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An Overview of Paradigm Shift Dynamics in Transportation: Use of Artificial Intelligence in Intelligent Transportation Systems in Türkiye

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ABSTRACT

Currently, technology-based methods are widely used in the solutions developed for smart cities and sustainable transportation. Owing to the rapid advances in technology, the traditional structure of transportation networks is undergoing a paradigm shift. Artificial Intelligence (AI), that has started to have disruptive effects in many sectors in the future, is expected to be one of the most influential factors in the paradigm shift in transportation. In this paper, the dynamics of the paradigmatic shift in transportation to promote sustainable transportation in Türkiye are evaluated through conducting a review of the existing literature. Scenarios exhibiting the use of disruptive and innovative technologies in transport systems, specifically, AI applications in intelligent transportation systems (ITS), are examined. Additionally, the economic, environmental, and social impacts of AI applications are discussed by emphasizing the need to identify priority areas for the effective use of AI in the field of intelligent transport. Thus, this paper, by summarizing the use of AI-based technologies for intelligent transport in Türkiye, contributes to the literature by providing an overview of the existing knowledge.

Keywords: Paradigm shift in transportation, artificial intelligence, intelligent transportation systems, sustainable transportation, Türkiye

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1. INTRODUCTION

Transportation systems are characterized by an ever-increasing claim on public resources and many challenges need to be overcome for the proper functioning of these systems. Some of these challenges include the efficient management of the large number of components involved in the systems, involvement of multiple stakeholders seeking to achieve several goals that may conflict with each other, and their multidisciplinary structure.

Considering the increasing demand for transportation triggered by economic development and the growing desire of individuals to travel with more comfort, there is a need to strengthen traditional transportation systems with innovative approaches to overcome the difficulties presently experienced by passengers. In this regard, it becomes necessary to adopt a management strategy that focuses on the needs of stakeholders in the field of transportation and allows the integration of different transportation modes and stakeholders in an efficient and coordinated manner. While determining these strategies, a paradigm shift is observed that focuses on the digitalization of transportation processes and ensuring optimal interoperability between different actors and transportation modes. In such a paradigmatic shift, it is observed that principles such as sustainability, accessibility, connectivity, security, and safety constitute the fundamentals of transportation and mobility design. Intelligent transportation systems (ITS), that is one of the main approaches employed in this paradigmatic shift, and which is in line with these principles, is increasingly attracting researchers' attention due to its potential to revolutionize the way passengers and freight are transported. Disruptive technologies such as artificial intelligence (AI), Big Data, Internet of Things (IoT), and distributed ledgers are used in ITS to effectively address and prevent accidents, recognize unusual traffic conditions, optimize routes, and maintain roads (Oladimeji et al., 2023). In addition to AI and its technologies, several innovative technologies such as Connected, Cooperative and Automated Mobility (CCAM), cloud computing, open data, blockchain technologies, drones, air taxis, immersive interfaces, digital twins, Mobility as a Service (MaaS), smart roads, and hyperloop are used in this paradigmatic shift to address transportation problems. These technologies offer a diverse range of benefits and impacts for individuals, countries, and governments as compared to that by traditional approaches. This digital transportation infrastructure also brings with it a dynamic governance approach that involves continuous change and improvement.

This paradigm shift in the field of transportation, that is associated with dynamic governance and factors (hereinafter referred to as "paradigm shift dynamics"), is dominated by disruptive and innovative technologies that provide solutions to the existing problems, benefits from several AI applications, and reveals a data-based, human and environment-oriented perspective. It is open to constant development, and this vivid and developing nature of the technologies in the paradigm shift in transportation is effective in achieving sustainable, fair, environmentally friendly, and efficient transportation by focusing on data, which is considered a valuable mine in this century. Thus, more effective and intelligent decision-making is possible in such data-driven transportation management frameworks. Within the context of this shift, the variety and volume of mobility data collected is increasing every day due to the widespread use of different technologies such as surveillance cameras, LIDARs (Laser Imaging Detection and Ranging), and detectors for effective traffic management. The data collected from sensors are obtained from monitoring (i) physical elements such as roads, vehicles, and pedestrians, and (ii) digital components for ensuring the reliability and security of the communication network. AI systems employing these data are increasingly penetrating into our lives every day, triggering radical changes in transport systems. Machine Learning (ML) approaches, subfield of AI, are among the currently used innovative methods to analyze the collected transport data (Schneider, Kutila, & Hoess, 2021).

The main topics focused in this paper that aim to shed light on the factors currently driving the paradigm shift in the transportation sector, are as follows:

- Dynamics of the paradigmatic shift in transportation systems
- Disruptive and innovative technologies that play a significant role in the paradigm shift in transport
- AI-based ITS applications that are used to promote sustainable transportation in Türkiye
- The use of AI applications in ITS and their economic, environmental, and social impacts
- Academic studies in Türkiye that employed AI algorithms for various aspects of transportation management
- Evaluations and suggestions for the stakeholders in Türkiye to enable them to benefit from the paradigmatic shift in the field of transport, including legal infrastructure

The remainder of this study is organized as follows: in Section 2, the method followed by the authors of this paper for conducting a review of past literature is summarized. In Section 3, an overview of the dynamics of the paradigmatic shift in transportation systems is presented with a focus on disruptive and innovative technologies that play a role in the transformation of transport systems; additionally, AI applications in ITS along with AI's historical evolution and impacts are discussed. In Section 4, the dynamic paradigmatic shift in transportation and AI applications used in ITS regarding the promotion of sustainable transportation in Türkiye are examined. Finally, Section 5 presents the discussion and conclusions.

2. METHOD

This paper reviews recent studies, national strategy and policy documents, and evaluations to shed light on the factors currently shaping the paradigm shift in the transportation sector. It aims to highlight the dynamics of transformation affecting the future of sustainable transportation. Considering past studies in the literature, the paper focuses on the disruptive and innovative technologies used in transport and AI technologies that help achieve sustainability goals in the transportation sector. In this regard, these topics are evaluated from a global perspective, and impacts of AI, especially in the ITS sector, are discussed. A current situation analysis is conducted to reveal the dynamic paradigmatic shift and the view of sustainable transportation in Türkiye.

