivotal breakthroughs in robotics or autonomous systems, while others may play out gradually, such as by enabling cumulative improvements to the planning, design, construction, maintenance, and operation of transportation networks. Factors like data quality and implementation costs will influence which technologies and applications are most practical to pursue in the near term. And the capabilities provided by technologies that can be deployed early may not always match the most urgent needs. But as they advance and become increasingly integrated, these three allied technologies promise to yield innovations that will serve a growing array of transportation interests. Figure 1, for instance, illustrates how these technologies can work individually and synergistically to address many of the key interests of owners and operators of transportation systems.

Ultimately, success in tapping this enormous potential will be judged by the beneficial impacts on the economy and daily lives of people. Transportation agencies will want to use them to make it safer, easier, and less costly for people to access the places they want to go and for businesses to move their goods and services faster and more efficiently. In short, success will be measured in saved lives, serious injuries avoided, and desired trips made as expeditiously as possible.

The discussion that follows is intended to inspire transportation practitioners to envision the possible uses of AI, digitalization, and advanced automation and to encourage the research community to help realize them. Examples of capabilities, innovations, and candidate applications are therefore given for illustration and illumination. They are drawn from case studies, published reports, and ongoing research exploring multiple possibilities to improve transportation performance to benefit the public.[2] They illustrate, for instance, how these technologies can improve traveler and work-zone safety, enhance traffic management, optimize infrastructure maintenance, and expedite project delivery. Some forward-looking examples describe possibilities that await development.

The examples are not meant to be exhaustive, nor are they accompanied by a complete treatment of the potential benefits, costs, challenges, and opportunities. Indeed, there is uncertainty about how a wide range of issues associated with the development and deployment of innovations leveraging AI, digitization, and advanced automation may play out, including the emergence of new and unforeseen challenges. Such uncertainties present fertile ground for research on interests ranging from making sure that automated driving capabilities align with safe systems to ensuring that the surveillance capabilities of digital infrastructure do not neglect privacy concerns. While this publication was not developed to identify, much less discuss, all these uncertainties and interests, it was born

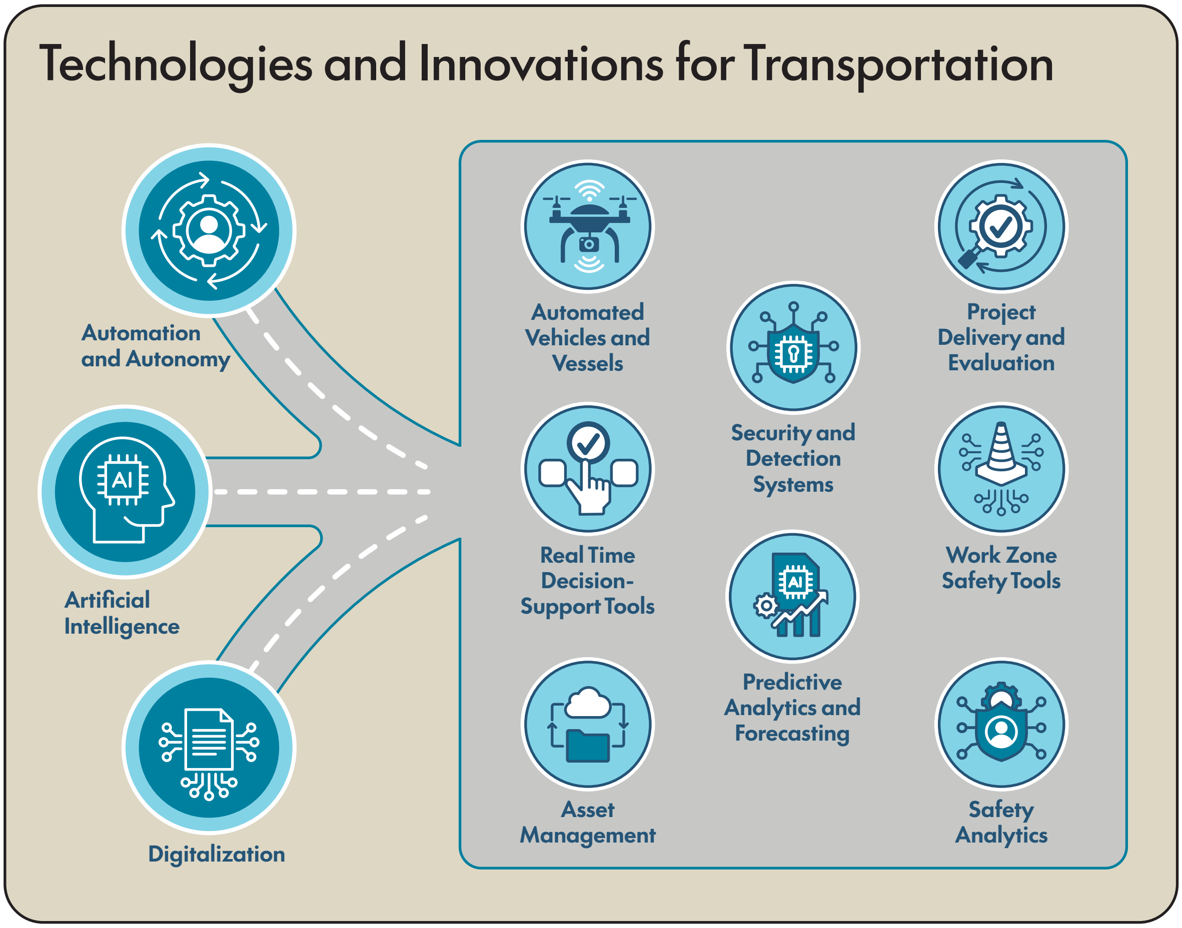


FIGURE 1. Artificial intelligence, advanced automation and autonomy, and digitalization are separately and jointly producing innovations in transportation.

from a recognition that research will be crucial to addressing them.

The publication starts with AI, describing its current capabilities and potential uses for improving transportation. The AI discussion ends with a brief look at emerging agentic AI and the role of AI in safety-critical systems. It then covers digitalization, focusing on digital infrastructure, infrastructure modeling, "building information modeling (BIM)," and digital delivery for construction. This is followed by reviews of recent progress in advanced automation and autonomy across road, air, rail, and marine transportation. For reasons given in Box 1, the discussion is structured to present the technologies one at a time but with recognition that the greatest benefits may derive from their combined powers.

The publication concludes with observations of what may be needed to accelerate the advancement and implementation of these technologies in transportation, including supportive public-sector actions. However, this publication is just a beginning. Discussions and collaborations—within and across transportation modes and

BOX 1

The Combined Power of Artificial Intelligence, Digitalization, and Advanced Automation

This publication, because its purpose is to highlight these three technological areas, presents each technology independently and selects example use cases that best illustrate the technological category. However, many of the discussed applications are examples of the combined power of these technologies working synergistically, as illustrated in Figure 1. For example, autonomous vehicles depend on artificial intelligence (AI) to collect and analyze data and perform perception of surroundings, digitization to provide detailed maps, and automation to control vehicles. Digital twins of infrastructure allow the use of AI and advanced automation to inform design, maintenance, and operation decisions. Moreover, as discussed further in the concluding section, AI and advanced automation applications depend on accurate and reliable digitalization, sometimes at a massive scale. To the extent that the lack of digital data is a roadblock to future applications, AI and advanced automation may also be the solution to creating the necessary scale of free-flowing data.

Future groundbreaking innovations in transportation are also likely to come out of the combined power of AI, digitalization, and advanced automation.

subspecialties—that continue to bring together agency leaders, experts in the technologies, and transportation researchers and practitioners will be necessary. Transforming transportation through research and investments in these technologies will require a multitude of people working on numerous projects and programs, ranging from the highly experimental to implementing proven innovations in the field.

The Power and Promise of AI

This publication uses AI as an umbrella term for a group of technologies that aims to perform tasks that typically require human-like intelligence, such as for learning, reasoning, problem-solving, perception, and understanding language. To highlight the AI possibilities for transportation, this publication examines AI in terms of its capabilities or use cases. Although generative AI, used in large language models, is currently receiving considerable discussion in media and policy circles, many of the capabilities highlighted in this publication can be produced using purpose-built AI models that use established machine learning techniques.[3] Figure 2 explains the different types of AI and how they relate to each other. The current usability of the depicted types, however, will differ, as some are now in use or will be ready for implementation in the near term, whereas others are the subject of research that could result in longer-term opportunities.

