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Faculty of Economics and Administration

Institute of Systems Engineering and Informatics

Analyzing the Concept of Internet of Things with Specific Reference to Intelligent Transportation System

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Theses guidelines

The aim of the thesis is to explore and elaborate the key concepts of Internet of Things (IoT) and critically analyze its application within Intelligent Transportation Systems (ITS), focusing on how IoT technologies enhance efficiency, safety, and sustainability in modern transportation infrastructures.

Outline:

- Definition of Internet of Things (IoT).
- Importance of IoT in modern infrastructure.
- Introduction to Intelligent Transportation System (ITS).
- Systematic literature review to reveal drivers and challenges of IoT in ITS.
- Evaluation of the benefits and challenges of IoT in ITS.

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AUTHOR'S DECLARATION

I declare:

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Samuel Yeboah Afram b.o.h.

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ABSTRACT

This research investigates the usage of IoT for ITS to improve urban traffic management and reduce congestion. The research addresses four key objectives: (1) analyzing the current traffic management practices using ITS, (2) identifying areas requiring improvement, (3) proposing IoT-based solutions, and (4) assessing the potential of IoT-driven technologies to optimize traffic flow in urban areas. The subject has been thoroughly studied through both quantitative and qualitative research methods. The qualitative research evaluated a systematic literature review of articles related to IoT and ITS, while the quantitative method utilized a questionnaire to understand end-users' perception about IoT in ITS.

KEYWORDS:

Internet of Things (IoT), Intelligent Transportation System, Smart Transportation, Traffic Management, Transportation Infrastructure, IoT Challenges.

NÁZEV:

Analýza konceptu internetu věcí se zvláštním zřetelem k inteligentnímu dopravnímu systému

ABSTRAKT

Tento výzkum zkoumá využití internetu věcí pro ITS ke zlepšení řízení městské dopravy a snížení kongescí. Výzkum se zaměřuje na čtyři klíčové cíle: (1) analyzovat současné postupy řízení dopravy pomocí ITS, (2) identifikovat oblasti vyžadující zlepšení, (3) navrhovat řešení založená na internetu věcí a (4) posoudit potenciál technologií založených na internetu věcí pro optimalizaci provozu v městských oblastech. Předmět byl důkladně studován pomocí kvantitativních i kvalitativních výzkumných metod. Kvalitativní výzkum hodnotil systematický literární přehled článků souvisejících s IoT a ITS, zatímco kvantitativní metoda využívala dotazník k pochopení toho, jak koncoví uživatelé vnímají IoT v ITS.

KLÍČOVÁ SLOVA:

Internet věcí (IoT), Inteligentní dopravní systém, Chytrá doprava, Řízení dopravy, Dopravní infrastruktura, Výzvy IoT.

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LIST OF ABBREVIATIONS AND SYMBOLS

ARIMA	Auto-Regressive Integrated Moving Average
CNN.	Convolutional Neural Network
DLT.	Distributed Ledger Technology
FTPG	Fine-grained Traffic Prediction Method
IoT	Internet of Things
ITS.	Intelligent Transportation System
LSTM	Long Short-Term Memory
ML	Machine Learning
SDN	Software-Defined Networking
SLoT	Social Internet of Things
STMP	Simple Mail Transfer Protocol
VANETs	Vehicle Ad-hoc Networks
V2I	Vehicle to Infrastructure
V2X	Vehicle to Everything
ZKRP	Zero Knowledge Range Proofs

INTRODUCTION

The exponential growth of the Internet of Things (IoT) has revolutionized various sectors by enabling the seamless interconnection of physical devices, sensors, and systems. This technological evolution has had a profound impact on healthcare, manufacturing, energy, and transportation. IoT enables devices to communicate and make autonomous decisions, leading to the development of intelligent infrastructures and services (Miorandi et al., 2012).

One of the most transformative applications of IoT is found within Intelligent Transportation Systems (ITS). ITS involves the use of advanced technologies to enhance the safety, efficiency, and reliability of transportation networks (Lee, Kim, & Varaiya, 2012). By integrating IoT into ITS, transportation systems can achieve real-time traffic monitoring, adaptive traffic control, predictive maintenance, and seamless vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication leading to smarter and more efficient urban mobility (Al-Kuwari et al., 2016).