3. DYNAMICS OF THE PARADIGM SHIFT IN TRANSPORTATION

In addition to changes in the demand for transport services, the attributes of the emerging technologies also shape the transport sector. Especially in urban transport, various types of mobility systems are emerging; due to the radical change facilitated by these technologies, they are often termed "disruptive and innovative technologies." The concept of intelligent transportation has gained prominence in smart cities due to the integration of elements of the fourth industrial revolution into transportation systems, including IoT, sensor technologies, autonomous vehicles (AVs), cloud computing, Big Data, AI, digital twins, and blockchain (Önder & Akdemir, 2020), thus taking its place among the dynamics leading the paradigm shift in transportation.

Urban mobility, through which human needs can be observed intensively, is one of the most dynamic areas in the paradigmatic shift experienced in transportation. Consequently, many researchers are currently working on the development of new mobility technologies in line with smart city and urban transport concepts that have the potential to change many aspects of urban transport, from the type of fuel to the style of driving. Some of these developments are as follows: the ability of vehicles to cooperate and communicate with each other while gradually becoming automated, the emergence of radical changes in travel patterns in the long term with the concept of MaaS, etc. (Medina-Tapia & Robusté, 2018). Table 1 presents the paradigm shift in transportation. This has been adapted from (Litman, 2013)'s work and updated in accordance with the current trends in transport sector.

Table 1. Paradigm Shift in Transportation

Criteria for Comparison	Old Paradigm	New Paradigm
Definition of transport	Mobility (physical traveling)	• Accessibility (the ability of people to reach services and activities)
Planning objectives	Reduced congestion, journey times, accidents, emissions, and costs	• Provision of efficient and fair transport services for all road users, including disadvantaged groups
Modes considered	Preference for individual car use	• Multimodal approach (walking, public transport, cycling, etc.)
Common effects	Travel speed and congestion duration, cost of vehicle operations, accident and emission rates	• Several economic, social, environmental, and mental impacts, including indirect impacts • Sustainable transportation
Performance indicators	Vehicle traffic speed, road level of service (LoS), distance-based accident and emission rates	• Quality of transport options • Multimodal LoS • Compatibility of land use with accessibility
Consideration of transport demand management (TDM)	Deeming it necessary to reduce individual vehicle use in general and acceptance of TDM as the last alternative	• Support for TDM when it is cost effective
Transport improvement strategies	Increased road capacity and parking areas	• Improvement of transport options • Use of TDM • More accessible urban space planning
Impact on sustainability	Reduced rates of traffic accidents and pollution emissions per kilometer	• Reduced accident and emission rates per capita • Improved physical activity and basic access conditions
Technology utilization level	Use of traditional transport modes and transport systems	• Intensive use of ITS that combines traditional and innovative technologies • Integrating CCAM with the existing technologies in use • Widespread use of electric vehicles and technologies • Increasing use of disruptive and innovative technologies

In the following sections, disruptive and innovative technologies that constitute the paradigmatic shift dynamics in transportation systems and AI applications used in ITS that lead this paradigmatic shift are examined.

3.1. Disruptive and Innovative Technologies in Transport

Currently, traditional methods used for solving critical transport and infrastructure problems are increasingly exposed to disruptive effects due to technological advances. This has led to providing people with new opportunities for development. The innovative modes of transportation facilitated by these opportunities are transforming the way we travel; they are also making transport solutions increasingly dependent on the use of digital technologies (European Bank, 2019). The disruptive and innovative technologies that are triggering a paradigmatic shift in transport systems are depicted in Fig. 1. They are categorized in terms of (i) Information and Communication Technologies (ICT), (ii) Transportation, and (iii) ICT and Transportation.

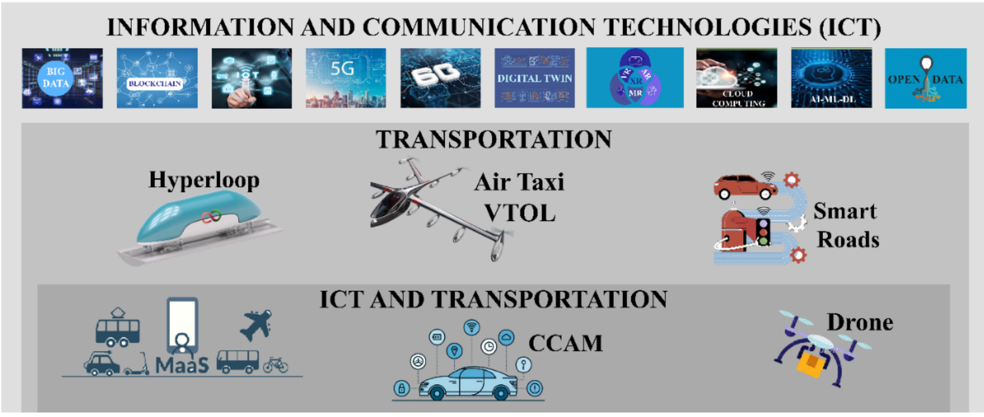

Figure 1. Disruptive and Innovative Technologies in Transport (Source: Authors)

3.1.1. Disruptive Technologies in ICT

IoT technology offers solutions that introduce radical changes in generally accepted approaches in several areas of transport such as traffic management, public transport, electric vehicles and charging infrastructures, railway systems, logistics and supply chain, fleet tracking, CCAM technologies, smart contracts, and last mile transport. IoT technology-based transport solutions aim to provide more flexible, efficient, safe, and secure mobility options. Traffic safety and security is one of the main issues of urban mobility and IoT solutions play an active role in detecting user errors, preventing traffic accidents, and facilitating effective traffic management (Derawi, Dalveren, & Cheikh, 2020). Further, Connected and Automated Vehicles (CAVs) can act in a more informed and coordinated manner owing to their ability to interact with everything using IoT devices (Nikitas, Michalakopoulou, Njoya, & Karampatzakis, 2020).

Big Data has been increasingly attracting the attention of researchers worldwide in terms of its application for the transportation sector. This technology provides data for transportation from several sources such as social media, data centers, sensors, vehicles, and open data platforms (Torre-Bastida et al., 2018). Regarding ITS, the application of Big Data can help reduce supply chain wastes, consolidate shipments, optimize logistics activities, contribute to improving the end-to-end user experience, and reduce negative environmental impacts of transportation (Hashem et al., 2016).

Within the framework of cloud computing technologies, researchers have proposed ITS-Cloud, that comprises traditional-static and temporary-dynamic cloud submodels for ITS to improve the efficiency of transport applications and services (Bitam & Mellouk, 2012).

Open transport data platforms provide information to the public and private sectors to create efficient transport solutions. They also provide opportunities for road users to efficiently manage their travels (T.C. Ulaştırma ve Altyapı Bakanlığı, 2022b).