Harnessing the power of AI for transportation requires matching current or near-future AI functional capabilities with transportation-related tasks or objectives. This could mean exploiting AI's computer vision and image processing capacities to increase traffic safety or deploying AI's pattern recognition of time series data to make predictions that improve travel forecasting. It could also mean tapping opportunities to use generative AI, such as for personalization to users' experience and behavior or the generation of synthetic data to create more robust models of hazard scenarios. Decision-makers will also have to weigh the safety,

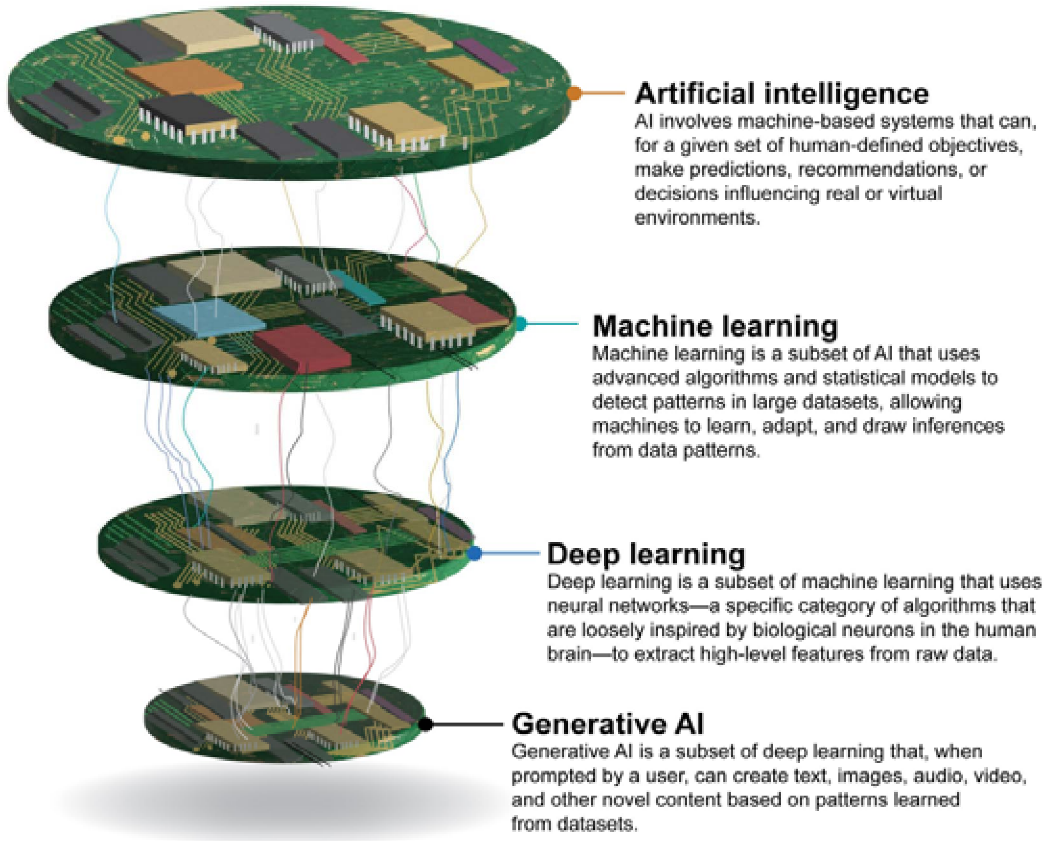


FIGURE 2 Artificial intelligence (AI) and its machine learning, deep learning, and generative AI subtypes defined.

SOURCE: U.S. Government Accountability Office. 2025. "Artificial Intelligence: Generative AI Use and Management at Federal Agencies." GAO-25-107653.

security, and cost implications of using a cloud-based AI or "edge AI," where the AI is embedded in or near the infrastructure or tool itself.[4] Examples of these and other AI use cases in transportation are shown in Table 1. The possibilities are many, but they will need to be screened for accuracy, fit, and other factors such as cost-effectiveness.[5]

TABLE 1 Types of Artificial Intelligence (AI) Activities and Uses with Transportation Examples

AI Activity	Typical Uses	Transportation Examples
Content creation	Generating new artifacts such as video, audio, narrative, software code, synthetic data	Visualizations of travel data
Content synthesis	Combining and/or summarizing parts, elements, or concepts into a coherent whole	Analysis of public input
Data governance	Cleaning, processing, and assessing data for quality, accuracy, security, and utility	Data quality for automated vehicles, logistics, and traffic management
Decision making	Selecting a course of action from among possible alternatives to arrive at a solution	Determining route for emergency response
Detection	Identifying by pattern matching and clustering of large and complex datasets for actionable insights	Infrastructure condition inspection
Diagnosis	Finding or recognizing something that meets the definition of a specified condition or problem	Infrastructure condition inspection
Digital assistance	Acting as a personal agent for understanding and responding to commands and questions, and carrying out requested tasks in a conversational manner	Customer service
Discovery	Recognizing patterns in datasets that a person may not find or find quickly	Research in innovative materials
Image or audio analysis	Recognizing attributes within digital images or audio data to extract meaningful information	Safety analysis
Information retrieval/search	Finding information about specific topics of interest	Online decision-support tools
Monitoring	Observing, checking, and watching over the process, quality, or state of something over time to gain insights into how something is behaving or performing	Security cameras or sensors
Performance improvement	Improving quality and efficiency of the intended outcomes	Traffic management
Personalization	Designing and tailoring something to meet an individual's characteristics, preferences, or behaviors	Trip planning for people with disabilities

Prediction	Forecasting the likelihood of a future outcome	Travel forecasts
Process automation	Performing repetitive tasks, removing bottlenecks, reducing errors and loss of data, and increasing efficiency of a process	Crash reporting in the field
Reasoning	Performing tasks involving symbolic logic, deduction, or inference	Research
Recommendation	Suggesting or proposing a manageable set of viable options to aid decision making	Emergency preparations for extreme weather
Robotic automation	Using physical machines to automate, improve, and/or optimize a variety of tasks	Maintenance activities
Vehicular automation	Automating physical transportation of goods, instrumentation and/or people	SAE Level 4 car or bus

SOURCES: Adapted from Theofanos, M., Y-Y. Choong, and T. Jensen. 2024. *AI Use Taxonomy: A Human-Centered Approach*. NIST Trustworthy and Responsible AI NIST AI 200-1. Gaithersburg, MD: National Institute of Standards and Technology. https://doi.org/10.6028/NIST.AI.200-1; Kerry, C.F., and S. Mishra. 2025. "The Myth of the Monolith: AI Is Not One Thing." Brookings, October 9. https://www.brookings.edu/articles/the-myth-of-the-monolith-ai-is-not-one-thing; Vasudevan, M., H. Townsend, T.N. Dang, A. O'Hara, C. Burnier, and K. Ozbay. 2020. "Identifying Real-World Transportation Applications Using Artificial Intelligence (AI): Summary of Potential Application of AI in Transportation." FHWA-JPO-20-787. https://rosap.ntl.bts.gov/view/dot/50651.

AI Tools and Capabilities Applied to Transportation

Public investments advancing AI applications are coming from federal transportation agencies, university transportation research centers, and state and local transportation agencies. These investments are producing a growing body of explorations, small-scale pilots, and other research and development (R&D) activities that explore what is possible, feasible, and implementable with AI's current capabilities. Recent federal investments have enabled AI projects on predictive real-time traffic management,[6] evaluating pavement condition and safety,[7] using mixed-reality vision to enhance infrastructure inspections,[8] and using digital twins for safety analysis.[9] Among the numerous AI research projects launched by University Transportation Center researchers in 2025 alone are projects on tracking structural changes in infrastructure,[10] integrating AI into intersection safety planning and design,[11] delivering preventive maintenance for coastal bridges,[12] addressing cybersecurity and resilience of vehicle-to-everything (V2X) networks,[13] and leveraging AI to use robots to install precast bridge components.[14] Additional examples of using AI to improve safety, security, traffic management, project management, and asset management are also discussed in other sections of this publication.

AI APPLICATIONS FOR ROAD AND RAIL SAFETY

Using AI to improve transportation safety has attracted significant excitement, in part because it facilitates accessing new sources and types of data and new types of analysis to support determinations of causation and means of prevention and mitigation. The road and rail examples that follow provide examples of projects using AI to improve transportation safety.

