ARTIFICIAL INTELLIGENCE FRONTIERS IN TRANSPORTATION

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Pedestrians pause to watch a sensor-studded autonomous vehicle navigate San Francisco's Lombard Street, a popular landmark known as the crookedest street in the world. A common Bay Area sight, self-driving cars are among the many transformations that artificial intelligence is propelling in areas from shipping logistics to traffic abatement and road repairs.

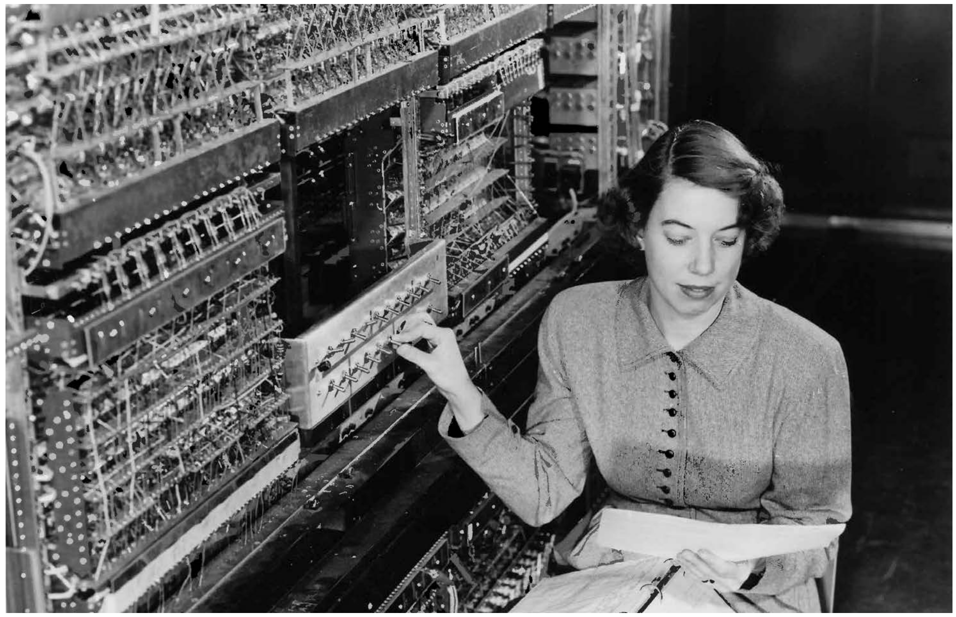
By now, almost everyone has read about or played with ChatGPT, a fast-growing application that reached 100 million users within two months of its public release in November 2022. Billed as the iPhone moment of artificial intelligence (AI) technology, the chatbot, featuring capabilities that include responding to questions and composing poems, articles, and other written content, has been widely cited as the defining technology of our time—for better or worse. Transportation professionals are no strangers to AI, however. Such technologies have fueled advances in autonomous driving and intelligent transportation systems, for example, enabling the public in Phoenix, Arizona; San Francisco, California; and other cities to hail a self-driving taxi from their smartphone apps. Transportation professionals also are tapping computer-vision technologies to manage transportation assets, collect traffic data, and dynamically adjust traffic signals.

Despite such promising developments, many who work in transportation continue to see AI as a theoretical concept in a black box and don't know how to successfully deploy projects that could enhance safety and human decision making in the real world. While it is impossible to review all key AI technologies in full, this article highlights several successful transportation applications as well as the challenges and risks of implementing them. In addition, a few suggestions are offered on how to successfully apply AI technology in transportation.

Evolution of AI and Key Trends

Although there is no single agreed-upon definition, AI is often referred to as methods and approaches to create machines that mimic biologically intelligent behavior, such as visual perception, speech recognition, and decision making. The modern history of AI can be traced back to the 1950s, when British mathematician Alan Turing proposed an imitation game—known as the Turing Test—to challenge a machine's ability to mimic human behavior. In 1956, computer scientist John McCarthy coined the term "artificial intelligence" with other colleagues at Dartmouth College. AI has seen ups and downs in the ensuing years, but the progress made over the past decade alone has been breathtaking.