The deployment of IoT-powered ITS has already shown positive impacts in many urban areas, offering solutions to critical issues such as traffic congestion, environmental pollution, and public safety. For instance, smart traffic lights, automated tolling systems, and IoT-based fleet tracking are becoming increasingly common, contributing to improved commuter experience and more sustainable urban development (Zanella et al., 2014).

Integrating IoT into transportation offers several advantages, but it also presents several technical, economic, and ethical challenges. Addressing issues like data security, user privacy, and the high cost of infrastructure upgrades is crucial to ensure the long-term viability and public trust in IoT-enabled transportation systems. Analyzing the underlying concepts and practical implementations of IoT in ITS is therefore imperative.

This study aims to critically examine the concept of Internet of Things (IoT) and assess its practical application in Intelligent Transportation Systems (ITS). By reviewing current technologies, real-world applications, and potential challenges, the study seeks to provide valuable insights into the role of IoT in shaping the future of smart transportation.

1. BACKGROUND OF STUDY

The IoT is a new megatrend in technologies that physically and digitally interconnects with each other via networks of devices, sensors, and systems using the internet. It enables components to communicate among themselves without human interference in data acquisition, exchange, and action; thus, it is of high relevance to modern urban infrastructure development. Key components of IoT include sensors, actuators, communication protocols, cloud platforms, and analytics tools, which together create a robust ecosystem capable of real-time monitoring, automation, and decision-making (Dubey & Yadav, 2024).

This interconnected ecosystem is integral to urban environments as it enhances sustainability, efficiency, and quality of life through diverse applications in areas such as transportation, energy management, waste disposal, and public safety (Razmjoo et al., 2022). For instance, IoT's integration with technologies like cloud computing and edge computing facilitates seamless interaction between heterogeneous devices, thereby optimizing urban infrastructure operations (Singh et al., 2019).

The concept of IoT goes beyond mere connectivity to encompass the sharing of information and support for innovative applications. For example, Social Internet of Things (SIoT) combines physical objects and information networks to provide reliable networking solutions, further expanding the potential of IoT in urban development (Roopa et al., 2019). Furthermore, the implementation of sophisticated communication technologies, including 5G, alongside analytical frameworks on the Internet of Things (IoT), facilitates scalability and interoperability, thereby mitigating issues associated with urban expansion and complexity (Alahi et al., 2023).

While IoT offers immense benefits, including real-time data-driven decision-making and enhanced resource management, its adoption in urban infrastructure also poses challenges. These include concerns about data privacy, security, and the need for standardized protocols to ensure interoperability across devices and systems (Ishaq & Shah Farooq, 2023). However, with continuous development in machine learning and artificial intelligence, IoT will be further integrated into the infrastructure in cities to make them much adaptive and responsive to the needs of its dwellers continuously (Ng et al., 2018).

By revolutionizing how urban infrastructure operates, IoT has become a cornerstone of modern smart city development, with its applications increasingly aligned with global sustainability goals, such as the United Nations Sustainable Development Goal 11 for sustainable cities and communities (Zeng et al., 2024).

1.1. Significance of IoT in City Infrastructure and Development

Internet of Things (IoT) has emerged as a transformative force in urban development, fundamentally reshaping how cities operate and grow. With the rising global population and accelerated urbanization, IoT offers innovative solutions to enhance urban efficiency, sustainability, and quality of life (Alahi et al., 2023). By enabling interconnected networks of devices, IoT facilitates real-time data collection and analysis, providing the foundation for smarter and more responsive urban infrastructure (Zeng et al., 2024).

IoT is important in solving urban problems and ways of bringing efficiency and sustainability. For example, in a smart city, IoT-based systems optimize energy use, adequately dispose of waste, and even check environmental parameters like air and water quality. According to (Razmjoo et al. 2022), it detects pollutants such as CO_2 and sulfur oxides using IoT sensors, which helps cleaners build an eco-friendly urban environment. The adoption of Green IoT (G-IoT) in sectors like green computing and waste management further highlights its role in fostering cleaner production and environmental protection (Ullah et al., 2024).

IoT significantly enhances urban residents' quality of life by enabling smart infrastructure and services. Applications in public safety, smart homes, and intelligent transportation systems improve convenience and security while reducing congestion and travel times (Razmjoo et al., 2022). For example, IoT-powered smart parking solutions help drivers find available spots, reducing stress and fuel consumption. Additionally, IoT's integration with Artificial Intelligence (AI) allows cities to analyze vast datasets, paving the way for advanced urban planning and management systems (Alahi et al., 2023). These technologies collectively create more comfortable, sustainable, and productive urban environments, transforming cities into thriving ecosystems (Ishaq & Shah Farooq, 2023).