AI-powered video analytics has the potential to overcome the reliance of safety analysis on incomplete and imperfect crash data alone. The city of Austin, Texas, tested the video analytics capabilities of multiple vendors, comparing their ability to identify and analyze near misses involving a range of modes at 26 intersections across the city. The experiment was successful enough for the city to turn to developing best practices.[15] Working with the city of Bellevue, Washington, researchers have pilot tested using AI-powered video analytics to improve road safety at intersections by analyzing relationships between vehicle turning movements, intersection design, and traffic safety, especially pedestrian safety. Although the pilot test showed that video analytics of complex intersection environments was feasible, research results that would be implementable for safety would require a significant expansion of the number of intersections analyzed.[16]

Highway–rail crossings are also attracting interest in using AI to improve safety such as using AI-powered sensors to identify and warn pedestrians and bicyclists at risk of collision.[17] Researchers are using video analytics of highway–rail grade crossings to identify the extent and type of safety violations and the factors contributing to them. This information could then be used to implement appropriate engineering, enforcement, or educational efforts to reduce unsafe incidents.[18] Additional discussions using AI for rail safety are included in the sections on digitalization and on advanced automation.

Road safety often depends on improving and maintaining road conditions, including the visibility of signs, pavement markings, and road surfaces. Instead of relying on visual inspection or fixed-interval maintenance schedules, AI can be used to produce location-specific maintenance schedules. Agencies could then address the condition of safety-critical elements before they degrade, while not wasting resources on elements that are still performing as intended. For example, the retroreflectivity of pavement markings must be maintained above a certain level to meet minimum performance standards. Recent research has shown that AI-powered models can predict the degradation of retroreflectivity with enough accuracy to be useful for maintenance scheduling.[19]

AI-POWERED PREDICTIVE ANALYTICS

Because of AI's ability to reveal patterns and correlations across complex phenomena shaped by many variables, it has become a powerful tool for predictive analytics. AI-powered predictive analytics could improve forecasts of travel demand, anticipate and prioritize safety risks, and improve operations and maintenance, as well as enhance other business functions related to transportation services such as revenue forecasts, future workforce needs, or marketing effectiveness.

Highway travel models in seven states already incorporate AI techniques, specifically boosting and/or decision trees, and research into applying other AI tools to discrete choice models is currently under way.[20] The objective and promise of AI-powered travel models are improved predictions more sensitive to changes in the age of travelers, the accessibility of neighborhoods, income, vehicle ownership, and household composition. Researchers are also examining the use of large language models to improve travel modeling and predict traveler behavior.[21]

AI-powered predictive analytics have the potential to find applications across a wide swath of transportation. For traffic management on highways, predictive analytics has the potential to, for example, guide incident management and even prevention, make it easier to open highway shoulders for temporary use, fine-tune ramp metering, or enhance setting variable speed limits based on weather or traffic.[22] AI-powered predictive algorithms are also being developed to estimate asphalt pavement performance and life.[23] Travel safety is another area where predictive analytics have been identified as a way to close gaps in knowledge and adopt better safety interventions. For example, concurrent with the most recent update of the *Highway Safety Manual*, researchers acknowledged that crash prediction still required additional research, including by specific road and user types and for crash severity.[24]

AI-POWERED FUNDAMENTAL RESEARCH IN TRANSPORTATION

AI is well established as a research tool that is already advancing knowledge about the fundamental aspects of transportation. Travel behavior trends and changing travel patterns, especially as they relate to changes associated with new technologies, are areas where AI tools and big data, including real-time data, could improve transportation professionals' understanding in ways that immediately affect policy decisions.[25] Examples of such research include examinations of changing freight delivery patterns and trends in telecommuting during and after the pandemic.[26] Researchers are also exploring using large language models to increase knowledge about travel behavior.[27] The availability of AI research tools also opens up the possibility of using new sources of data, such as Wi-Fi or biometric data, to inform future design choices based on travel behavior.[28] AI models could also make it easier to tap into additional sources of safety data, such as hospital emergency room data[29] or vehicle telematics.[30]

AI-powered research tools also support advances in simulation and rapid iteration, which could be applied to other areas of research in transportation such as innovations in construction materials or infrastructure design. AI models have been developed for understanding traffic flow dynamics, such as for predicting queue length[31] and detecting shockwaves.[32]

AI RESEARCH TOOLS IN TRANSPORTATION PLANNING

Certain transportation activities require research as part of regular practice. For example, transportation planning typically involves quantitative and qualitative data gathering and analysis. In addition to the analysis of socioeconomic data as discussed above for travel demand forecasts, AI tools also hold possibilities for public involvement or customer satisfaction activities, especially for analyzing surveys and other qualitative data. Although there is still room for improvement, AI tools have the potential to allow for additional open-ended questions or comments, while still producing analysis results and actionable insights in a timely manner. They could also be used for analyzing more detailed interview and focus group data or for tracking public sentiment, such as expressed on complaint forms or social media platforms.[33]

Transforming Decision-Support Tools

Transportation professionals have long used decision-support tools designed to make it easier to apply a curated knowledge base to a specific use case. These ubiquitous standards, manuals, and guidebooks are often accessed today with online tools. As with other decision-support tools, an AI-powered decision-support tool presents alternative actions or recommends an action, but only the human takes the action. As defined here, an AI-powered decision-support tool does not change, on its own, the digital or physical world.

Among the potential benefits of using AI for decision-support tools are improvements to a tool's knowledge base; data processing for integrating siloed knowledge bases; real-time updates of the data describing specific uses cases or their context; and predictive capabilities. AI-powered decision-support tools could also improve the knowledge and productivity of certain transportation professionals.

STATIC AI-POWERED DECISION-SUPPORT TOOLS

Static decision-support tools, such as the standards and manuals of today that are updated through an established process on a transparent schedule, are critical foundations for planning, designing, and constructing infrastructure projects. They provide a common understanding of expectations across the public and private sectors, and their use establishes legal liability protection. It will be important to integrate the benefits of AI into these tools, such as by incorporating AI-powered research, analysis, or data collection, while also maintaining their larger functions that today are rooted in their stability and their formal update processes controlled by government agencies or industry organizations. A place to start is fostering AI-powered transportation research that will improve a tool's knowledge base. Developing this research could be an ad hoc process, or it could follow the more coordinated process used in the past decade to address automated and autonomous vehicles in the *Manual on Uniform Traffic Control Devices* and the *Highway Capacity Manual* (see discussion below in the section Advanced Automation in Road Transport). The more radical changes to the body of static decision-support tools will be new tools that are built from the ground up using AI or that integrate formerly siloed information.

DYNAMIC AI-POWERED DECISION-SUPPORT TOOLS

Dynamic AI-powered decision-support tools have the potential to collect and analyze data in real time, such as analyzing real-time weather conditions, traffic levels, and the locations and types of crashes to predict their impact on the transportation system and recommend interventions. Decision-support tools, for instance, are critical to integrated corridor management approaches that analyze real-time data to monitor, predict, and manage traffic congestion across freeways, arterials, and transit systems. The tools are suited for adaptive control of signals, ramp metering, and speed limits. Future agentic AI systems may be able to seek out new sources of input data or choose specific use cases.

An agentic AI-powered decision-support tool could also update its own knowledge base, either through analysis of internal data or seeking relevant information from outside the AI model. For the transportation professional, this could mean that the menu of alternatives or the recommended action would change as the knowledge base updates, potentially in real time. The private sector is likely to take the lead in developing these new types of decision-support tools. Already today, there are companies developing tools that, for example, integrate site-specific weather analytics into construction project management tools[34] and that are experimenting with generative AI for traffic management.[35]

Generative AI is the most recent frontier in decision-support tools for transportation. In California, Caltrans is working to develop a new vulnerable road user (VRU) safety tool that uses generative AI to integrate safety-related data and its VRU safety knowledge base. Among its uses are identifying high-risk locations, risk contributors at specific locations, recommended actions, and predicted effectiveness in reducing fatalities and serious injuries. The initial model ingested 12 datasets related to incidents, infrastructure, land use, and mode use and 29,000 websites or documents containing standards, design manuals, or other guidance documents.[36]

SUPPORT TOOLS FOR TRAVELERS AND CUSTOMERS

Because private companies serve large customer bases and have access to big data, they have developed many decision-support tools that are now a standard part of travel. These include apps that help drivers plan routes and avoid congestion, provide real-time information for transit users, and support air travel and package delivery. While AI can further improve these tools, their basic capabilities are already well established.