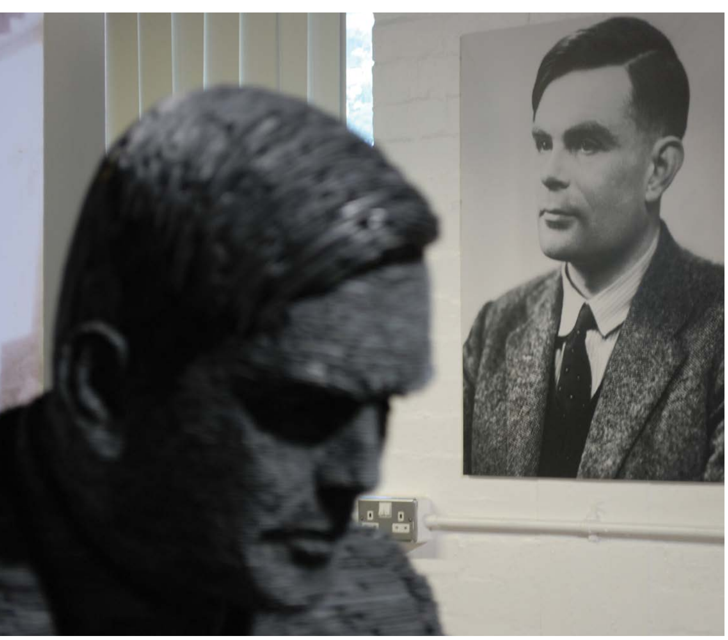
Several key forces have driven AI's recent surge. They include an explosion in the availability and diversity of large datasets, the huge amount of computing power available on the cloud, and the development of new algorithms. The San Francisco–based AI research laboratory that created ChatGPT, for example, was able to train the 3.5 version with 175 billion parameters—the configuration variables needed to be adjusted in the AI model—using 300 billion words from the Internet. In the transportation sector, a deluge of telemetry data is now being collected from connected vehicles and smart sensors installed on infrastructure. Other rich repositories include traffic, weather, video, radar, and social media data. A dramatic reduction in the cost of data storage—plunging from $700,000 per terabyte of computer memory in 2000 to $2,100 in 2022, according to one analysis—has also fueled AI development over the past decade (*1*).



Courtesy of Argonne National Laboratory

Dwarfed by a room-size rack of electronics, computer scientist Jean F. Hall programs Argonne National Laboratory's first digital computer. Though surpassed soon after its 1953 launch, the machine—which contained thousands of vacuum tubes and 3.5 miles of wiring—helped spur leaps in processing speed and memory that underlie today's AI technologies.

Much of the recent progress would not have been possible without the rapid development of hardware technologies, notably graphics processing units. Moore's Law, articulated in 1965 by semiconductor pioneer Gordon Moore, famously predicted that the number of transistors in an integrated circuit doubles about every two years. Indeed, between 2000 and 2022, the computing power of the world's fastest supercomputer increased almost 100,000 times (*2*). Such high-performance computing resources were formerly available mainly to large research institutes and government agencies. Now, cloud computing makes these resources readily accessible to smaller businesses and even to individuals.



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Captured on camera and in slate, Alan Turing occupies a commemorative niche at Bletchley Park, England's World War II code-cracking center. The British mathematician, who played a key role in deciphering Germany's Enigma system and securing the Allies' victory, is considered the father of theoretical computer science and AI.

Recent developments in AI algorithms and model architecture have led to new capabilities and emerging behaviors. AI algorithm development has been a fast-evolving field, with new algorithms and research papers published every day. Although there have been many innovations in computer architecture in the last five years, AI development can be traced to the deep-learning model proposed in a 2017 paper published by Google (*3*). The model, dubbed the Transformer, set the foundation to produce superior performance for language-understanding tasks, such as text summaries. It also has shown the potential to be generalized across natural language processing and computer vision, as well as other domains. Propelled by the forces of big data, cloud computing, and algorithm development, AI is quickly moving from research laboratories to real-world applications that impact people's everyday lives.

