Bölüm 6

IoT-Based Smart Public Transport Systems

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Abstract

Today, rapidly increasing urbanization and population density cause serious traffic problems in cities. Among these problems, the inadequacy of public transportation systems used by a significant number of people, especially in large cities, is also a serious problem. IoT (Internet of Things) and Artificial Intelligence technologies, which have gained importance in recent years, are used to provide solutions to traffic and public transportation problems in cities. In this study, IoT and Artificial Intelligence technologies in public transportation and public transportation systems are discussed and theoretically examined. As a result, IoT-based smart public transportation systems stand out as one of the cornerstones of the smart cities of the future as well as solving today's transportation problems.

1. INTRODUCTION

Today, rapidly increasing urbanization and population density cause serious traffic problems in cities. Especially in urban transportation, there are problems such as heavy traffic, increased waiting times in traffic, increased traffic accidents, air pollution, which have serious negative effects on the health of urban residents (Dui et al. 2024). In addition to these problems, the inadequacy of public transportation systems used by a significant number of people, especially in big cities, is also a serious problem.

The Internet of Things (IoT-Internet of Things), which has become increasingly important in recent years, is especially used in solving urban

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problems. IoT can be defined as a system in which all devices/objects that can be connected to a network can collect and share data among themselves within the framework of certain protocols without the need for human intervention and data input (Syed. Et al., 2021). Devices connected to each other over the internet; sensors, cameras, vehicles, buildings, machines, electrical appliances, etc. can be included in this system. The important thing is that these devices can collect data and share this data within the system. Due to these features, IoT technology is trying to find solutions to the problems experienced in public transportation systems in cities.

Smart city management aims to manage the city's resources more efficiently with the help of technology and thus improve the quality of life of city dwellers. IoT has an important place in smart city management. Important operations such as collecting, storing or processing data in smart city management can be done with IoT technology (Doruk, 2022).

IoT technology used in traffic systems in cities enables more effective management of traffic systems by collecting public transport vehicles, stops, passengers, intersection traffic information and providing real-time data exchange between the control center (Dui et al. 2024, Javaid et al., 2018). Especially in big cities, more than half of road transportation is carried out by public transportation. In big cities such as Istanbul, Ankara and Izmir, the intensity of public transportation use is higher. IoT technology helps to make transportation processes safer, faster and more user-friendly by providing real-time data exchange between vehicles, infrastructure and passengers, especially in large cities where public transportation is used more.

2. INTERNET OF THINGS AND PUBLIC TRANSPORTATION

The concept of the Internet of Things (IoT) was first used in 2005 by the International Telecommunication Union (ITU), an expert organization of the United Nations (ITU, 2005). IoT enables objects or devices to communicate and exchange information by connecting them through the internet, radio frequencies, GPS and laser scanners (Bao, 2016). Today, IoT technology is used in many fields such as logistics, transportation, security, energy, medicine, architecture, manufacturing, home, retail (Dai et al. 2021).

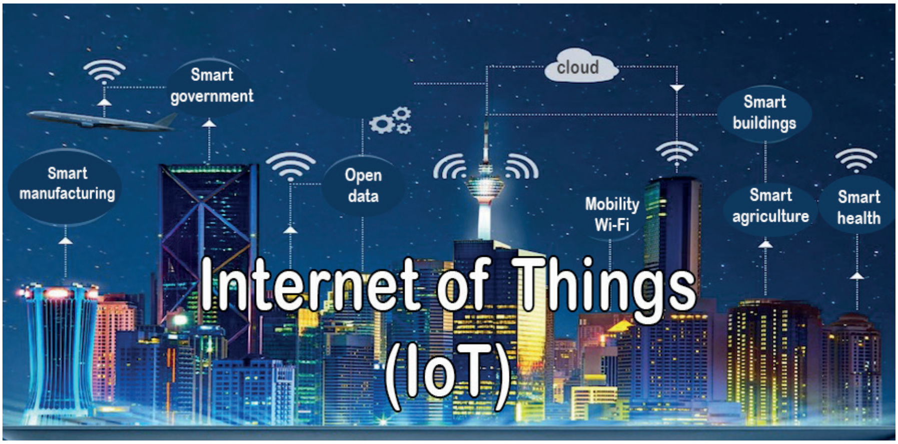

Figure 1. Internet of Things (IoT)

IoT is a system that enables physical objects that can collect data or share data on the network to communicate with each other and central systems over the internet, and process data from objects in real time.

IoT applications are used to make the sensors within the system accessible and to generate data by combining the data obtained from these sensors. High amounts of sensor data coming from physical environments are transmitted to operators or relevant people as information after evaluations, or the data is processed with the help of systems to make decisions about a situation (Giordano et al. 2011).