In contrast, some specialized needs have not been met because the user base is small or other barriers exist. One example is Truck Parking Information Management Systems (TPIMSs). The Washington State Department of Transportation (DOT) is testing a predictive TPIMS that uses machine learning to forecast truck parking availability along I-5 up to 4 hours in advance, with the information delivered to drivers through private vendor communication systems.[37] Minnesota DOT has launched a similar project.[38]

The Future with Agentic AI

Agentic AI goes beyond traditional or reactive AI and can operate with limited human supervision. As IBM explains, agentic AI can make decisions, take actions, solve complex problems, and interact with real-world environments beyond the data used to train it. It can also learn as it operates, effectively expanding its own knowledge.[39] An agentic AI platform typically includes a lead AI agent that coordinates specialized AI agents and other digital tools or models. A related concept is embodied AI, in which the agent acts through a robot or physical system.

These capabilities enable futuristic scenarios. In transportation, an agentic AI could support the management of snow and ice control by using weather forecasts and real-time conditions for routing trucks and plows, adjusting equipment settings, and updating routes as conditions change. Over time, the system could learn how to optimize operations for local geography and weather for authorities to restore safe travel as quickly as possible.

Agentic AI in transportation could increase labor productivity, streamline operations, and speed up the use of new information in decision making. For example, researchers are exploring an AI agent to increasingly automate the management and interpretation of bridge inventory data and augment what is an otherwise complex manual process.[40] Similarly, researchers are developing an AI agent that integrates text, such as crash reports, with image data to perform analyses that lead to safety recommendations.[41]

At the same time, risks grow as agentic AI takes on more critical tasks. Using AI chatbots to support customer surveys or public engagement poses relatively low risk.[42] In contrast, a hypothetical

AI agent for driver safety could analyze public records, traffic camera images, and social media to automatically suspend a driver's license. In such cases, the benefits to safety would need to be carefully weighed against risks to legal fairness and the economic harm of incorrect decisions. Managing these risks in safety-critical systems is discussed further below.

AI in Safety-Critical Applications

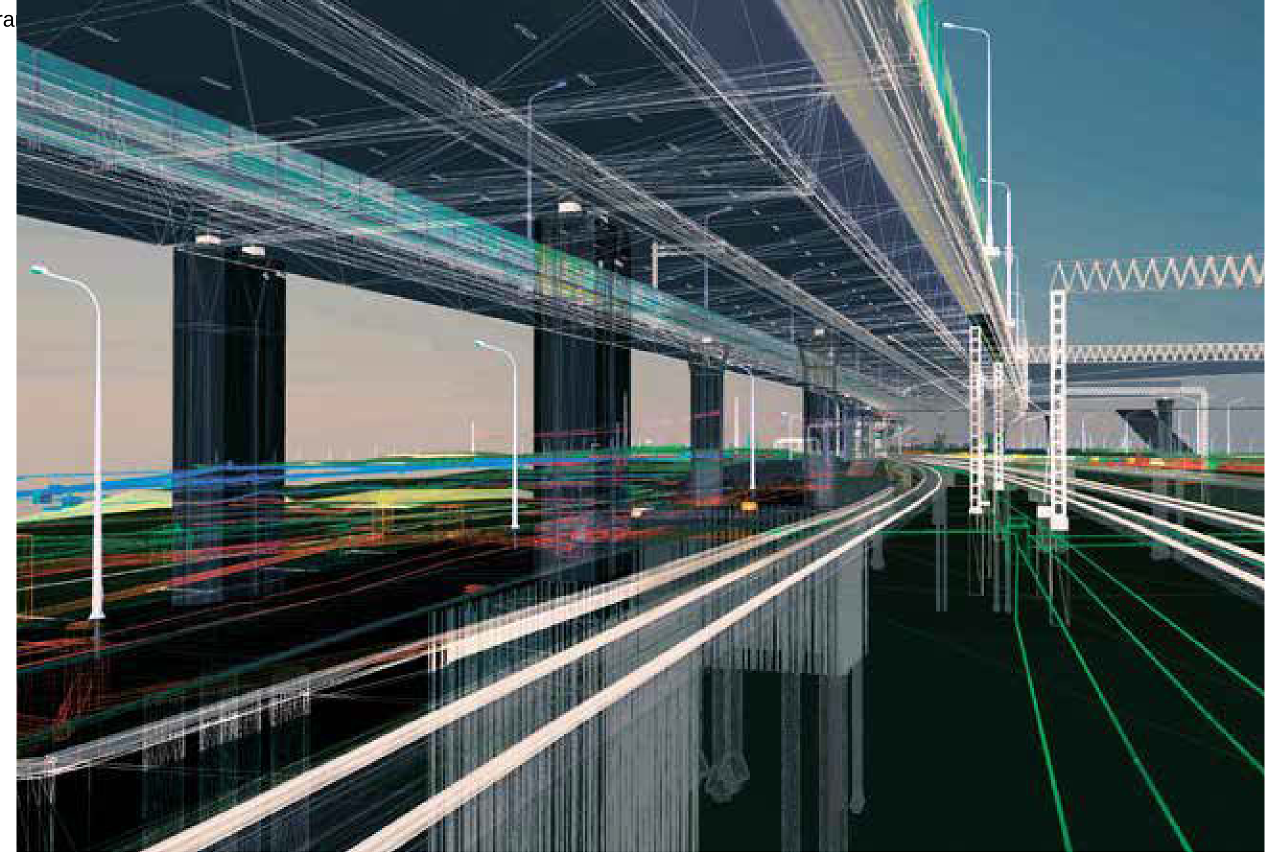
Agentic AI presents the most extreme examples of the risks that accompany deploying AI in transportation. However, for safety-critical systems, the errors associated with AI can still have significant consequences even if the AI is only embedded in decision-support tools that require humans to act. Risks in higher-risk activities are mitigated by human-in-the-loop protocols, where a human operator reviews machine-generated decisions before deployment to ensure well-founded conclusions and safeguard against the creation of additional hazards by actions that conflict with situational context. Thus, integrating AI into safety-critical systems puts a burden on the engineers of such systems to understand the "failure modes" of AI and to design their systems to prevent or mitigate these new types of errors.

A 2025 National Academies' consensus study found that "current [machine learning] components fall short of safety-critical standards because they rely on statistical assumptions that discount rare events and cannot guarantee consistent performance across all operating conditions." The study identifies the need for a new approach to safety research that brings together AI and systems engineering experts, including for transportation, and for new standards, regulations, and testing methods.[43] Box 2 further discusses a possible approach to overseeing the introduction of automated and autonomous technologies using AI to help ensure their safety benefits.

BOX 2

The Safety Case: A Regulatory Approach that Encourages Innovation

Both Waymo and Aurora, American autonomous vehicles companies, are relying on the "safety case" approach to presenting their safety plans before public officials and the public.[44] The safety case approach used by some nations for managing high-hazard industries is much more performance based than the prescriptive regulatory regime in the United States.[45] Instead of requiring strict adherence to existing regulations, the safety case obligates proposers to make a definitive case that they will achieve a safety level that is as low as reasonably practicable and requires ongoing monitoring by regulators. By waiving adherence to regulations developed specifically for preceding operations, the safety case may allow for greater innovation. Confidence in safety cases can be built by allowing operations on a small scale coupled with clear evidence of safety benefits before allowing wider operations. Waymo has been sharing safety statistics in peer-reviewed articles as it was allowed to move from having human monitors in autonomous taxis to remote monitoring only. The percentage reductions in crash types in Waymo's operations compared to those that are human operated are large, statistically significant, and promising.[46,47] A similar approach for urban air mobility proposals intended to ultimately evolve to autonomous operations would rely on the safety case coupled with Safety Assurance and Safety Management Systems used in aviation and some high-hazard industries.[48]



The Power and Promise of Digitalization

The digitalization of transportation infrastructure and operations continues to offer new possibilities to enhance transportation efficiency, mobility, and safety. Digitalization leverages digital tools to transform business, management, and operations activities. The following section outlines technologies and innovations that are expanding the benefits from transportation digitalization.

Infrastructure Modeling, and Digital Delivery and Asset Management

Digital data that describe transportation infrastructure and operations combined with advanced software and modeling programs can contribute to optimizing asset management, accelerating project delivery, and streamlining infrastructure projects. To take full advantage of digitalization's promise also requires integrating data from diverse sources across multiple platforms. Transportation agencies generate massive amounts of data throughout the life cycle of assets, but much of it resides in disconnected systems and silos, making it difficult to share information.