Blockchain technology can be used in various areas related to transport and mobility such as in data sharing, payment systems, MaaS, supply chain and logistics services, and CCAM technologies (T.C. Ulaştırma ve Altyapı Bakanlığı, 2020).

The use of digital twins facilitates the accurate simulation of the real transport and road network. This technology can also be applied to predictive analytics-based approaches to make decisions regarding transport enhancements, including making decisions based on the analysis of traffic congestion (Rudskoy, Ilin, & Prokhorov, 2021).

Immersive technologies offer cost-effective solutions that address transportation requirements such as improving user experiences, testing areas for AVs, platforms for urban design, and training and education of pilots, drivers, and passengers (Li, Trappey, Lee, & Li, 2022). These technologies contribute to the transformation of the automotive and transport sector by virtual (VR), augmented (AR), and mixed (MR) reality solutions. These immersive systems and scenarios are often used to understand transport-related situations such as the operation of AVs, operation of railway systems, maintenance for motorways and vehicles, air traffic management, complexity of the real dynamic traffic environment, and cost uncertainties.

3.1.2. Disruptive Technologies in Transportation

Roads no longer constitute a physical entity or solid ground alone, but also include many supporting elements that are introduced by disruptive and innovative technologies. Currently, they are equipped with ICT, provide renewable energy, weigh the load of the moving vehicles, automatically charge electric vehicles, instantly detect traffic violations, communicate with road assets, have smart intersections and lights, and include fast emergency rescue features (Toh, Sanguesa, Cano, & Martinez, 2020). Smart roads not only use devices such as speed and noise detectors, CCTV (Closed Circuit Television) cameras, smart traffic lights and street lights, road and weather monitoring systems, digital signage, parking systems to improve transport safety, but also interact with CAVs, making the driving experience safer by enabling route tracking (Koptelov, 2022).

Hyperloop, described as the “fifth mode of transport,” is a transport and mobility alternative that is operated with energy obtained from renewable energy resources. It consumes less energy as compared that of an aircraft and can travel at a speed of approximately 1,200 km/h. It is resistant to earthquakes and weather conditions, and is not exposed to traffic problems (T.C. Cumhurbaşkanlığı Dijital Dönüşüm Ofisi, 2020).

The features and benefits of an air taxi that is one of the disruptive and innovative technologies in transportation, are summarized in (Pan & Alouini, 2021) as (i) supporting environmentally friendly transport, (ii) enabling transport without traffic congestion, (iii) providing flexible and fast door-to-door transport, (iv) requiring less ground support infrastructure, (v) allowing more space for road users, and (vi) lower maintenance and construction costs.

3.1.3. Disruptive Technologies in ICT and Transportation

In (ERTRAC, 2022), that discusses the effects of AI in the framework of CCAM, the applications of AI and its effects in the context of autonomous driving are comprehensively examined. AV is a broad and dynamic concept under development, that plays an important role in the paradigm shift of urban transport (Medina-Tapia & Robusté, 2018). AV technologies use a combination of hardware and software components to effectively employ driverless features. Owing to the sensitive communication AVs establish with each other, they can reduce traffic congestion and simultaneously perform intelligent fleet management. Additionally, current AVs are equipped with a 360° vision, that can significantly help to reduce accidents (Oladimeji et al., 2023). AVs, that use hardware such as radar, LIDAR, and cameras to perceive the environment, can benefit from ML models for planning and decision-making by interpreting data collected from sensors (Schwarting, Alonso-Mora, & Rus, 2018). CAVs can transform mobility needs, transportation networks, and road infrastructure by transferring vehicle control and driving responsibility from humans to machines with immense AI and wireless connectivity capabilities (Nikitas et al., 2020).

Drones, especially when used in logistics activities, have the potential to have a positive impact on the environment by significantly reducing the number of vehicles on the road. The use of drones is bringing about radical changes to asset management, infrastructure inspections, and field survey tasks. It also supports logistics activities within the framework of consumer services and product deliveries in several developed and developing global markets (European Bank, 2019). In future, a drone (i) can be an alternative vehicle for the delivery of emergency aid, time-sensitive products, medical supplies, etc. without facing the difficulties of waiting in traffic or location access, (ii) can be a more feasible solution for urban air mobility, (iii) can record high-resolution images and videos, (iv) can be employed in emergency response and disaster relief cases, (v) can be used in the monitoring and management of parking spaces in urban areas owing to its advanced sensors, real-time data transfer ability, and effective traffic management (Vega, 2023). Thus, Unmanned Aerial Vehicles (UAV), also known as drones, are among the paradigmatic shift tools that use AI and wireless technologies for air transportation (Nikitas et al., 2020).

MaaS is a system that offers digital packages of personalized multimodal mobility services through an intelligent online platform that can provide integrated journey planning, booking, smart ticketing, and real-time information services (Nikitas et al., 2020). Thus, MaaS, as one of the technologies facilitating the paradigmatic shift in transportation, has the potential of reducing individual car use, and helps passengers to choose the most efficient mobility service based on their specifications. In this approach, optional access to various types of transportation is possible in line with user demands, individual travel options are offered for each user, and users can choose the best offers from a digital platform (Talih & Tektaş, 2023).

3.2. AI in ITS and its Impacts

This section discusses the following: the historical development of AI, and the use of AI in ITS and mobility solutions, and AI's economic, social, and environmental impacts.

3.2.1. Historical Evolution of AI

Although AI technology is currently widely used in numerous sectors, including transportation, its emergence dates back to the 1950s. Alan Turing's article titled "Computing Machinery and Intelligence" laid out the framework on how to build and test AI in 1950. In 1949, Norbert Wiener, who is considered the modern-day father of the field of cybernetics, stated that machines could accomplish everything that was done in an understandable and straightforward manner. Wiener revealed the possible disruptive effects of AI on the economy by emphasizing that the value of regular factory workers will gradually decrease with the development of the skills of machines (Markoff, 2013). Between 1958 and 1959, Ord. Dr. Cahit Arf gave talks on the thinking potential of machines as part of the Atatürk University Public Conferences (Sarı, 2021).