AI Applications in Transportation

Drivers who use a navigation app already are using machine learning and big data to calculate the fastest routes and

Courtesy of Oak Ridge National Laboratory

Housed in 74 liquid-cooled cabinets, Frontier—the world's first (and still fastest) ultrapowerful supercomputer—fills a 7,300-square-foot room at Oak Ridge National Laboratory in Tennessee. Able to perform a quintillion calculations per second, the machine has been advancing innovation in AI and other fields since its 2022 debut.

avoid congestion. Vehicles also are getting smarter. Sensors provide input to advanced driver-assistance systems that boost safety and help with such basic navigation tasks as keeping in the lane, managing cruise control, and avoiding collisions or other dangerous situations. In addition, computer-vision algorithms have been used to capture images of cars, pedestrians, and street signs to better manage transportation assets and optimize traffic flow.

The hallmark application of AI in transportation is autonomous vehicles, which rely on a variety of perception sensors that generate an estimated four terabytes of data per hour per vehicle (*4*). Self-driving vehicles use deep-learning algorithms to identify objects on the road, such as cars, pedestrians, and traffic signs. Localization and motion-planning systems use machine learning to determine the precise location of the vehicle within centimeters and to plan optimal travel paths that avoid collisions. Simulation environments for testing autonomous vehicle operations have become more common in recent years, partly because of the high cost of collecting on-road driving data. Using simulations instead of on-road testing may accelerate the speed of algorithm development and enable the collection of crash data in safe environments. Promising advances suggest that—eventually—learning can be transferred from the simulated to the on-road environment (*5*).

AI and automation technology have also been widely deployed in logistics systems, such as those run by nationwide and online retail giants. For example, a consumer-demand forecasting algorithm helps companies avoid overstocking or running out of products and enables just-in-time delivery. Another important AI logistics technology is route optimization, which reduces delivery time and costs by taking traffic, weather, packing, and shipping processes into account to maximize efficiency. AI-based predictive maintenance can be used to manage large fleets of vehicles equipped with modern tracking and telemetry technology, while an increasing number of warehouses use AI-powered robotics to automate the packing process.

AI has also gained traction in managing transportation infrastructure and traffic. Understanding the condition of assets such as traffic signs and pavement conditions is a time-consuming task that once involved taking pictures while driving along the roadway. The rapid development of computer-vision algorithms allows transportation professionals to automate the process of measuring the health of assets, monitoring traffic safety at intersections, and streamlining customer interactions such as face-scanning, ticketless fare systems for subways and trains in China. Adaptive traffic control

Courtesy of Smart Transportation Applications and Research Laboratory, University of Washington

Bright green boxes frame highway signs discerned by AI on a busy stretch of I-5 in Seattle, Washington. Machine learning and computer vision, which power tools such as this automated traffic-sign recognition system being developed by University of Washington researchers, hold promise for enhancing safety and inventory management efficiency.

has been used for decades to adjust signal timing based on traffic conditions. Researchers also use deep-learning–based frameworks to reinvent travel-demand modeling and traffic-flow analysis.

While there has been exciting progress, most AI developments in transportation are still pilot projects in a research environment and not yet deployed in the real world at scale. Many transportation professionals still struggle to understand and leverage AI technology effectively in their projects. As writer William Gibson, who coined and popularized the term cyberspace, put it: "The future is already here—it's just not evenly distributed."

Implementing AI in Transportation

Several best practices and key considerations could help when implementing AI technology in transportation projects. First, work backward from the user's problem. A classic mistake in implementing any technology can be encapsulated in the saying, "If all you have is a hammer, then everything looks like a nail." Many AI projects have failed because of a lack of clear end goals or measurable impacts at the outset. Some appear to have begun with the mindset of simply applying AI technologies to see what they can do. Instead of starting with a predefined solution, successful implementations put users at the center and work backward to decide the right approach to solve their problem. In many instances, AI may not be the most suitable solution, nor would it justify the return on investment.

Another effective strategy is to start small and iterate fast. AI projects usually have many unknowns and uncertainties when applied to real-world problems. It is impractical to capture all of these in the planning phase. Starting to test AI solutions in small pilot projects in a fail-safe environment allows operational or data quality issues to be identified early in the project. AI solutions determined to be effective can then quickly scale up. Pilot projects also help earn the trust of the business and legal communities, as well as users and the public. Involving all groups from the outset can mitigate risks and capture potential issues. It is also important to make sure from the beginning that a solution is fair, equitable, and protects people's privacy to proactively avoid the downsides of AI technology.