For infrastructure projects and assets, digital tools can produce digital outputs for planning and decision making and create online portfolios that cover the life cycle of an asset. For example, infrastructure modeling and digital delivery bring together the physical and digital components of a construction project and can be used to improve design and planning, optimize resources, and accelerate project delivery.[49] A key component of infrastructure modeling includes the 3D and digital twin modeling of transportation assets, such as bridges, tunnels, and ports. These models act as dynamic digital replicas of physical infrastructure, which can be used to test real-world scenarios, enable real-time monitoring and predictive analytics, and optimize the system before changes are implemented on the physical system. 3D models and digital twins may include real-time incident detection and notification for drivers and first responders; integrated sensors on bridges and roadways for synchronization and dynamic signaling; and simulations of incidents, extreme weather, and traffic.[50] For example, a pilot project in Washington State integrates active sensors on real bridges and roads with digital twins to monitor conditions and detect safety concerns for informed maintenance and decision making.[51]

In coordination with infrastructure modeling, Business Information Modeling (BIM) is a digital process that enables people to create and manage digital 3D models of infrastructure projects throughout their life cycle, from the design and bidding process to post-construction as-builts. BIM is a collaborative method for managing an agency's data across an asset's life cycle—freeing data from siloed systems and integrating the data into semantically rich 3D models and digital workflows. By moving from paper-based plans to connected digital models, agencies can improve project delivery, reduce errors, and make more data-driven decisions.

Case studies of BIM use show it can decrease costs and time spent by reducing the number of change orders throughout a project, enhancing project delivery, and enabling the use of automation. Digital delivery projects use a similar approach, where all aspects of a project life cycle are conducted through modeling software, digital twins, asset management databases, and other digital tools. Pilot projects across states intend to use digital delivery systems to reduce error and risk in project management, increase accuracy of models and designs, allow for the digital transfer of data from design to construction, enable more precise and competitive design bids, and improve decision making.[52,53] Indeed, some state DOTs have advertised construction projects for which 3D models, rather than paper plans, represent the controlling legal document. States anticipate that digital delivery should reduce the number of change orders during construction and the overall project risk, improve communication across partners, improve safety on construction sites, and reduce construction costs.[54] For example, Pennsylvania DOT is conducting a series of digital delivery pilot projects focused around 3D modeling and detailing tools for bridges and highway projects, design development and delivery processes, and project analysis.[55]

Iowa DOT implemented BIMs and digital models that represent as-built infrastructure conditions, known as digital as-builts, to improve asset management and enhance project delivery throughout their I-80/I-380 Interchange Reconstruction Project.[56] The project utilized a collection of technologies to collect and manage data, including geospatial data, design and modeling, e-ticketing and document management tools, web interfaces to visualize data, and asset management systems to allocate resources. Iowa DOT found that the digital model could be continuously updated during construction, allowing for real-time project data, modeling, and analysis. At the same time, Iowa DOT noted that there are still challenges in integrating these new technologies, including the large investments needed for training and development and the lack of standardization across software, protocols, and data types. In this regard, it merits noting that the American Association of State Highway and Transportation Officials (AASHTO) has endorsed the use of an open, international standard (ISO 16739) for sharing BIM data across different software applications and ensuring vendor-neutral interoperability. In addition, the Federal Highway Administration (FHWA) worked with state DOTs and industry to develop the BIM for the Infrastructure National Strategic Roadmap.[57]

Digital Infrastructure: Sensors, Imaging, Hardware, and High-Speed Computing and Communications

In its fullest form, digital infrastructure combines sensing, imaging, hardware, processing, and communication systems to enable continuous data transmission and information exchange between data systems, users, public agencies, and operators. Advances in computing, sensing, and communications technologies enable monitoring and collection of real-time data about the transportation system while geolocation systems determine location for mapping and navigation and communication systems facilitate data exchange between and across systems.

Sensors installed along transportation corridors, including roadways and railroads or within vehicles, collect the data needed for digital infrastructure. Sensing and imaging technologies include speed detection, video-based systems, light detection and ranging (lidar), radio detecting and ranging (radar), motion detectors, and more. Within roadway infrastructure, these devices can detect accident hazards, weather and road conditions, lanes and medians, and the presence of vehicles, pedestrians, and bicyclists. Similarly, sensors are used in other modes for detecting hazards, monitoring weather, preventing collisions, and tracking vehicles or passengers. For example, prototypes are in development that combine sensors and AI to lower the cost of rail track inspections.[58] While many sensing technologies have been established for decades, the combination of sensors with advanced computing, geolocation, and communication technologies have advanced innovations across transportation.

DIGITAL INFRASTRUCTURE FOR ROAD SAFETY AND TRAFFIC MANAGEMENT

Roadway digital infrastructure utilizes sensors, imaging, hardware, and communication technologies to manage travel and safety, including for the safety of road users and highway workers. Although many other potential applications exist, the following paragraphs highlight a few examples of key roadway innovations already being piloted and implemented across the country, including for traffic management, pedestrian safety, and safer construction zones.

In high-traffic cities and transportation centers, digital infrastructure systems can detect and respond to vehicle and pedestrian patterns across a network to actively manage traffic, optimize the movement of vehicles, improve safety for roadway users, and reduce congestion. For example, the city of Bellevue, Washington, piloted passive pedestrian detection technology to increase safety at intersections. The system uses lidar to map objects across an intersection, AI-powered software to detect pedestrians and vehicles, and feedback into the city's adaptive signal control system to alter the timing of stoplights and pedestrian signals.[59,60] Similarly, adaptive signal control technology (ASCT) uses sensors to detect vehicles, assess performance, and automatically adjust signal timing based on real-time roadway conditions. Pilot studies in Arizona and Florida found that ASCT systems significantly reduced traffic delays and decreased overall travel time for drivers.[61,62] In addition, advances in data extraction may make it possible to leverage existing traffic sensing technologies to produce traffic volume data for motorized and non-motorized traffic in real time and on a continuous basis, which could be used to improve signal timing and traffic flow as well as other applications in traffic safety, planning, and statistics.[63]

In 2024, Utah DOT, Colorado DOT, and Wyoming DOT partnered with transit authorities, local cities, and the private sector to establish the Connecting the West program, which focuses on communications and sensing technologies for roadways.[64] One project focuses on Traveler Information Messaging, which uses data from roadside detectors and connected vehicles[65] to alert drivers about road conditions, weather changes, lane closures, and work zones. The Transit Signal Priority program provided wireless communication between Utah Transit Authority buses and traffic signals along key corridors, allowing drivers to request additional green light time to maintain the bus schedule. Other projects are exploring lidar and connected vehicles to improve efficiency, safety, and connectivity. The Connecting the West program plans to increase deployment across all three states, with aims to improve interoperability and connectedness across state lines.

Vehicle telematics is the collection and transmission of in-vehicle data, such as vehicle speed, location, turning movements, and condition, as well as driver phone use or other distracted behavior. Commonly used in fleet management and driver insurance, advances in vehicle telematics that can collect, communicate, analyze, and anonymize these data in real time could be used for a variety of safety and operations applications.[66] For instance, New York City (NYC) DOT is piloting using vehicle telematics collected from commercial vehicles to track speed, travel time, and vehicle class on specific streets and roadway segments. NYC DOT intends to use this information to identify problem zones for speeding and congestion and to inform traffic interventions that improve safety and mobility, such as reduced speed limits, optimized infrastructure design, and signal timing.[67]

Faced with new and growing demands on curb space, the Boston Department of Public Works is using AI and lidar technology to read and process street-level imagery for converting parking layout and regulations into a digital format.[68] The information will be used to create an interactive map of the city's curb network to provide motorists with access to real-time information on parking inventory and street sign rules. The interactive map is expected to add convenience for travelers and limit the congestion caused by vehicles circling and blocking lanes in search of parking.