Smart cities worldwide are integrating IoT technologies to revolutionize urban management and service delivery. For instance, Barcelona has implemented IoT-driven solutions across multiple sectors, including smart parking, waste management, and public transportation. Sensors installed in parking spaces guide drivers to available spots, reducing congestion and emissions, while IoT-enabled waste bins optimize waste collection schedules (Razmjoo et al., 2022). Similarly, Singapore's Smart Nation project utilizes IoT and big data to enhance urban planning and environmental monitoring, such as real-time air quality and flood sensors, which improve disaster preparedness and response (Zeng et al., 2024).

In India, the Smart Cities Mission incorporates IoT into traffic management and smart lighting systems. For example, IoT-enabled adaptive streetlights in Pune conserve energy by dimming during low traffic periods. These examples illustrate how interconnected IoT systems streamline operations, enhance resource utilization, and contribute to smarter, more sustainable urban development (Ishaq & Shah Farooq, 2023).

Improvement in public safety is also ensured using IoT-based surveillance and emergency response systems. Cities that have started using IoT to check crimes, such as video analytics and predictive policing, are showing better outcomes regarding security concerns (Alahi et al., 2023).

The IoT in healthcare facilitates telemedicine and remote monitoring of patients, especially needed in the post-pandemic situation. Smart waste management maintains cleaner environments because waste level monitoring and efficient collection systems track waste disposal on time. (Ullah et al., 2024). In figure 1 depicts the collective network performance of IoT in urban development entailing how beneficial its implementation will have on cities and end-users alike.

IoT adoption in smart cities fosters innovation, promotes sustainability, and improves the lives of citizens. By showcasing tangible benefits, these developments demonstrate the potential of IoT to create resilient and efficient urban environments.

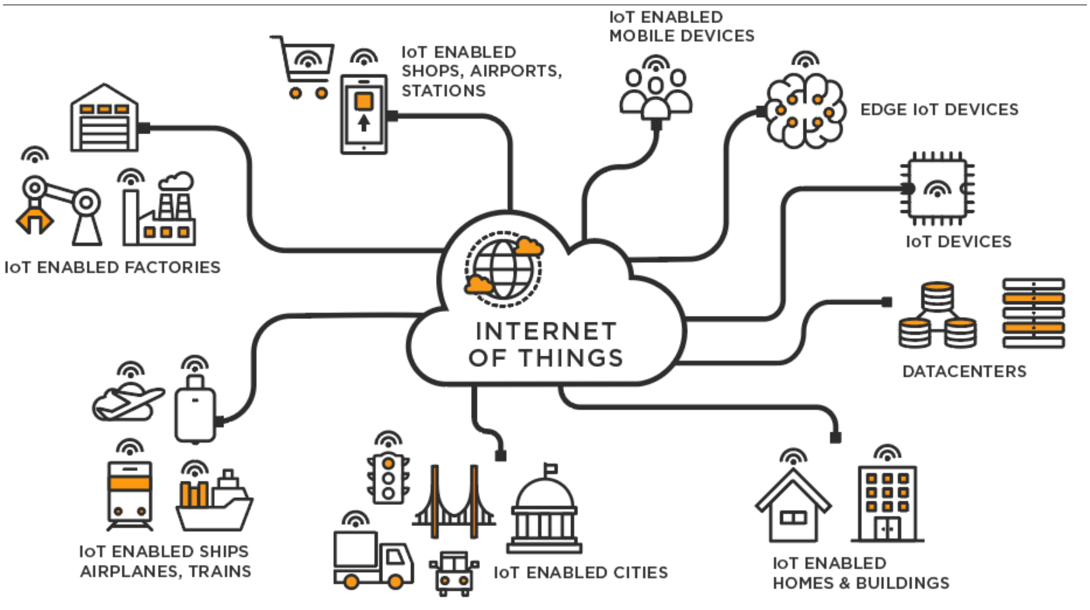

Figure 1: IoT use in daily life. *Source: (Rachman et al., 2024)*

1.2. Problem Statement

Rapid urbanization has brought about several challenges in managing traffic. One of the primary effects is the increase in population density and vehicle populations on the roads, leading to congestion. This congestion often occurs because city growth precedes infrastructure growth, resulting in overcrowded streets and longer travel times. Economies like New York and Mumbai suffer significant losses due to wasted fuel and man-hours due to congested roads. (Razmjoo et al., 2022).