However, subsequently, the development of research in the field of AI stagnated due to financial difficulties and the inadequacy of the equipment to conduct practical experiments based on the theory put forward in the 1950s. In 1966, a report published by the Automatic Language Processing Advisory Committee argued that no improvement was achieved by AI-based systems after evaluating these systems in terms of quality, speed, and cost, without considering their scientific value. Later, in the Lighthill report published by the British government, it was claimed that both the public and scientific community found AI to be insufficient in terms of industrial applications. The report anticipated that traditional engineering approaches would produce better results. In this environment, the funds allocated to AI research decreased and developments were disrupted. After this period, AI evolved into a new paradigm, Expert Systems, that focused on transferring the experience of humans in their field of expertise to machines and running it on personal computers. Digital Equipment Corporation announced that the expert system called XCON (eXpert CONfigurer) saved them 40 million dollars a year between 1980–1986. The US invested approximately over 1 billion dollars in Expert Systems in 1985. While the UK launched the Alvey program worth 350 million pounds, Japan announced an investment of 850 million dollars within the scope of the 5th generation computer project (Delipetrev, Tsinaraki, & Kostic, 2020).

In the years between 1990 and 2010, the concept of ML, a subbranch of AI, dominated the research landscape (Balasubramanian, Libarikian, & McElhaney, 2021). With the developing hardware and increasing amount of data, the problem-solving capabilities of algorithms began to be evident in many areas. However, it was noted that when there is an abundance of data, standard ML algorithms encounter challenges, whereas Artificial Neural Network (ANN) based models provide better results. In 2009, in the ImageNet (Hou et al., 2022) competition, an event in which advanced image classification models compete, 3.2 million labeled images were made available for 5,247 classes. In the performance evaluations during this competition, the deep learning model known as AlexNet achieved significant success as compared to other competitors; this attracted the attention of researchers toward this direction (Krizhevsky, Sutskever & Hinton, 2012). Thus, deep learning (DL) models, that are a subset of ML methods, started to emerge. While there are separate models in ML algorithms that extract summary information from images and perform classification and recognition using this information, both tasks can be performed within a single ANN in DL models (Dilek & Dener, 2023). This pioneered a paradigmatic shift in AI technologies. Currently, with the introduction of Big Data and powerful hardware, AI models and algorithms have become a formidable actor that forces radical changes in traditional methods used in ITS. Specifically, deep ANN-based models developed after 2010 have begun to be used in many sectors, including transportation. As research in the field of AI accelerates, models with new capabilities will emerge. The historical evolution of AI technologies is depicted in Fig. 2.

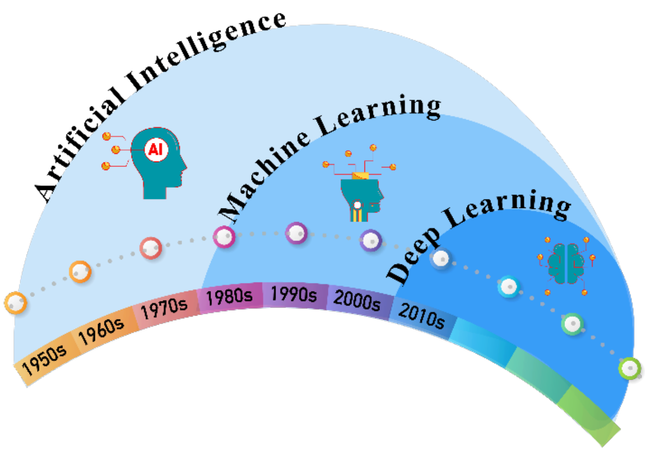

Figure 2. Historical Evolution of AI Technologies (Source: Authors)

3.2.2. AI in ITS

ITS, that can be defined as the transition of traditional transportation systems to a data-driven mechanism, is an ecosystem that includes many subtopics—ranging from innovative transportation systems to logistics, and from communication to security of its infrastructure. AI, which is one of the pioneers of the paradigmatic shift in transportation, has a wide range of application areas within the framework of ITS, as shown in Fig. 3.

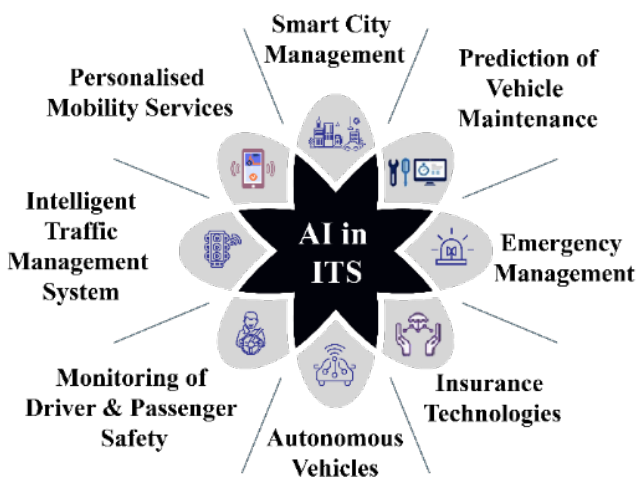

Figure 3. AI Application Areas Within the Context of ITS (Source: Authors)

AI is a powerful tool that, when used consciously, has the potential to foster a shift to a paradigm that uses resources more efficiently, facilitating sustainable living. AI technologies are used in various areas of ITS. Some of these areas include AVs, traffic monitoring, traffic sign recognition, pedestrian detection, traffic flow analysis, computer vision (CV) assisted parking management, road condition monitoring, automatic detection of traffic incidents, automatic number plate recognition, driver tracking systems, and infrastructure health inspection. AI models are also widely used in the prediction and detection of traffic situations such as road conditions, and traffic volume, density, and incidents. Owing to AI applications, it is possible to improve decision-making mechanisms, increase the efficiency of public transportation systems to promote sustainability, and reduce accidents in the road network (Abduljabbar, Dia, Liyanage, & Bagloee, 2019).

A detailed analysis of the use of ML algorithms used in ITS was presented by (Yuan et al., 2022). In their study, the use of ML algorithms in the field of ITS has been systematically addressed under three categories, mainly (i) detection/recognition, (ii) prediction, and (iii) management. The AI tasks and application scenarios utilized in the field of ITS are summarized in Table 2.

Table 2. AI Tasks and Application Scenarios in the Field of ITS (Adapted by the authors)

AI Tasks	Application Scenarios
Detection/Recognition	· Detection and classification of road assets (vehicles, pedestrians, traffic lights, signs, road lines, etc.); detection of obstacles, transportation infrastructure damages, road status, etc. · Detection and classification of vehicles according to their types · Detection of pedestrians and behavior analysis of drivers · Grouping data packets in order of importance in traffic communication networks, detection of network intrusions, and security vulnerabilities
Prediction	· Traffic density prediction · Travel time estimation · Prediction of vehicle and pedestrian behaviors · Route planning · Accident prediction and warning systems
Management	· Traffic signal management: Organizing traffic lights and active speed limits according to road conditions · Resource management: Optimizing communication systems and balancing storage/computing loads · Demand management: Providing route optimization for service providers such as those providing rental car, taxi, bicycle services, etc.