Today, urban areas, especially large cities, face transportation problems due to population growth and increasing use of individual vehicles. The convenience and comfort of individual vehicles has led to a large increase in the number of motor vehicles in cities. As a result, the high demand for transportation in urban centers leads to heavy traffic and related

problems such as air and noise pollution and traffic accidents (Greene, 1997; Newman and Kenworthy, 2006). For this reason, developed countries are adopting more sustainable policies such as reducing the use of individual vehicles, encouraging nonmotorized transportation, developing practices to support pedestrians to provide a more comfortable and safe transportation, improving public transportation systems in particular, and reducing greenhouse gas emissions (Newman and Kenworthy, 2015; Pojani and Stead, 2015).

Individual car use has some negative effects on human health. According to the researches, it has been determined that public transportation users walk between 8-33 minutes more than individual vehicle users. In the same study, it was found that about 30% of public transportation users' physical activity during the day is only walking to the transportation vehicles. Although it is considered that these walking times are not sufficient for human health, walking to access public transportation provides health benefits (Rissel et al. 2015).

In order to collect various data in public transportation systems, sensors with various features are installed in public transportation vehicles. Thanks to these sensors, data such as the speed, location, number of passengers, temperature, fuel quantity, etc. of the public transport vehicle can be monitored instantaneously and these data are collected in a center and used to evaluate the system performance. These collected data are helpful for system users or system administrators in many areas such as real-time location tracking, dynamic route and time calculation, energy efficiency, vehicle maintenance tracking, and passenger experience.

2.1. In-Vehicle Sensors and GPS Technology

In-vehicle sensors used in public transportation collect various types of data to improve the safety, efficiency and passenger experience. These sensors are usually installed in

public transportation vehicles such as buses, trams, subways and trains, which are used by a large number of people.

Thanks to the in-vehicle sensors in the IoT system, data such as speed, location, passenger density of the public transportation vehicle as well as technical data of the vehicle can be obtained. For example, fuel information, engine status, temperature inside the vehicle. Thanks to this data collected, instant data about the vehicle condition can be obtained and the maintenance needs of the vehicle can be determined in advance. Some types of sensors and their intended use can be summarized as follows;

Speed and acceleration sensors are generally used to measure the dynamic movements of vehicles. The data obtained is sent to the central system and processed. These sensors contribute to ensuring in-vehicle passenger safety and detecting the driver's driving habits by detecting situations such as sudden braking or acceleration of the vehicle. In addition, it can also be used to detect mechanical problems that may occur in the vehicle or to determine the causes of the accident when an accident occurs thanks to vehicle speed and acceleration data.

Passenger counting sensors are used to detect the current density in public transportation. The systems usually use cameras and image processing methods, infrared sensors or by monitoring the weight change of the vehicle to obtain occupancy information. These sensors are usually installed in vehicles such as buses, trains and subways, counting the number of passengers boarding and alighting the public transportation vehicle and determining the occupancy status of the vehicle (Pronello et al. 2023). Passenger mobility data can also be used to plan future services.

Air conditioning sensors measure parameters such as ambient temperature, humidity, carbon dioxide (CO_2) level and air quality. These sensors are used in public transport to increase

passenger comfort or optimize energy consumption. For example, in crowded countries such as China where public transportation is used intensively, ventilation systems are optimized and fresh air flow is ensured thanks to the data received from air conditioning sensors (Zhang et al. 2023). Smart air conditioning systems use only as much energy as necessary based on data from sensors. For example, thanks to the temperature control used in trains and buses, energy consumption is minimized, contributing to reduced operating costs and environmental impact (Cepeliauskaite et al. 2021).

Vibration and noise sensors have a wide range of applications in public transport systems, both to improve passenger comfort and to optimize infrastructure and vehicle maintenance. Thanks to noise sensors, internal noise data of public transport is collected and acoustic insulation can be optimized when necessary. In this way, passengers can travel more comfortably. There are also projects where environmental noise and vibration effects of public transport vehicles are analyzed and necessary optimizations are carried out (Seismic Surveys).

The Global Positioning Systems (GPS) is a network of 27 satellites orbiting the earth that was first developed by the US military as a military navigation system, but later made available to everyone (Theiss so., 2005, gps.gov). GPS is a system based on measuring the time of data exchange from at least 4 satellites that determine the position of a GPS device located anywhere in the world at any given time. In the GPS system, the earth is divided into 6 orbits determined by certain angles and there are 4 satellites in each orbit. In this way, a GPS device whose location is being determined can exchange data with at least 4 satellites (BOUN, 2022). Thanks to the connection of the GPS device with satellites, its position on the earth can be determined.