DIGITAL INFRASTRUCTURE FOR IMPROVED SECURITY

Across all modes of transportation, digital infrastructure can bolster security, surveillance, and communications. In aviation and rail, surveillance cameras and AI-powered detection systems can identify and report security threats. For example, airports in Charleston, South Carolina, Los Angeles, California, Columbus, Ohio, and Charleston, West Virginia are implementing shooter detection systems that use acoustic and infrared sensors, cameras, and AI-based video analytics to detect gunshots and track suspects.[69,70] Detection systems along railroads use a similar combination of AI-based detection systems and sensors, including video sensing, infrared, radar, lidar, and fiber technologies, to detect trespassers in restricted areas, announce pre-recorded warnings, and send alerts to personnel and law enforcement.[71] Within maritime environments, sensing technologies are being studied for surveillance and data collection for tactical surveillance and undersea missions, including autonomous sensors and intelligent sensor systems.[72]

The Power and Promise of Advanced Automation and Autonomy

Advanced automation, often enabled by AI, has progressed significantly across transportation over the past two decades. While much attention is given to automated vehicles and vessels, advanced robotics may also transform how infrastructure is built and maintained. These applications do not have to be highly complex. Simpler technologies can also be valuable, such as AI-enabled hearing protection for highway workers that blocks noise while allowing critical safety sounds through.[73]

Most progress in advanced automation and autonomy for transportation will likely continue to come from the private sector. Transportation agencies will often be in the position of adapting to changes in the vehicles, vessels, and industries that use their infrastructure. Their primary role likely will be to manage and regulate new technologies rather than deploy them directly. Accordingly, collaboration between the private and public sectors needs to be ongoing to ensure the public infrastructure is not only capable of accommodating the future demands of advanced automation but will in fact meet these demands. Regulatory activities will include addressing the use of embodied AI in safety-critical autonomous vehicles, automated driving systems, and other types of uncrewed vehicles and vessels. In some cases, agencies may adopt advanced automation for their own operations and encourage their contractors to do the same.

Advanced Automation in Road Transport

Advanced automation and autonomy in road-based travel is progressing, albeit not at the pace imagined in the mid-2010s. Applications of these technologies are expanding for private and commercial vehicles, public transit, and road construction and maintenance.

PRIVATE AND COMMERCIAL VEHICLES

Since the 2010s, the private sector has made significant advancements in automated driving, many aspects of which are today maturing, if not mature, technologies. Advanced automation in road vehicles continues to improve along two main tracks: advanced driver assistance systems (ADASs) and autonomous (or self-driving) vehicles (AVs) for specified operational design domains (SAE Level 4 autonomy).[74] ADAS functionality is likely to continue to expand, with new or improved capabilities dispersing at varying rates into the private and general commercial vehicle fleets. For AVs, numerous private companies globally have begun to put vehicles into revenue service, transporting passengers or freight. While the number and types of operational design domains are expanding, the vehicles themselves remain in specialized fleets controlled or managed by the technology providers. It is not yet clear when or whether AVs will find paths into personal vehicle or general commercial vehicle markets at scale.[75]

A mixed fleet means that transportation agencies responsible for road travel will continue to be responsible for constructing, operating, and maintaining road systems traveled by vehicles having a range of capabilities. In addition, agencies tasked with regulating and enforcing driver safety will also be confronted with a multiplicity of "drivers," as ADAS capabilities test the boundaries of human and automation "co-drivers" and as AVs continue to spread. An example of how even individual technologies can shape vehicle–driver–road functionality is the use of high-definition (HD) maps. AVs that have access to HD maps are much less dependent upon the quality and consistency of the infrastructure than AVs or ADASs that do not use HD maps. However, even AVs with HD maps may be challenged during confrontations with other AVs, ADASs, or human drivers responding unpredictably to unclear or confusing infrastructure. The future use of HD maps is just one dimension of driver automation technologies that may impact agency policies for the design, maintenance, and operation of road infrastructure.[76]

Shortly after this century's first burst of self-driving technology improvements became evident in the 2010s, federal and state transportation departments embarked on numerous and significant research efforts on the technology's ramifications for road transportation that anticipated many of the issues that are still in play today.[77,78] Many of the studies were complete in the late 2010s and early 2020s, before there were multiple AV systems in revenue service and before the most recent advances in ADASs. However, because of the early developmental work, some major decision-support tools already address advanced automation. For example, FHWA's *Manual of Uniform Traffic Control Devices*, released in December 2023, includes an entire part on "traffic control device considerations for automated vehicles," which covers "key principles" and considerations for the selection of traffic control devices as well as other topics.[79]

The *Highway Capacity Manual*, published by TRB in 2022, includes capacity adjustment factors for connected and autonomous vehicles.[80]

PUBLIC TRANSIT: BUSES AND MICROTRANSIT

Advanced automation is already shaping the delivery of mass transit and paratransit services. The routing and dispatch algorithms and advances in communication technologies that led to the massive expansion of ride-hailing services in the 2010s have their parallels in the public transit industry. These advances have allowed public paratransit services to offer same-day reservations and even spontaneous rides.[81] They have also enabled expanded services areas, especially in rural areas.[82] In urban areas, AI-powered cameras notify transit agencies of vehicles blocking bus lanes and bus stops.[83] In addition, the communications advances (e.g., real-time arrival apps) have transformed how most riders interact with public transit services.

Driving automation has not transformed public transit yet, but this could be changing.[84] The expansion of ADASs has the potential to increase safety, while making the job of human driver easier. Public transit agencies have partnered with AV companies to provide taxi services to their eligible riders.[85] AV pilots and partnerships are also occurring in public microtransit services.[86] Pilot projects of Level 4 full-size, full-speed AV buses serving fixed routes are also expanding globally. If successful, self-driving buses on fixed routes have the potential to reduce the cost of offering more frequent service for more hours of the day, especially in areas experiencing shortages of human drivers. Transit agencies may still have an agency representative on the vehicle, but their primary tasks are likely to be customer care.[87]

ROAD CONSTRUCTION AND MAINTENANCE

Construction work zone and maintenance activities have typically been seen as creating challenging environments for automated vehicles. However, new research approaches have sought to test whether the technological capabilities of the travelers' vehicles can be used to make work zones safer for travelers and workers on site.[88] In addition, the technologies behind ADASs and AVs, along with other robotics, are advancing the equipment used for road construction and maintenance.[89] Advanced automation may increase safety directly or indirectly, through simplifying the set of skills required to operate the equipment safely. Remote operations that remove the human driver or worker from hazardous environments also can increase safety. Through automated machine guidance and more advanced automated machine control technologies, which use lasers and position location information, contractors can feed the 3D model into their equipment to build exactly what is in the model. FHWA reports that these technologies can increase construction accuracy and precision, reduce surveying costs and time, save fuel owing to fewer passes, and increase safety by requiring fewer people in the vicinity of heavy equipment performing tasks such as setting up stakes and checking grades.[90]

Along with contractors, transportation agencies may be the major market for various types of advanced equipment, putting them in a position to take a leadership role. For example, Minnesota DOT has invested in research prototyping an ADAS for snowplows that supports drivers in low visibility environments,[91] and Colorado and Utah DOTs have equipped snowplows with V2X technologies that allow snowplows to preempt red light signals.[92] "InfraROB," a European Union–funded project, is promoting advances in automation and robotics for road construction and maintenance activities to reduce repetitive tasks and exposure to hazards by road workers.[93]

Advanced Automation in Air Transport

Advances in automation and autonomy are part of the impetus behind increasing interest in Advanced Air Mobility (AAM). AAM is an umbrella term for the diversification in aircraft made possible by recent technological innovations in aircraft design and operation and the associated air- and land-based infrastructure and airspace management needed to support them. Chief among the innovations are advances in vertical take-off and landing and short take-off and landing capabilities, including reductions in noise. These advances may make it feasible to allow take-off and landing facilities to be inserted into the landscape in more difficult terrain and in more densely built-up areas. Advances in automation and autonomy will be leaned on to lower the cost of these "air taxis" as well as to assure travelers and people on the ground that these aircraft will be operated safely.[94] However, yet to be determined is whether the cost reductions and safety assurances are such that small aircraft carrying a relatively small number of passengers making local or regional trips will be affordable and convenient to a larger group of travelers than today's privately owned or chartered planes, jets, and helicopters. These new air services would also need to be competitive with moving people or freight by motor vehicle, boat, or rail.

Private-sector investment in developing and applying innovative aircraft technologies and potentially airspace management technologies is foundational to future applications of these technologies. However, the federal government, state and local governments, and airport authorities will have significant roles to play in facilitating innovation and implementing new services. The federal government released "The Advanced Air Mobility National Strategy: A Bold Policy Vision for 2026–2036" in December 2025. It exercises federal leadership through six pillars: airspace, infrastructure, security, community planning and engagement, workforce, and advanced automation.[95] In addition, the federal government is responsible for certifying the safety of aircraft and integrating new aircraft into the national airspace. At the direction of Congress, the Federal Aviation Administration (FAA) adopted new regulations in October 2024 that use performance-based approaches to safety for innovative aircraft.[96] A 2022 National Academies' report offers guidance on how to ensure the safety of the design and operations of these vehicles.[97] When demand for such air services proliferates beyond existing helipads and airports, state and/or local governments will be responsible for locating and regulating the necessary "vertiports" and other associated land uses. State and local governments may also integrate these new air services in their economic development plans.