ANNs, Genetic Algorithms, Simulated Annealing, Artificial Immune System, Bee Colony Optimization, Ant Colony Optimiser, and Fuzzy Logic Model are among the AI methods that are used to increase the intelligence level of ITS (Abduljabbar et al., 2019).

3.2.3. Impacts of AI

It is anticipated that the use of AI technologies in ITS can provide time and financial savings, reveal potential assets that generally remain hidden in business development processes, and provide substantial gains in data governance in many areas, ranging from individual mobility of people to management of traffic in the logistics sector. Some economic, environmental, and social impacts of AI technologies are examined in the following sections.

- Economic Impacts

As expressed by (Howarth, 2023), 83% of companies state that using AI in their business strategies is their top priority. In 2035, the base gross revenue in the transport, logistics, and warehousing sector is estimated to be USD 2,131 billion, where the contribution of AI is estimated to be approximately USD 744 billion (nearly 35%). AI is also projected to cause severe fluctuations in employment, as automating physical and cognitive tasks is likely to lead to massive job losses for low-skilled workers in the transportation industry (Manyika James and Sneader Kevin, 2018). This negative gross impact is estimated to be approximately 10% by 2030 (Bughin Jacques, Seong Jeongmin, Manyika James, Chui Michael, & Joshi Raoul, 2018). While low-skilled workers are at risk of being replaced by technology and machines, demand for highly skilled workers in areas such as data analytics, engineering, cybersecurity, and vehicle monitoring, that enable the development of AI-powered mobility solutions, is expected to increase.

It is projected that AI models will gradually add approximately 13 trillion euros to the global economy by 2030 that is equivalent to approximately 14% (Rao, Verweij, & Cameron, 2020). Moreover, AI is estimated to contribute to an average annual productivity growth of approximately 1%–2% for the same period (Bughin Jacques et al., 2018).

Daily losses in automated parking systems and city traffic management can be prevented by employing AI-based techniques. Improving traffic congestion saves time and money by minimizing unnecessary fuel consumption. In the European Union (EU), congestion often occurs in and around urban areas. This congestion costs approximately 100 billion euros annually, which is roughly 1% of the EU’s Gross Domestic Product (GDP). AI has the potential to reduce travel times for the benefit of both individuals and the industry. AI applications can be used to adaptively design road infrastructure and signaling systems to better evenly distribute traffic by forecasting future demands. Efficient AI-based traffic management is expected to reduce waiting time at traffic lights by up to 47% (Batura et al., 2021).

Another contribution of AI is reducing road maintenance costs. It is reported that expenses will be minimized with fully automated transportation systems and will create a contribution of 38 billion euros across Europe (Batura et al., 2021). With the spread of AVs, a significant decrease in accident rates is expected, leading to reducing damage to public property and health costs due to injuries.

The interaction between ITS and AI also has an economic impact on energy savings. Some studies show that for various deployment scenarios, significant energy savings will be achieved from the use of smart cars (both electric and hybrid) (Chase, Maples, & Schipper, 2018). Specifically, the management of public transport and taxi mobility and shared passenger strategies can avoid a significant waste of public resources.

Fleet tracking systems are an additional energy saving mechanism. Truck platooning can reduce logistics costs and it is indicated that a fuel saving of 4% can be achieved in such a driving protocol as wind resistance will be reduced. This system's ability to keep the convoy model continually mobile is another economic benefit (Pham, 2018). By changing the driver of the tired leader vehicle, the convoy can be actively maintained.

Another dimension related to the economic impacts of AI in the field of ITS is related to insurance companies. Individual policies can be created based on the data collected from personalized vehicles; thus, more advantageous insurance service packages can be created. However, it is also predicted that the insurance industry's revenues will tend to decrease in the long term, especially with the introduction of fully automated vehicles. Additionally, the commercial taxi sector will also be affected as AI-assisted innovative transport trends will replace traditional approaches. In addition to these expectations, it is estimated that AI will trigger new sectors and lead to the creation of new business areas. Business areas pioneered by CAV technologies are expected to create 25.000 new jobs by 2035 (Batura et al., 2021).

- Environmental Impacts

The use of AI within the framework of ITS will also have positive effects on the environmental conditions. AI will have such positive effects through ensuring energy efficiency of vehicles, AV applications that can make decisions according to traffic conditions, and improving road conditions. With the support of ITS powered with AI, it is predicted that traffic management systems will be enhanced and the traffic congestion problem will be mitigated (Batura et al., 2021). AI-assisted management of traffic flow will enable the reduction of congestion and engine idling by ensuring steady traffic flow at optimum speeds. AI will also make it feasible to select the fastest and most energy-efficient route using traffic prediction. Thus, greenhouse gas emissions, fuel consumption, air pollution, and noise pollution can be prevented. As there will be less braking in a steady traffic flow, nonexhaust emissions will also be reduced. Thus, owing to the increased operational efficiency using AI-assisted systems, especially in the logistics sector, savings of approximately 500 billion dollars will be achieved, while the creation of 280 megatons of waste will be prevented worldwide in terms of reduction in carbon dioxide (CO_2) emissions (Transforming Transport, 2017).

The use of AI-supported applications in the field of ITS may have negative impacts as well. For example, since the training of advanced AI models has long computation times, model training processes have a significant carbon footprint. Hence, this needs to be considered in terms of environmental impacts of AI.

- Social Impacts

The European Environment Agency states that transport has a significant impact on the quality of life, especially in cities, and that reducing traffic-related pollution (air, noise, greenhouse gas emissions) significantly improves the quality of life (European Environment Agency, 2016). With the autonomy facilitated by AI applications, it is expected that there will be significant changes in people's lives from social aspects. Psychological problems caused by traffic congestion will decrease and the quality of life will increase. Since AVs are expected to obey traffic rules and avoid over speeding, they will help mitigate the emission of harmful gases and reduce the number of accidents caused by drivers due to making mistakes or intake of alcohol. It is also estimated that, due to increased road safety, fatal accident rates will decrease.

AI applications have the potential to enhance transportation services in both urban and rural regions, resulting in an improved travel experience (Batura et al., 2021). Owing to the increased accessibility to various destinations, significant improvements can be achieved with AI technologies for less mobile population groups such as the elderly and disabled. Thus, the disadvantaged groups will have increased opportunities of socialization.