Consider using AI to enhance rather than replace human decision making. Despite tremendous strides, AI still has many limitations, such as biases, inconsistency, and robustness issues. "Hallucination" is another challenge with ChatGPT and other recent generative AI models that fabricate text, images, and other creative content. It is important to be careful about what decisions can be fully automated versus those that should be made by humans. This is especially true for transportation projects that directly affect public safety. The behavior of existing AI systems is not fully understood. As AI models grow larger, many may come to be seen as black-box systems. AI should be treated as a tool to facilitate human decision making rather than a system capable of making decisions on its own without proper monitoring or fail-safe mechanisms.

It is useful to think about the full life cycle of an AI project and be prepared to handle uncommon situations, or edge cases, in rare or extreme conditions. What works well in the laboratory can go wrong in many ways in a real-world environment. Most transportation AI projects remain in the pilot phase, undergoing feasibility tests. However, monitoring operations require very different skills. Real-world data often include errors, servers may go down, and an AI application may get confused if it encounters a scenario that was not in the training dataset. For example, a computer-vision algorithm trained with images collected during daytime may perform poorly when processing images collected during nighttime or foggy weather. AI model performance also may deteriorate over time, fail in edge cases, or both, so it is important to have a backup plan.

Challenges of AI in Transportation

Despite exciting progress, AI technology still abounds with important challenges to which good answers have yet to emerge. Key among them is the need to identify and remove gender, ethnicity, and other biases in AI algorithms so that decisions based on that application are fair. AI algorithms can be biased if they are trained on biased input data. For example, if an AI algorithm was mostly trained on men driving cars, it may make inaccurate predictions or decisions about female drivers. A Massachusetts Institute of Technology study found that popular facial-analysis software had error rates of 0.8 percent for men with fair skin and 34.7 percent for women with dark skin (*6*).

As AI models get larger, publicly available data are often used to train them. However, there is no clear guideline to protect personal data and intellectual property. For example, ChatGPT used the entire Internet to train the ChatGPT model, but it is unclear whether the process violated authors' copyrights and how it should be regulated. There were accusations—quickly addressed and remedied by ChatGPT's creators—that the chatbot leaked internal documents or personal information in its answers. However, the issue underscores the importance of coming up with public policy and design mechanisms to protect personal data and privacy in the age of AI.

Multiple studies have estimated the effects of AI technology on the labor force. OpenAI published reports on ChatGPT that found around 80 percent of the U.S. workforce could have at least 10 percent of their tasks affected by large language models, while about 19 percent of workers may see at least 50 percent of their tasks affected (*7*). Other types of AI technology, such as self-driving cars, will continue automating human tasks in transportation sectors.

Some observers argue that humans always find ways to adapt to new technologies, as when machines and computers were introduced in the workplace. Others contend that, unlike past technological revolutions, AI is the first with the potential to replace human intelligence and decision making. While the verdict remains to be revealed, the debate highlights a clear need to ensure that AI is used to enhance human capabilities instead of replacing people altogether without installing safeguards.

As AI accelerates its transformation of society, the job of transportation engineer will be redefined. While the core concepts of engineering remain critical to the profession, they are no longer sufficient to prepare future transportation engineers in the age of AI. Incorporation of machine learning and AI courses into transportation education and training will require an increasing emphasis on interdisciplinary approaches to instill the mathematical, computer science, and statistical background necessary to understand AI methods. The goal is not to make every transportation engineer an AI researcher but to prepare them to know how to work with AI effectively and responsibly in their day-to-day jobs.

Conclusion

AI is changing how people live and work, and transportation professionals are at the forefront of this technology-driven paradigm shift. While there are many promising AI applications, successful implementation requires working backward from users' problems; starting small and iterating quickly; and considering how to operationalize projects over the long term by addressing uncommon situations in the real world. Many challenges remain to ensure that AI applications are equitable, fair, and that they protect privacy, but there are reasons to remain optimistic about AI's potential to make transportation systems safer, more efficient, and more sustainable.

Morning commuters stream through an exit gate at busy Xi'erqi Subway Station in Beijing, China. Rapid developments in AI and computer-vision algorithms have enabled Chinese transit services to streamline customer interactions with ticketless fare systems such as this one.

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