The signal sent by GPS satellites to users consists of a Pseudo Random Noise (PRN) code and a navigation message that

does not contain any information. The PRN code, which is generated using the binary number system (0 and 1), resembles a random sequence of numbers and is generated using a shift register according to a specific algorithm or rule. In satellites, PRN codes differ from each other thanks to the output bits from different cells in the shift registers (Tsui, 2004). PRN codes not only identify the satellite from which the signal is received, but are also used to calculate the distance between the receiver and the satellite. Traditional GPS satellites have two different PRN codes. One is the C/A code (Coarse Acqusition) for civilian users and the other is the P- (Precision) code for military applications. These two PRN codes and the navigation message are overlaid on the L1 carrier frequency. L2 carrier frequency consists of only the P code and the navigation message (Kahveci, 2012).

GPS consists of three main parts: space, control and user. The space segment consists of satellites that send navigation information to users to help them calculate their threedimensional position and velocity. The user section of receivers that provide time, position and velocity information for civilian and military purposes. The main function of the control section is to set satellite clocks, correct deviations in satellite orbits, monitor GPS satellites, correct and update errors in the content of the navigation message, identify and correct clock errors of satellites, check battery charge status, orbit information, satellite health status and correct operation. Another task is to activate the backup satellite in case of any problems with the satellites (Kahveci, 2012, Zhang, 2013, Kaplan, 2006)

Thanks to the GPS devices installed in public transportation vehicles, the location of the vehicles can be continuously monitored and real-time traffic information can be transmitted to the center. In this way, the necessary route arrangements of public transportation vehicles can be made and passengers can be instantly informed about vehicle location or arrival times (Spatialpost, 2023).

2.2. Smart Stops and Passenger Information Systems

Smart stops refer to stops designed to serve passengers using public transportation systems thanks to technological tools. These stops are usually equipped with information screens for passengers, free Wi-Fi service for passengers, sensors for data collection, digital signs, etc. These stops are designed to reduce waiting times, provide accurate information to passengers, improve the travel experience and increase energy efficiency (Republic of Turkey Ministry of Environment, Urbanization and Climate Change, 2024)

Passenger Information Systems (PIS) are systems that aim to provide accurate, timely and easily comprehensible information to passengers in vehicles in the public transportation system and also at stops. Thanks to these systems, passengers who will use public transportation can organize their travel plans by accessing information such as estimated arrival times of vehicles, vehicle routes, and passenger density in the vehicle. In addition, they can also determine the routes they will use to reach their destination thanks to the route and route screens at the stops (Bursa Metropolitan Municipality, 2024, Istanbul Metropolitan Municipality, 2024, Izmir Metropolitan Municipality, 2024).

Passenger information screens are also used inside public transportation vehicles as well as at bus stops. Passengers can access data such as the estimated time left to reach their destination, the route to be used during the journey and stop information from inside the vehicle. Passengers can also access this information through mobile applications developed by municipalities. Thus, these systems aim to increase the efficiency of public transportation systems and improve the passenger experience.

The functions of passenger information systems can be summarized as follows:

- Live Information: By providing real-time movement information of public transportation vehicles such as buses, subways and trams, information such as estimated arrival times of vehicles, stops on the current route and transfer points can be transferred to passengers
- Route and Route Information: Shows which vehicles and routes travelers should choose to reach their destination.
- Announcements and Emergencies: Provides instant notifications about technical problems, delays or schedule changes.
- Language and Accessibility Support: It offers more comfortable information to foreign passengers with multilingual options. It also includes special designs for disabled individuals.

3. ARTIFICIAL INTELLIGENCE IN PUBLIC TRANSPORTATION SYSTEMS

Machine learning is one of the fastest growing fields today, located at the intersection of computer science and statistics and at the center of artificial intelligence and data science. Within artificial intelligence (AI), machine learning has emerged as the method of choice for developing practical software for computer vision, speech recognition, natural language processing, robot control and other applications (Jordan and Mitchell, 2015).

For machine learning, a model is first created and thanks to this model, suggestions or predictions about the future are produced from the available data. Some of the data in machine learning is used in the training of the model and some of it is used as test data to determine whether the model produces correct results as a result of training (Grigorev, 2020).

Intelligent transportation systems (ITS) typically refer to the application of information, communication and sensing

technology to transportation and transit systems. ITS is likely to be an integral component of tomorrow's smart cities and will include a variety of services and applications such as road traffic management, passenger information systems, public transport system management and autonomous vehicles. ITS services are expected to contribute significantly to road and traffic safety, transportation and transit efficiency, as well as increasing energy efficiency and reducing environmental pollution. Although ITS applications have been made possible by unprecedented advances in sensing, computing and wireless communication technologies, they will pose several challenges due to their scalability and various quality of service needs, as well as the large amount of data they will generate (Yuan et al., 2022). In particular, it is important that the data obtained can be used in artificial intelligence technologies to provide solutions to the city's current or potential traffic problems.