However, with the penetration of AI and autonomous systems into our lives, security-related issues will emerge. Detection of incidents in public transportation or in public areas will be possible with CV technologies using cameras. Identification of vehicles or people sought by law enforcement and the routes followed by criminals can be easily accomplished by processing millions of data by AI. However, the use of AI brings the issue of personal rights to the fore. With the development of facial recognition systems, concerns arise that governments may implement more pressured policies on some individuals (Dilek & Dener, 2023).

4. PARADIGMATIC SHIFT DYNAMICS AND AI APPLICATIONS IN TRANSPORTATION SYSTEMS OF TÜRKİYE

Paradigmatic shift dynamics in transportation and AI applications used in ITS to promote sustainable transportation in Türkiye are examined in the following sections.

4.1. Paradigmatic Shift Dynamics in Transportation

It is observed that the disruptive and innovative technologies that focus on intelligent transportation and data are the triggers of the new transportation paradigm. AI strategies for Türkiye are discussed (T.C. Cumhurbaşkanlığı Dijital Dönüşüm Ofisi, 2021) in "2023 Industry and Technology Strategy", which states that disruptive technologies such as AI transforms the national policies of countries where there is a significant investment made in automated mobility and UAVs (T.C. Sanayi ve Teknoloji Bakanlığı, 2019). Additionally, "Mobility Vehicles and Technologies Roadmap" reveals a governance model that includes innovative solutions and technologies in line with the global context and trends, strategic goals, action plans, and critical projects within the framework of mobility (T.C. Sanayi ve Teknoloji Bakanlığı, 2022). Moreover, there are short-, medium-, and long-term goals and actions that support innovation in transportation in the strategy document and action plan for the advancement of ITS in Türkiye (T.C. Ulaştırma ve Altyapı Bakanlığı, 2020).

In the "11th Transportation and Communication Council" held in 2013, where developments in transportation were discussed, intelligent transportation targets were determined as follows: (i) Deployment of ITS in cities and ensuring the integration of national ITS applications, (ii) improving traffic safety and travel comfort, (iii) ensuring uninterrupted traffic flow conditions, (iv) developing intelligent transportation infrastructures and systems to ensure the integration of the railway network with other transportation systems, (v) establishment of smart motorways and state roads by 2035, and (vi) effective use of ITS in all cities with clean-fueled and highly energy-efficient vehicle technologies. While the focus was on the mission, vision, and targets set in the "National ITS Strategy Document and the 2020–2023 Action Plan" (T.C. Ulaştırma ve Altyapı Bakanlığı, 2020) along with sustainable transportation and increasing the deployment of ITS in the "12th Transport and Communication Council" report published in 2021, it is observed that the targets set in the "Green Deal Action Plan" (T.C. Ticaret Bakanlığı, 2021) are in line with the targets of the "European Green Deal" that states that Europe aims to be the first climate-neutral continent in the world in 2050. In the last two council meetings, it is noticed that the issues of digitalization, decarbonization, and autonomous and universal access to transportation have been brought to the agenda of transportation (T.C. Ulaştırma ve Altyapı Bakanlığı, 2023d).

In the "12th Development Plan", AI is regarded as one of the pioneering technologies for the green and digital transformation of sectors and it includes several measures to strengthen the cooperation of the public, academia, and private sectors in the field of AI (T.C. Cumhurbaşkanlığı Strateji ve Bütçe Başkanlığı, 2023).

In addition to the issues covered in the abovementioned policy and strategy documents, some initiatives among the paradigmatic shift dynamics of transportation aimed at ensuring sustainable transportation in Türkiye are summarized as follows:

- The concept of IoT is considered as an important paradigmatic shift dynamic for developing innovative solutions in transport, industry, research, and service projects for many sectors in Türkiye. In several Turkish cities, such as İstanbul, Kayseri, Konya, Ankara, and İzmir, intelligent transportation solutions and applications designed for urban traffic management using data collected from IoT assets such as traffic measurement sensors, surveillance cameras, and Global Positioning System (GPS) sensors are employed (T.C. Ulaştırma ve Altyapı Bakanlığı, 2020; T.C. Çevre Şehircilik ve İklim Değişikliği Bakanlığı, 2022).
- Safe, secure, and smart roads that can communicate with their environment constitutes one of the main elements of the paradigm shift in transportation. Some motorways in Türkiye that include basic smart road components are the Ankara-Niğde Motorway[1] and Northern Marmara Motorway[2].
- Long-term targets were included in the "National ITS Strategy Document and the 2020–2023 Action Plan" in line with the need for legislative regulations for vehicles such as air taxis, drones, etc. (T.C. Ulaştırma ve Altyapı Bakanlığı, 2020).
- The "National ITS Strategy Document and the 2020–2023 Action Plan" is a supportive and guiding roadmap to promote CCAM technologies in Türkiye, and it is observed that the use of disruptive and innovative technologies such as AI in transportation is a part of the strategy (T.C. Ulaştırma ve Altyapı Bakanlığı, 2020).

[1] https://www.ankaranigdeotoyolu.com
[2] https://www.kuzeymarmaraotoyolu.com

- "Driving Architecture for Autonomous Vehicles and Determination of Connected Vehicle Traffic Test Scenarios Project" and "Determination of Technical Characteristics of In-Vehicle Information and Communication System Project" (HGM, 2022b) have the potential to be effective in the development, deployment, and raising awareness regarding CAV technologies in Türkiye. Additionally, with the implementation of "Deployment of C-ITS (Cooperative ITS) Test and Application Corridor" action, a test zone will be built in Türkiye where several C-ITS use cases will be tested and new solutions can be developed (T.C. Ulaştırma ve Altyapı Bakanlığı, 2020).
- The "Mobility as a Service Project" (HGM, 2022a), that is under development in line with the long-term targets set in the "National ITS Strategy Document and the 2020–2023 Action Plan" (T.C. Ulaştırma ve Altyapı Bakanlığı, 2020), is among the personalized sustainable mobility solutions being developed in Türkiye.
- The "Digital City Twins–Creating a 3D Model" study, initiated by the Ministry of Environment, Urbanization and Climate Change in 2016–2017, continues to cover all Turkish provinces and districts and coastal regions (T.C. Çevre Şehircilik ve İklim Değişikliği Bakanlığı, 2022).
- Hyperloop is a promising and innovative transportation solution of the future for long-distance freight and passenger mobility; however, as it a future solution, there is no associated regulation in place in Türkiye (T.C. Cumhurbaşkanlığı Dijital Dönüşüm Ofisi, 2020).
- Several datasets are shared in open data portals regarding transportation and mobility categories. In order to promote the sharing of collected data, studies are generally conducted by countries within the framework of the existing legal infrastructure. In both the "11th Development Plan" and "12th Development Plan", a measure to establish a "National Open Data Portal", where public data will be shared, including transportation and mobility data in Türkiye, has been outlined. These plans also outline the process to determine data anonymization standards (T.C. Cumhurbaşkanlığı Strateji ve Bütçe Başkanlığı, 2019), (T.C. Cumhurbaşkanlığı Strateji ve Bütçe Başkanlığı, 2023). Some of the municipalities in Türkiye that have open data portals are presented in Table 3 (AVTED, 2023).

