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The Role of Artificial Intelligence in Transportation

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Introduction and Background

Although artificial intelligence (AI) is not a new concept, a number of technological trends such as increased computing power, mass data storage, and innovations in algorithms are contributing to renewed interest (Vasudevan, et al., 2020). According to Smith (2023) AI refers to the simulation of human intelligence in machines that are programmed to think and learn like humans. AI involves the development of computer systems that can process and analyze data, such as visual perception, speech recognition, decision-making, and language translation, at a scale and speed that would be impossible without technology (Smith, 2023) (Cambridge Systematics and ITS America, 2023). By processing, categorizing, and collating data quickly, AI has the potential to provide meaningful insights from large volumes of transportation data (Cambridge Systematics and ITS America, 2023).

In 2017, the 115th Congress proposed the FUTURE of Artificial Intelligence Act, which defined AI as:

1. Any artificial systems that perform tasks under varying and unpredictable circumstances, without significant human oversight, or that can learn from their experience and improve their performance. Such systems may be developed in computer software, physical hardware, or other contexts not yet contemplated. They may solve tasks requiring human-like perception, cognition, planning, learning, communication, or physical action. In general, the more human-like the system within the context of its tasks, the more it can be said to use artificial intelligence.

2. Systems that think like humans, such as cognitive architectures and neural networks.

3. Systems that act like humans, such as systems that can pass the Turing test or other comparable test via natural language processing, knowledge representation, automated reasoning, and learning.

4. A set of techniques, including machine learning, that seek to approximate some cognitive tasks.

5. Systems that act rationally, such as intelligent software agents and embodied robots that achieve goals via perception, planning, reasoning, learning, communicating, decision making, and acting.

AI Basics

Two different approaches and capabilities within the field of AI include “Narrow AI” and “General AI.” Narrow AI (sometimes referred to as Weak AI) is designed and trained for a particular task. It excels in that specific area but lacks the ability to transfer its knowledge to other domains

(Frankenfield, 2022) (Gülen, 2023). Examples include virtual personal assistants like Siri, Cortana, or Alexa (Joby, 2020). General AI (sometimes referred to as Strong AI) is a more advanced form of AI that has the ability to understand, learn, and apply knowledge across different domains, similar to human intelligence (IBM, No Date). General AI is still largely theoretical and has not been achieved yet (Abdullahi, 2023).

Understanding AI requires familiarity with several foundational concepts, including machine learning, deep learning, and neural networks. Machine Learning is a subset of AI focused on developing algorithms that allow computers to learn from and make decisions based on data. Machine learning can encompass: 1) supervised learning, 2) unsupervised learning, and 3) reinforcement earning. Supervised learning involves training a model on a labeled dataset. The goal is for the model to learn a mapping from inputs to outputs that can be used to predict the labels for new, unseen data (IBM, 2024). A core objective of supervised learning is to minimize error between the predicted output and the actual output. Common applications can include image classification, speech recognition, and predictive maintenance. Unsupervised learning deals with unlabeled data. The objective is to discover hidden patterns or data groupings without the need for human intervention (IBM, 2024). Unlike supervised learning, there are no explicit outputs to predict. Instead, the goal of unsupervised learning is to discover patterns or features in the data. Common applications can include traveler segmentation and anomaly detection. Reinforcement learning (RL) is a type of machine learning process that focuses on decision making by autonomous agents. An autonomous agent is any system that can make decisions and act in response to its environment independent of direct instruction by a human user. With reinforcement learning, an autonomous agent learns to perform a task by trial and error in the absence of any guidance from a human user (IBM, 2024). Common applications can include robotics and automated vehicles. Deep learning is a subset of machine learning that uses multi-layered neural networks, called deep neural networks, to simulate the complex decision-making power of the human brain (IBM, 2024). A neural network is a machine learning program, or model, that makes decisions in a manner similar to the human brain to weigh options and arrive at conclusions (IBM, 2024). Each learning type (supervised, unsupervised, and reinforcement) can use neural networks and deep learning techniques to learn from data.

Implementing AI in transportation (or any other discipline) requires three elements: 1) data, 2) algorithms, and 3) computing power. Large volumes of high-quality data are necessary for training AI to identify patterns, make predictions, and continually improve. Depending on the application, data can come in many forms such as text, images, audio, video, and sensor inputs to name a few (Greer, 2019). In addition to data, rules and mathematical models (i.e., algorithms) that define how AI processes data and make decisions are necessary (Rossi, 2023). The algorithms can include a range of types (e.g., supervised learning, unsupervised learning, reinforcement learning, and deep learning) and techniques (e.g., statistical methods to advanced neural networks). Finally, computing power includes all of the hardware and enabling resources required to run the AI algorithms.