Data from ITS paves the way for machine learning's ability to discover knowledge from data. The results obtained from machine learning algorithms such as regression, classification, prediction, clustering and even decision-making form the basis for solving transportation problems (Yuan et al., 2022).

Accurately forecasting the demand or need for public transport in a city in the short term is very important for public transport users. For example, knowing where and when future passenger congestion is likely to occur will help improve the quality and reliability of service by allowing public transit agencies to quickly adjust their schedules. Liyagane et al. (Liyanage. S, et al. -2022) used AI-based deep learning models to predict bus passenger demand based on real user data from a smart card system in Melbourne. They used real data from 18 bus routes and 1,781 bus stops from the busiest bus routes in Melbourne. LSTM and BILSTM deep learning models were evaluated and compared with five traditional deep learning

models using the same dataset. As a result of the study, they predicted passenger demands with an accuracy of over 90%.

Artificial intelligence applications exist for passenger density forecasting in air transportation. Jin et al. (Jin et al., 2020) used passenger demand data from Beijing, Guangzhou and Pudong airports in different artificial intelligence models to predict passenger demand with high accuracy.

Especially in big cities, malfunctions in public transportation vehicles pose a significant problem. Güven and Şahin (2022) ran classification techniques in machine learning based on vehicle health data obtained from IoT sensors in public transportation vehicles. For maintenance planning, they examined the probability of normal and faulty vehicles with fuzzy logic method. As a result of the study, they were able to detect almost all of the faults in vehicles with the methods they applied.

In public transportation systems, long queues for buying tickets, reading cards, etc. cause loss of time for passengers. In 2019, the authorities also announced the installation of a facial recognition system to help overcome overcrowding problems in Beijing's subway areas, the Daily Sun reported. With this system, they aimed to reduce the long queues that form during peak public transportation hours. The system analyzes facial data to ensure that only identified passengers enter the station. It can also detect potential threats as artificial intelligence quickly verifies identities and prevents unauthorized access (Biometricupdate, 2024).

In 2021, Dubai started using machine learning algorithms to manage crowds on public transportation. It is stated that the waiting time is reduced to 30 minutes thanks to the system that recommends the shortest time to reach the point they want to reach according to the crowds (RTA, 2021).

The safety of passengers on public transportation depends on detecting malfunctions before they occur. Thanks to a system

pioneered by Dell Technologies in the US, it has created a trackside portal that uses artificial intelligence to inspect trains traveling at speeds of over 125 miles per hour and flag any railcar problems in real time. This system captures 360-degree images of each train car in a very short period of time within seconds, and thanks to artificial intelligence systems, it can communicate potential problems to the center (Dell Technologies, 2024).

Energy management and optimization is an important issue for public transport systems. On average, 2.3 million passengers use the Madrid metro (Metro de Madrid) system every day, which includes a network of 294 kilometers of track and 301 stations. To help keep passengers cool inside the stations, especially during the hot summer months, Metro de Madrid operates 891 ventilation fans that consume up to 80 gigawatt hours of energy per year. An AI-based ventilation system used in the Madrid metro system reduces the cost of energy used for ventilation by 25%. Accordingly, it has reduced annual CO2 emissions by 1,800 tons. In this way, it improves the air quality in metro stations and offers passengers a more comfortable travel opportunity (Accenture, 2019).

4. CONCLUSION

IoT-based smart public transport systems transform the transportation infrastructure of modern cities, increasing efficiency, supporting sustainability and improving the passenger experience. Data from sensors, GPS devices and real-time processing by smart algorithms enable public transport vehicles to optimize their routes and manage traffic flow more effectively.

Among the most important benefits of these systems are dynamic service planning based on passenger demand, energy savings and reduction of carbon emissions, especially in public transportation systems. In addition, IoT technology increases safety in public transportation, enabling predictive maintenance practices and ensuring uninterrupted operation of the system.

However, the effective implementation of IoT-based systems faces significant challenges, such as data security, infrastructure costs and the development of harmonized standards. In the future, the integration of artificial intelligence and IoT technology could allow these systems to operate autonomously and open the door to a new era in public transportation services.

In conclusion, IoT-based smart public transportation systems not only solve current transportation problems, but also stand out as one of the cornerstones of the smart cities of the future. City planners, policy makers and technology providers can collaborate to implement these systems on a wide scale and build a more sustainable and user-friendly future for public transportation.

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