Airport ground transportation is also likely to be affected by advanced automation and autonomy in motorized vehicles. On the land side, automated and autonomous vehicles will be in the mix as travelers and employees navigate arrival/departure and parking at the airport. Personal mobility devices used by people with disabilities or older adults and that need to be accommodated for travel by air may also evolve. On the air side, advanced automation in ground transportation may also shape how aircraft are maintained and supplied.

Finally, aerial drones (regulated by FAA under the name unmanned aircraft system [UAS]) continue to find commercial uses. For example, aerial drones are in use for surveying, mapping, inspection, monitoring, security, and other activities related to delivering transportation services.[98] Partially autonomous drone delivery services, currently being used during emergencies and for delivery of medicines to isolated places,[99] may be breaking out from such niche use cases to more general consumer markets.[100] (See below for examples of aerial drones used to support marine and rail travel.) Lessons learned from existing use cases are providing opportunities to better understand human-autonomy teaming, which will be needed for more widespread autonomous operations.[101]

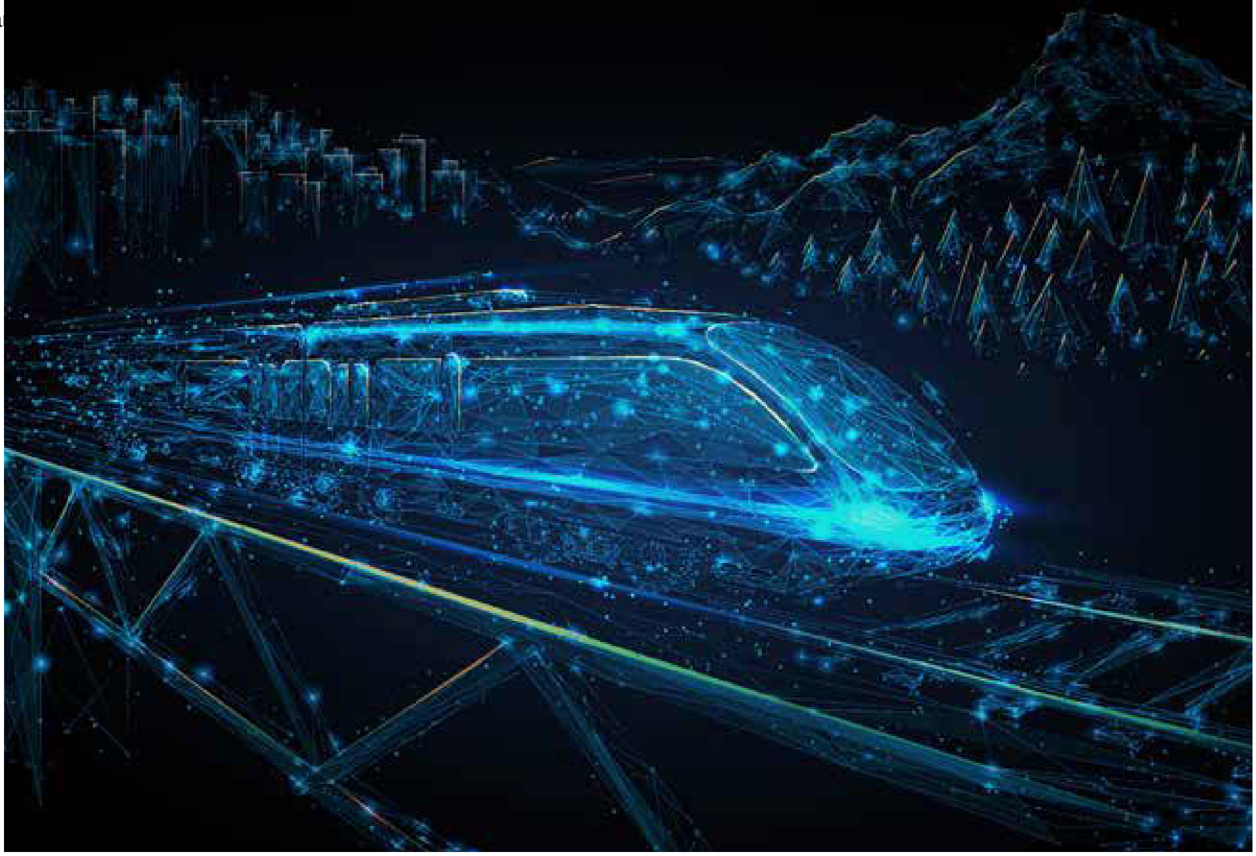
Advanced Automation in Rail and Marine Transport

Even more than in aviation, advances in automation for rail and marine transport will largely be driven by the private sector. The dominant public-sector role will be regulation and enforcement, which can support or hinder the pace of innovation.

Advanced automation in marine ships and vessels ranges from automated data collection and decision-support tools to autonomous propulsion, navigation, and collision avoidance. To date, human supervision on board or through remote operation centers continues. Like the technology adoption trajectory of motor vehicles, higher levels of autonomy are being deployed first in specific, simpler applications such as for scientific research, inspection activities, or other services with slow speeds on fixed routes close to shore.[102] The Coast Guard has the authority to permit testing and operation of autonomous vessels on a case-by-case basis or through establishing "equivalents" to current practice and technology. The International Maritime Organization (IMO), responsible for the regulation of ocean-going ships, developed interim guidelines for testing autonomous shipping technologies in 2019. The IMO is scheduled to finalize and adopt a non-mandatory Maritime Autonomous Surface Ships code in 2026.[103] Although the current regulatory framework is focusing on ensuring safety and operational efficiency for use cases in which advanced automation substitutes for human capabilities, future advances in automation may go beyond current practices to leverage additional sources of data or novel technology-based capabilities.[104] The Coast Guard announced in September 2025 that it will be investing $350 million in robotics and autonomous systems for its own operations, including an initial $11 million investment in UASs and unmanned ground vehicles as well as underwater robots.[105]

Advanced automation has been introduced to process and handle cargo at marine ports, especially container ports. In a 2024 report, the U.S. Government Accountability Office reported that terminals in all of the 10 largest U.S. container ports have adopted automation technology to some degree to load, unload, and move containers, while some also use automation for tracking and communicating container movements.[106] The report points out that foreign ports have been faster in adopting automation technologies, reflecting factors such as larger container volumes and variations in labor availability, relations, and rules.

The safety implications of advanced automation in rail transportation will be overseen by the Federal Railroad Administration (FRA) or the Federal Transit Administration for transit rail. In addition to the discussions in previous sections on examining roadway–rail crossing safety and deploying digital infrastructure for railyard security, conducting track inspections using advanced automation technologies has attracted industry interest. FRA recently approved a temporary waiver to allow freight railroads to test automated track inspection technologies, including substituting automated inspections for some visual inspections.[107] Research on automated track inspection continues. For example, one study is exploring using aerial drones capable of operating autonomously and without continuous access to the internet for track inspection and intrusion detection activities.[108]



Enabling and Advancing Possibilities

Although the possibilities of the promising technologies described herein appear endless, enabling progress in the near term requires selecting and prioritizing public-sector initiatives and investments. Federal, state, and local transportation agencies, along with their partners in universities and private industry, will face a multitude of decisions about where and when to advance or invest in these technologies and what regulatory precautions to take. Whereas some proponents assert that these technologies will lead to immediate and radical transformations in human society, others argue that they are "normal" technologies. If the latter is the case, the diffusion of these technologies is likely to occur over a time scale of decades, with attendant uncertainty about the scale and timing of their impact on transportation.[109] Although it is beyond the scope of this publication to weigh in on specific investment priorities, this concluding section offers observations about ways to advance promising candidates.