Potential Applications for AI in Transportation

The Intelligent Transportation Systems Joint Program Office (ITS-JPO) of the U.S. Department of Transportation has identified a number of potential AI applications in transportation, such as replacing or augmenting actions of handheld and remote sensing devices, connected and automated vehicles, traffic management center operators, transit and freight operators, decisionmakers, and travelers. Many of the use cases identified by the ITS-JPO have emphasized AI applications “to identify objects and images, recognize speech and audio, process large amounts of data to recognize patterns, learn from experience, and adapt to new environments to predict traffic phenomena, provide situational awareness, assist drivers with maneuvering, recognize unsafe driving conditions in real-time, identify or isolate malfunctioning or misbehaving system entities, improve cyber-security, operate infrastructure devices and vehicles, monitor pavement and support decision-making” (Vasudevan, et al., 2020). Sixteen potential categories of applications for AI are summarized in Table 1.

Table 1. Categories of Potential Applications for AI in Transportation

Accessible Transportation	This category includes use cases that aid older adults and travelers with disabilities. For example, AI can be used to provide optimal routes that consider factors such as wheelchair accessibility, step-free pathways, and proximity to accessible facilities for travelers with disabilities. AI voice assistants can also provide personalized travel assistance and navigation for pedestrians with visual disabilities. AI can also be integrated into vehicles to provide voice-activated interfaces, gesture recognition, and other features that make it easier for older adults and people with disabilities to use and interact with vehicles (Jalali, 2024) (SkedGo, 2023) (Papandreou, 2024).
Advanced Driver Assistance Systems and Automated Driving Systems	This includes applications and use cases that leverage AI for automated vehicles, connected vehicles, and driver warning systems (Boigon, 2024). Examples of these applications can include the use of AI in adaptive cruise control, intelligent speed adaptation, and lane-keeping systems generally associated with Level 2 vehicle automation. Additionally, AI can also be used to predict the potential of a redlight violation and generate warning alerts for roadway users (Patil, 2024) (Hever, 2023).
Air Traffic Management	This includes the use of AI to support air traffic management through predictive analytics, route optimization, collision avoidance, automated decision support, machine learning for air traffic patterns, weather assessment, dynamic airspace management, and autonomous aircraft operations. Both the Federal Aviation Administration (FAA) and the European Union Aviation Safety Agency (EASA) are exploring the potential use of remote air traffic control towers (Federal Aviation Administration, 2023) (Villamizar, 2024). These towers could use optical and infrared cameras, along with other sensors to aid in traffic management. In the future, AI may be able to aid in the processing of this data.
Asset Management and Infrastructure Construction and Maintenance	This category includes leveraging AI to monitor the performance of transportation assets and prioritize resource maintenance, preservation, repair, rehabilitation, and replacement (Alvarez & De Reyna, n.d.) (Maintain-AI - Better Roads, 2023).
Commercial Vehicle and Freight Operations	This includes the use of AI to ensure the safe and efficient management of commercial vehicle fleets and logistics (e.g., expediting the exchange of information between shippers, freight carriers, port authorities, and others). AI could also be used to support a variety of freight operations, including route planning, fleet management, drayage optimization, freight signal priority, asset tracking, cargo monitoring, and the automation of highway inspections, border crossing, and port operations (McCareins, 2024) (ITS International, 2021) (Jones, 2023).
Cybersecurity	This includes applications and use cases to provide enhanced cybersecurity in the communications and control of transportation systems; positioning, tracking, and navigation; and the operations and management of connected vehicles, devices, and infrastructure. Additionally, AI can also be used to monitor security risks and prevent the unauthorized access and exploitation of information technology systems in transportation (Wright, 2024). However, AI can also introduce new risks to cybersecurity such as hacking, deep fakes, data poisoning, data manipulation, privacy, and data management (Cities Today, 2023) (Kessler, 2024).