Table 3. Some of the Municipalities That Have Open Data Portals (Listed by the authors)

Category	Residential Location	Open Data Portal Address
CITY	Ankara	https://seffaf.ankara.bel.tr
	Antalya	https://acikveri.antalya.bel.tr
	Balıkesir	https://acikveri.balikesir.bel.tr
	Bursa	https://acikyesil.bursa.bel.tr
	Gaziantep	https://acikveri.gaziantep.bel.tr
	İstanbul	https://data.ibb.gov.tr
	İzmir	https://acikveri.bizizmir.com
	Kayseri	https://acikveri.kayseri.bel.tr
	Kocaeli	https://veri.kocaeli.bel.tr
	Konya	https://acikveri.konya.bel.tr
	Ordu	https://acikveri.ordu.bel.tr
	Sakarya	https://acikveri.sakarya.bel.tr
DISTRICT	Beyoğlu	https://acikveri.beyoglu.bel.tr
	Eyüpsultan	https://acikveri.eyupsultan.bel.tr
	Kadıköy	https://acikveri.kadikoy.bel.tr
	Küçükçekmece	https://acikveri.kucukcekmece.bel.tr
	Tuzla	https://veri.tuzla.bel.tr

4.2. AI-Supported ITS Applications

The new generation vehicles in Türkiye include systems such as pedestrian detection, automatic emergency braking, lane keeping assistant, smart speed control, fatigue detection, parking assistant, and adaptive cruise control and navigation. These AI-supported systems generally use components such as sensors and camera systems to help ensure safety and secure driving. Furthermore, AI-supported applications can quickly identify circumstances such as failure to wear seat belts and cell phone usage while driving, as well as driver fatigue symptoms such as exhaustion, distraction, and sleeplessness (Ulaşım Yönetim Merkezi, 2022).

For the first time in Türkiye, an AI-supported incident detection system was designed with domestic resources and deployed for the effective traffic management of the Ankara-Niğde Motorway. With the integration of the domestic AI-supported incident detection system into the cameras on the motorway, operators and drivers are warned if anomalous situations occur on the motorway (AUSPOSTASI, 2020).

Within the scope of the intelligent motorway project signed with the Scientific and Technological Research Council of Türkiye (TÜBİTAK) and the Northern Marmara Motorway Administration, detection of anomalies on roads will be made possible by equipping the roads with fiber optic infrastructure by utilizing advanced signal processing and AI techniques; further, imaging will be collected by sending autonomous drones to the relevant regions to collect further information (AUS Türkiye, 2022).

Fog, icing, and accident risks are automatically detected, and necessary precautions can be taken at the control center on a 24/7 basis due to the integration of AI systems into the cameras located on the 1915 Çanakkale Bridge (T.C. Ulaştırma ve Altyapı Bakanlığı, 2022a).

Trains are monitored in real time using AI technologies in the Train Monitoring and Coordination Center established by the General Directorate of Turkish State Railways Transportation Inc. In trains, CV technology detects sleepiness, absent-mindedness, and fatigue of the driver, and abnormal situations such as the train slipping off the track. Thus, drivers are warned when required so that possible accidents caused by human errors can be prevented (T.C. Ulaştırma ve Altyapı Bakanlığı, 2023b).

The disruptive impact of AI is predicted to be in the logistics sector. Within the framework of the agreements signed with AVL in Türkiye, a significant investment has been made in the truck platooning-automated convoy systems. It is emphasized that especially in 2025, heavy commercial vehicle classes will switch to smart truck convoys, and that owing to this new convoy technology, companies expect to obtain financial gains between 8–15% in convoys with three trucks (Ford Otosan, 2019).

An AI-based Video Analysis System (Eyeminer) developed by HAVELSAN; autonomous buses that have Level 4 autonomy developed by several technology and automotive manufacturers such as ADASTEC, Karsan, Anadolu Isuzu and Otokar; and, trucks that have Level 4 autonomy manufactured by Ford Otosan are among the other sustainable transportation applications in Türkiye that benefit from AI technologies. Efforts are also being made to increase the safety and security of transportation systems with AI technologies; some of these efforts include the Horizon 2020 InSecTT Project and Horizon Europe BRIGHTER Project, of which Marmara University is a participant. The InSecTT Project utilizes AI for two core tasks: (i) AI-supported embedded processing for industrial tasks and (ii) AI enhanced wireless transmission. Within the scope of the BRIGHTER Project, images obtained from the cameras located at smart intersections are processed by AI on edge computing devices and subsequently transmitted to the vehicles via Road Side Unit (RSU) devices. Thus, it aims to provide useful services for traffic efficiency and safety (T.C. Ulaştırma ve Altyapı Bakanlığı, 2023a, 2023c).

AI systems can identify structural flaws in the transportation infrastructure, including potholes, flooding, and ice on the road. While several studies regarding this topic have been conducted worldwide, Pendik Municipality in İstanbul has also taken steps in this direction (Pendik Belediyesi, 2015).

Some AI-supported solutions within the framework of ITS in Türkiye can be summarized as follows:

- AI-based incident detection and traffic prediction (INTETRA, 2023).
- Dynamic intersection control, vehicle counting, automatic tunnel incident detection, and the electronic enforcement system used within the scope of traffic control and management (ISSD, 2022).
- AI-supported cameras for vehicle detection, classification, and counting (Asya Trafik, 2022).
- Attention and fatigue measurement of drivers with image analysis, object detection, meta learning, and video segmentation; development of autonomous systems that provide environmental perception and decision support; adaptation to radar systems to improve remote sensing targets; and, increasing the capabilities of existing systems (ASELSAN, 2022).
- Autonomous vehicle technologies (Leo Drive, 2023).