Transportation agencies have already begun the work of developing initiatives and strategies focused on AI, digitalization, and advanced automation and autonomy. The U.S. Department of Transportation (USDOT) released its AI strategy in October 2025, which presents use cases and its maturity assessment.[110] State DOTs, transit agencies, and other transportation agencies have begun to do likewise; Box 3 summarizes a recent effort to produce an AI research roadmap for state and local DOTs.[111] Significant work still needs to be done. A 2025 AASHTO survey revealed that a majority of its members did not think

BOX 3

Research Roadmap for Artificial Intelligence

The National Cooperative Highway Research Program (NCHRP) produced a "Research Roadmap" in 2024 to advance the adoption of artificial intelligence (AI) tools by state and local departments of transportation. It contains research problem statements for the following 11 topics:

- Case Studies of Successful Implementation
- Guidance on the Selection and Deployment of AI Technologies
- Workforce Needs and Development
- Funding Strategies
- Guidance on Understanding Vulnerabilities and Security Concerns
- Integration into Multimodal Transportation Planning
- Validating Automated Pavement Condition Evaluation
- Natural Language Processing–Based Methods for Document Management and Public Interaction
- Collaboration with Industry Partners
- Sharable, Reliable Sources of Datasets
- Framework to Process and Manage Data

SOURCE: National Academies of Sciences, Engineering, and Medicine. 2024. Artificial Intelligence *Opportunities for State and Local DOTs: A Research Roadmap*. NCHRP Web-Only Document 403. Washington, DC: National Academies Press. https://doi.org/10.17226/27865.

that the transportation operations sector was even somewhat prepared to deploy AI systems responsibly at scale.[112] Survey respondents also identified the biggest challenge (76%) to be data quality and availability.[113]

Data Needs, Digitalization, and AI

Digitalization of the elements of the transportation system is a necessary step, including establishing data standards as appropriate. Training machine learning models requires enormous amounts of data; however, once a model is trained, it can be evaluated for how well it generalizes to a similar domain with little or no retraining or fine-tuning.

The transformative power of these technologies accelerates when formerly isolated knowledge bases and data sources can be integrated, requiring data that can be accessed by numerous applications and platforms. Providently, these technologies can be used to automate the process of creating high-quality digital representations of transportation systems. For example, an accurate streetlight inventory is critical for road safety research and interventions. Image analytics on a database of geolocated street images can be used to cost-effectively build such an inventory by identifying their presence and, just as importantly, their absence.[114]

Transportation agencies have been working on digitizing and improving the quality of their data for decades. Major efforts run the gamut from roadway elements115 to work zones116 to traffic crash reports.[117] State DOT–sponsored research is under way that tackles knowledge management for this new age of AI.[118] While advanced automation and digital infrastructure offer the potential to produce new sources of data to feed AI applications, data collection and digitalization efforts can still be expensive, and clarity about their benefits and cost-effectiveness may only be achieved in the intermediate or longer term.[119]

Because the private sector will continue to be a source of innovation for these technologies, it is important that private entities have ready access to data, when and where appropriate. Data standards developed by transportation agencies can also help maintain a competitive environment among existing and new technology vendors. The development of the General Transit Feed Specification (GTFS) in the 2000s is an example of the transformative potential of data standards. GTFS—the "G" originally stood for Google—smoothed the way for today's ubiquitous trip-planning and real-time arrival apps that make it easier for transit riders to navigate familiar and new destinations. GTFS is maintained by the non-profit organization MobilityData.[120]

In addition, data collection, storage, maintenance, and sharing will continue to require special care to address privacy, liability, surveillance, security, and cybersecurity concerns. Automated systems that integrate image, text, sound, and real-time data and AI-enabled analysis of such data also raise concerns about privacy, bias, and liability. Additional issues, such as the use of data beyond its original use case, will present themselves. In addition, autonomous vehicles, aircraft, and aerial drones raise complex, unresolved security[121] and privacy issues[122] that require further research, analysis, and policy resolution. New policies, procedures, and regulations may well be required.[123]

Supporting and Spurring the Innovation Process

Although transportation is increasingly benefiting from a plethora of innovations that leverage AI, digitalization, and advanced automation, the power and potential of these technologies has scarcely been tapped. TRB has prepared this publication both to inspire transportation practitioners to envisage the possibilities and to encourage the research community to help realize them.

To be sure, entrepreneurial forces will continue to drive the innovation process, but at a pace that may be constrained by the mixed public- and private-sector nature of the transportation enterprise. Reducing these constraints will require concerted efforts to support and spur innovation, such as through priority setting, regulatory flexibility, coordination across federal and state transportation R&D programs, standards development, and funding commitments. The rapid pace of technological development will also require concerted efforts to engage agency decision makers, who may need to be made aware of the potential uses and benefits of emerging innovations and who may operate in a risk-averse and budget-constrained environment that can complicate procurement.

Although most of the innovations in publicly owned and operated infrastructure will be delivered by state and local agencies, broader supportive and collaborative efforts will be needed. With USDOT assuming a national leadership role, TRB can play its traditional role of bringing together the many private- and public-sector parties engaged in transportation R&D—a role that can be instrumental in furthering innovation through the sharing of understanding and experiences. Advanced tools and exploratory applications that are within the domains of TRB's sponsors will require further R&D before they can be introduced, a process that is already under way. As detailed above, TRB's cooperative research programs, federally funded University Transportation Centers, and the research offices of USDOT and its modal agencies are pursuing such research, but within a dispersed environment that can hinder strategic coordination and integration to accelerate the innovation process.

Given the serendipitous and unpredictable nature of innovation, there is no way to predict all the innovations that will emerge from AI, digitalization, and advanced automation to the benefit of transportation, much less to reliably predict those that will be transformative. However, it is possible to identify barriers to innovation and to take actions to overcome them—and thus, to help expand and accelerate the pace of innovation. While R&D underpins innovation, TRB has prepared this publication with recognition of the importance of creating and sustaining a background environment that encourages and values innovation. Research can help inform the development of such an environment conducive to innovations and their use.

The following is an example set of topics that matter for capitalizing on the possibilities of AI, digitization, and advanced automation. Some present fertile ground for research, including policy research, while others are likely to require policy initiative, strategic coordination, and cultural changes so that the research and innovation processes can bear fruit.

1. **Regulation.** Current motor vehicle and road safety regulations were written largely with human-operated vehicles in mind. Advances in autonomy and their deployment are being constrained by such well-intentioned regulations. Allowing innovation that could enhance safety requires alternate approaches. The safety case mentioned above may be one. A comprehensive review of regulatory constraints could identify other options for preserving and enhancing safety. New regulatory approaches may also have to take into consideration liability for failures.

2. **Knowledge and skill gaps.** The staff of government agencies at all levels who would need to evaluate and implement potential innovations will require increasing amounts of guidance and training on the benefits, performance, and limits of the technologies described above. Agency workforces may well need bolstering with individuals who have the expertise needed. Many agencies are struggling to compete with private industry in attracting and retaining employees with the skills and abilities needed and need better strategies for doing so.

3. **Digitalization data standards and data sharing.** As noted above, AI requires data for training and the digitalization process itself requires greater data standardization to allow for deployment at scale. Even though state transportation agencies have been working on this issue for many years, much work remains to be done. Greater federal leadership and support could accelerate progress.

4. **Disruption risks.** Digitalization introduces risks of disruption from natural disasters and malevolent actors, as well as from service outages (e.g., cloud and web) and technology

support phase-outs (deprecation). These risks will need to be effectively mitigated to keep systems operating and to protect privacy and sensitive information. Further R&D to enhance cybersecurity is a clear priority.

5. **Agency and public trust.** There will be natural risk aversion and reticence to allow unfamiliar innovations to be introduced, particularly those based on generative AI using reasoning processes that appear opaque, without some form of independent verification and validation. Universities and other independent organizations could serve this function, providing verification, validation, and transparency.

6. **Building an evidentiary base for guidance.** Many decisions about infrastructure design, operations, and safety are driven by formal guidance documents and decision tools. While these resources are evidence based to the extent possible, many also rely on professional judgment and rules of thumb when data and research are lacking. The technologies described above provide opportunities to accelerate data gathering and research to develop sound evidentiary bases, but the opportunities will need to be exploited by parties responsible for updating guidance and decision tools.

7. **Monitoring and communicating progress.** The implementation of innovations depends on potential users being made aware of deployment opportunities and the potential benefits. Awareness and knowledge are gained through sharing and learning processes.[124] However, traditional processes may be overwhelmed by the expanse and rapid pace of technological development. AI may provide ways to track and categorize innovations to keep communities of interest better informed and able to share experiences.

As is often the case, marked progress in addressing many of the topics identified above to support and spur innovation will require a commitment of funding, particularly by agency implementers. Public agency budgets are finite and can provide little room for investments to obtain, operate, and maintain innovative technologies. For example, digital infrastructure requires not only capital investment but also ongoing spending on operations and maintenance. Likewise, applications that use AI can require large annual expenses for data storage, computing power, and software licenses. When additional public-sector funding for technologies is not forthcoming, transportation agencies may need to be encouraged and given more latitude to partner with the private sector to test and implement innovations, perhaps by building off the precedents of existing public–private partnerships that have been used successfully for the supply, operation, and maintenance of transportation infrastructure.

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