Demand Forecasting and Scheduling	AI could be employed to analyze historical data, weather conditions, special events, seasonality, and other factors to predict demand and adjust schedules accordingly. AI could also be used to adjust schedules in real-time based on current conditions, delays, and load factors. AI could also be used for route optimization and crew scheduling (considering regulations, crew preferences, and strategies to minimize fatigue) (Fontenla, 2024) (Muros Anguita & Olariaga , 2022).
Emergency Management and Incident Response	AI can be employed to support route optimization of incident responders and evacuations impacting the transportation network. It can also be used to predict the impacts of different types of disasters on the transportation network to aid in emergency planning. AI can also be leveraged to support incident response. For example, AI can be used to aid real-time incident reporting (e.g., providing data and alerts to first responders). This can include aiding in incident response by analyzing data from multiple sources and assisting with resource allocation (e.g., personnel and assets) (Federal Highway Administration, 2021) (Grigorev, Saleh, Ou, & Mihaita, 2024).
Predictive Maintenance	AI could be used to predict maintenance needs for vehicles and infrastructure. On vehicles, AI monitor vehicle status and predict maintenance needs to avoid mechanical issues. With respect to infrastructure, AI could analyze data from sensors on bridges, roads, public transit, and other infrastructure to detect and predict wear and tear, and other (i.e., seasonal) maintenance needs (International Transport Forum, 2021) (Federal Highway Administration, 2021).
Public Transportation and Airport Safety	AI could be used to help monitor passenger behavior and detect suspicious activities (Vorapatratorn, 2024).
Remote Sensing	This category includes the use of AI to support traffic monitoring, infrastructure inspections, and aerial mapping (Agresta, 2024).
Traffic Safety	AI could be used in a variety of contexts to support traffic safety. This could include leveraging AI to adjust the timing of traffic lights based on real-time traffic conditions to enhance safety; analyzing historical and real-time data to predict and if possible, prevent traffic incidents; and analyzing data from various sources (cameras, sensors) to detect accidents in real-time and notify emergency services (Huangfu, 2023) (International Transport Forum, 2021).
Traveler Decision Support Tools	This category includes leveraging AI to provide static and dynamic information about the transportation network, such as route and mode travel times, transit status, mobility services, flight arrivals, weather conditions, pricing information, and incentive data. AI has the potential to monitor information, process traveler requests, predict infrastructure conditions, and help travelers make more informed decisions about their trips (Chen & Wei, 2024).
Traveler Experience	AI could be used in a variety of contexts to provide personalized information and experiences throughout a traveler's journey. This could include providing travelers with recommended activities, personalized deals, dynamic pricing, virtual assistants (i.e., travel concierges), natural language processing (as part of booking and ticketing), facial recognition and biometrics to enhance security processing, personalized entertainment, optimized seating assignments, augmented and virtual reality (AR/VR) wayfinding, and recommendations to enhance the sustainability of trip (Crozer, 2024) (Deeply Human Inc., 2024).
Transit Operations and Management	This category includes AI applications to support the management, operations, maintenance and security of public transportation. Examples can include leveraging AI for predictive maintenance, incident detection, management of demand-responsive transit (i.e., paratransit and microtransit), and dynamic routing and trip planning (Katsarov, 2024).
Transportation Systems Management and Operations (TSMO)	This category includes AI applications that help transportation managers optimize network performance, and manage the supply and demand of the transportation network. This could include leveraging AI to help predict and manage the impacts of work zones, traffic incidents, and weather, and implementing responsive actions such as ramp meeting, variable speed limits, adaptive traffic signaling, and variable pricing (i.e., tolls) to encourage or discourage the use of particular modes and routes (Gettman, 2019).

Potential Implications for AI in Transportation

Given the vast number of possible applications for AI in the transportation sector, AI has the potential to impact the transportation sector in four key ways:

- **Safety**: AI has the potential to analyze vast amounts of data in real-time to predict and prevent accidents. Transportation systems equipped with AI may also be able to react faster than human operators (e.g., drivers, pilots, etc.). Faster reaction times could reduce the frequency and severity of safety incidents. However, AI could also introduce new safety risks such as hardware and software failures; cybersecurity risks (i.e., hacking and data breaches); decision-making errors such as algorithmic bias; difficulty interacting with humans; tort and liability issues (i.e., who is responsible when an incident occurs); and ethical issues (e.g., choosing between the lesser of two harms in unavoidable accident scenarios) (Cambridge Systematics and ITS America, 2023).

- **Efficiency and Environmental Impacts**: AI has the potential to manage traffic such as predicting congestion, optimizing control systems, and suggesting recommended routes. Additionally, AI has the potential to help fleet providers (e.g., public transit, logistics, air carriers, etc.) optimize routes, schedules, and utilization rates while also reducing energy consumption. In doing so, AI could help increase system efficiency and reduce environmental impacts such as greenhouse gas (GHG) emissions and energy consumption. However, technical failures, inconsistent performance, poor data, and other issues could present risks to leveraging AI for improved efficiency. Additionally, one study estimates that generative AI might use around 33 times more energy than machines running task-specific software (Baraniuk, 2024). Another study estimates that AI could cause a 160% increase in data center power consumption (Goldman Sachs, 2024). As such, the potential energy savings of AI use cases should be carefully balanced against new power requirements necessary to run those system (Cambridge Systematics and ITS America, 2023)s.

- **Economic Impacts**: If AI results in increased safety and efficiency, it could result in cost savings for the public and private sectors. With respect to employment, AI has the potential to displace some jobs and also create new opportunities in AI development, maintenance, and oversight roles (Cecchi-Dimeglio, 2024) (Tyrinopoulos & Milioti, 2022) (Pronello & Fedeli, 2024).