- Intelligent intersection management and signaling system, vehicle recognition, speed detection, traffic anomaly detection, and traffic management and control (MIA Technology, 2024).
- Traffic data collection, real-time video processing, real-time vehicle counting, and video processing (Neovision, 2021).
- Smart intersection management with AI-supported cameras (MOSAŞ, 2024).
- License plate recognition; recognition of the vehicle's model, color and brand; detection of the vehicle speed and vehicle tracking, and transfer of black and white list number plates to security units via the Police Information System (POLNET) (Divit, 2023).

The academia in Türkiye has also focused on utilizing AI in solving problems related to transport and traffic. Academic studies including scientific projects, theses, articles, and conference papers are published by several departments of universities. For conducting this review, we searched the Dergipark Academic Information System, National Thesis Centre, and Google Scholar for obtaining academic studies using Turkish keywords equivalent to "*artificial intelligence, transport, transportation, traffic, intersection, adaptive, vehicle, driver, signal, road, strategy, autonomous*". Some academic studies on the use of AI in intelligent transport solutions in Türkiye, obtained as a result of the search, are provided in Table 4.

Table 4. Some of Academic Studies Related to AI-Supported ITS

Study	Title
(Tektaş et al., 2002)	A Review on The Use of Artificial Intelligence Techniques in Traffic (Yapay Zekâ Tekniklerinin Trafik Kontrolünde Kullanılması Üzerine Bir İnceleme)
(Doğan, 2007)	Regression Analysis and Artificial Intelligence Approach with Traffic Accident Prediction Models for Türkiye and Some Chosen Big Cities
(Çevik, 2010)	Vehicle License Plate Recognition System with Artificial Intelligence Methods
(Erdal, 2018)	Use of Artificial Intelligence Techniques and Expert Systems in the Control of Terrestrial Intelligent Transportation Systems (Yapay Zekâ Teknikleri ve Uzman Sistemlerin Karasal Akıllı Ulaşım Sistemlerinin Denetiminde Kullanımı)
(Gülsün & Gonca, 2019)	Adaptive Traffic Management Systems
(Pazar et al., 2020)	Development of Artificial Intelligence-Based Vehicle Detection System
(Başkaya et al., 2020)	A Model Proposal on The Preparation of Effective Transportation Plans Using Artificial Intelligence Techniques Within the Context of Smart Cities
(Kadiroğulları et al., 2020)	Determination of Vehicle Number and Vehicle Transit Time for a Sample Intersection in Isparta Province Using ARIMA Artificial Intelligence
(Palandız et al., 2021)	Classification of Traffic Signs with Artificial Intelligence: A Sample Application for Denizli City Center
(Özmen et al., 2022)	Detection of Foreign Material Under Vehicle by Artificial Intelligence Methods and Automatic Passing System
(Demir, 2023)	Model Proposal for the Creation of Transportation Stories in The Context of Smart Transportation Systems and Artificial Intelligence
(Toğaç, 2023)	Gaziantep Province Artificial Intelligence-based Intelligent Transportation Systems, Adaptive Signalization Control and Simulation
(Ulu, 2023)	An Artificial Intelligence-Based Optimization Model and Application in Traffic Incident Management
(Narbay & Kirazlı, 2023)	Artificial Intelligence in Autonomous Vehicles, Processing of Personal Data and its Results
(Şafak, 2024)	Application of Artificial Intelligence Methods for Driver Assistance in Vehicles

AI-supported ITS studies in Türkiye focus on traffic management techniques, incident management and prediction methods, traffic control methods and measures, optimization models, development of vehicle number plate recognition and detection systems, classification of traffic signs, driver support systems, adaptive signaling control, and model proposals for the preparation of effective transportation plans with AVs, as shown in Table 4.

Based on our review, we observed that academia and public and private sectors in Türkiye employ AI-based methods in ITS such as AVs, pedestrian detection, management of traffic signalization systems and detection of traffic signs, travel time estimation, monitoring of road conditions, traffic incident detection, automatic number plate recognition, monitoring of driver behaviors, and vehicle detection systems. In this context, the main areas where AI and intelligent transport issues are addressed together in Türkiye are summarized below. It should be noted that the issues are not limited to these alone.

- Traffic analysis, control, and optimization methods, including traffic monitoring and management
- Decision support for ITS
- Detection of driver behaviors
- Travel time prediction
- Preparation of effective transport plans including the use of infrastructure
- AVs

5. DISCUSSION AND CONCLUSION

Issues such as increase in population and vehicle ownership rates and rapid urbanization in developing countries as well as in developed countries worldwide have made it necessary to investigate innovative approaches for efficient transport management. Dynamic factors such as the increase in daily journeys, transformation in mobility trends, digitalization, and autonomy in vehicles make it necessary to plan, develop, and deliver transport services beyond the traditional boundaries. To ensure improvement and sustainability in the field of transport, a paradigm shift involving disruptive and innovative technologies is observed that has become a necessity in the age of globalization.

It is noticed that transportation and mobility solutions can be significantly improved with the introduction of ITS, CCAM technologies, and innovative technologies that leverage AI, Big Data, and IoT. AI technologies stand out among the elements responsible for the paradigm shift dynamics in transportation since they enable efficient use of resources, that accelerates the development of countries with strategic steps and lower budgets. Consequently, it is essential for Türkiye to focus on AI technologies in the field of transportation by referring to a variety of use cases in the world, investing in this field using domestic resources, and adopting it in national policies. By following the worldwide trends in the public sector, academia, and private sector, determining prioritized scenarios in the field of ITS, conducting studies in line with the visionaries of the academia together with the workforce of the private sector will contribute to the development of sustainable transportation systems in Türkiye.

In this study, the dynamics of a paradigmatic shift in the field of transportation are examined and the role and impacts of AI-supported ITS applications for the establishment of sustainable transportation systems are analyzed. Moreover, AI applications used in the ITS sector and academic studies to promote sustainable transportation in Türkiye are presented. Considering the current situation in Türkiye, in order for the paradigmatic shift dynamics in transportation to successfully transform the transport sector, it is necessary to determine the legal framework, facilitate interoperability and data sharing, and create a supportive framework for CCAM technologies. Additionally, while deploying AI-supported systems in transport services, ensuring data security, identifying potential risks, addressing liability concerns, determining the strategy to increase the dissemination and acceptance rate of innovative applications, and building capacity through training and awareness activities is of critical importance.

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