- **User and Equity Impacts**: AI has the potential to provide personalized travel recommendations and services based on user preferences and behaviors. It could also provide additional accessibility features for people with disabilities. However, concerns over how personal data is collected, stored, and used by AI in transportation systems can deter users from engaging with transportation services that use AI. Additionally, AI has the potential to perpetuate or exacerbate biases present in training data, leading to unfair treatment of certain users and groups. Additionally, bias in AI can result in discriminatory practices, such as prioritizing services for some users over others based on flawed, inappropriate, or prejudicial criteria (Cambridge Systematics and ITS America, 2023).

Potential Public Sector Roles

The public sector could play a key role in AI and transportation in several key areas, such as:

- **Regulation and Policy Development**: The public sector could develop and enforce standards for the safe and ethical use of AI in transportation, including data privacy, cybersecurity, and operational safety. Congress and state legislatures could consider crafting legislation that governs the deployment of AI in vehicles, traffic management systems, and other transportation systems. This could also include regulations and policy to secure the transportation data collected by AI and protect traveler privacy when their data is used.

- **Infrastructure Investment**: The public sector could invest in digital infrastructure that supports or enables AI in transportation for connected signals, smart corridors, and intermodal facilities. The public sector could also invest in technologies that enable to the use of AI to enhance route planning, scheduling, and efficiency of public transit networks.

- **Research and Development**: The public sector could provide funding and grants that supports research in transportation AI applications. This could also include funding for demonstration programs to test and train AI in real-world settings.

- **Safety and Oversight**: The public sector could establish safety standards for the use of AI in transportation systems. Additionally, the public sector could establish protocols for investigating safety incidents involving the use of AI in transportation.

- **Environmental and Social Considerations**: The public sector could explore potential use cases for AI in transportation that help reduce emissions, mitigate congestion, and increase energy efficiency. The public sector could consider establishing standards for assessing the equity impacts of AI in transportation to prevent adverse impacts on underserved communities and protected classes.

- **Workforce and Economic Development**: The public sector could support the development of AI in transportation through tax and other incentives. Additionally, the public sector could consider establishing workforce programs to train the public with the skills needed to work with AI in a variety of transportation contexts.

- **Institutional Readiness and Collaboration**: The public and private sectors could work together to harmonize standards and regulations for AI in transportation.

To this end, informed policymaking on AI in transportation can help guide the safe and ethical development of AI that serves the public interest. State governments can advance this by:

Understanding AI and Transportation	Policymakers should enhance their understanding of how AI works, including potential capabilities, limitations, and use cases.
Engaging Stakeholders	Policymakers should engage a range of stakeholders including industry experts, academia, non-government organizations, ethicists, and other stakeholders on technical, social, privacy, and other issues.
Considering Ethical and Social Issues	Policymakers should consider developing or applying existing ethical frameworks to guide AI applications in transportation. This could include fairness to prevent perpetuating or amplifying bias; transparency to disclose how AI is applied across contexts accountability to establish responsible oversight; and privacy.
Developing Regulation and Standards	Policymakers could consider developing working groups to advise on AI in transportation. Policymakers could also develop one or more regulatory frameworks for AI use cases in transportation. The framework(s) could include mechanisms for harmonizing policies with other legislative and regulatory bodies, as well as collaboration with standards development organizations (SDOs). The framework(s) could also include risk-based approaches for tailoring regulation to di erent types of transportation use cases. Given the pace of evolution in this space, potential framework(s) could include processes for adaptation as the field continues to evolve.
Educating the Public and Preparing the Workforce	Local and state governments can invest in education and training programs to raise public awareness about how AI is being used in transportation; o er training for professionals interested in AI transportation use cases; and promoting AI curricula in K-12, college, university, and workforce training programs.
Researching AI in Transportation	Policymakers can provide funding for AI research and development; foster public-private research collaboration between the public sector, academia, and the private sector; and establish testbeds and sandboxes where AI can be safely tested.
Monitoring and Evaluating Outcomes	Policymakers can support agencies and processes to monitor AI applications in transportation. This can include conducting impact assessments, developing methods for assessing the equity impacts of AI applications and use cases; implementing feedback mechanisms to refine and adapt policies based on emerging lessons and publishing findings documenting the impacts of AI on the transportation sector.

Methods, References, and Recommended Reading

This brief was developed using a mixed-method approach comprised of a literature review and expert interviews. The literature review included government reports, academic papers, conference proceedings, and other items. Due to the limited nature of peer-reviewed published research specific to AI in transportation, the literature review was supplemented with an internet search documenting recent and emerging developments in the field. The semi-structured expert interviews (n=36) were conducted between January and May 2024. The interviewees represented diverse perspectives and professional backgrounds, including policymakers, industry experts, researchers, ethicists, and other experts. Each interview lasted approximately one hour and were conducted using a semi-structured interview protocol with open-ended questions.

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