These are further exacerbated by inefficient systems of traffic management and the inability of obsolete technologies to respond to shifting volumes of traffic. Poorly coordinated traffic signals and a lack of real-time monitoring result in increased emissions, wasted energy, and dissatisfied commuters. The economic and ecological consequences of such inefficiencies pressingly call for novel solutions to optimize the flow of traffic flowing through cities (Zeng et al., 2024).

Insufficient infrastructure is one of the biggest challenges faced in managing urban traffic. Many cities still rely on systems from some generations ago that are not effectively designed to handle current needs. Inefficient systems of traffic regulation, combined with poorly maintained roads and limited public transportation options, are major issues for effective mobility (Alahi et al., 2023).

A major concern is the increasing density of vehicles on the roads. While urban populations are growing at phenomenal rates, there has been unprecedented pressure on the current road infrastructure due to a boost in private vehicle ownership. Recent studies evidence that vehicle density in urban areas has increased by over 50% in the last decade, more than what the urban infrastructure was ever designed to handle (Ullah et al., 2024).

These are part of complex challenges that require innovative approaches toward the management of traffic. Through drivers such as IoT, big data, and artificial intelligence, ITS have appeared to be a very promising solution. ITS technologies, including real-time monitoring, predictive traffic analysis, and adaptive signal control, hold great potential for significantly enhancing the flow of traffic and reducing congestion (Razmjoo et al., 2022).

Advanced technologies ensure decreased travel time, reduced environmental impact, and increased levels of safety. An example includes how a smart city like Singapore or Barcelona employed IoT-powered city-wide traffic management systems that manifest a massive reduction in congestion and gas emissions by providing smart traffic lights and dynamic routing systems

(Ishaq & Shah Farooq, 2023). Urbanization is on a constant rise, and embracing these innovations plays a crucial role in developing green and effective urban mobility.

1.3. Research Objectives

1. Analyzing existing traffic management practices using ITS.
2. To discern regions that require enhancement within existing systems.
3. Suggesting new approaches based on IoT technologies
4. Evaluating the potential of IoT-driven solutions to optimize traffic flow and mitigate congestion in urban areas.

1.4. Investigative Questions

1. How effectively does the ITS handle the traffic today?
2. Which aspects of the modern traffic management system need improvements?
3. How will the IoT technologies be adopted in proposing new solutions for traffic management?
4. What impact will these new IoT-based interventions have on traffic movement and congestion dynamics in cities?

2. LITERATURE REVIEW

2.1. IoT and ITS Overview: Basic Concepts and Definition

2.1.1. Internet of Things (IoT) in Traffic Management

The Internet of Things (IoT) is a transformative technology that connects physical devices via the internet to enable data observation, sharing, and intelligent decision-making. In traffic management, IoT plays a crucial role in reducing congestion, enhancing road safety, and promoting environmentally friendly transportation solutions. IoT-based traffic systems utilize wireless communication technologies and advanced sensing tools to monitor real-time traffic conditions, efficiently manage traffic flow, and proactively address incidents (Agarwal et al., 2021).

IoT-enabled traffic management systems often rely on frameworks such as Vehicle Ad-hoc Networks (VANETs) and vehicle-to-everything (V2X) communications, which enhance road awareness by enabling dynamic rerouting and adaptive traffic signal adjustments based on real-time data (Dui et al., 2024).

Despite these advancements, the implementation of IoT in traffic management presents several challenges. Scalability remains a significant issue as the number of connected devices grows, making seamless integration increasingly complex. Security vulnerabilities are also prevalent, with IoT systems prone to cyberattacks that risk data breaches and system manipulation. Additionally, energy management is a concern, as IoT devices require efficient power consumption strategies to ensure long-term sustainability.

Frameworks such as Software-Defined Networking (SDN) have been proposed to address these challenges, offering enhanced scalability, security, and energy efficiency. These align with the solutions proposed in this study, such as decentralized systems and encryption protocols, to enhance traffic management systems. A comparison of IoT methodologies across urban areas reveals varying levels of scalability and applicability. While advanced IoT frameworks are extensively used in developed regions, resource constraints in developing areas limit widespread implementation. This highlights the need for scalable, cost-effective IoT solutions that can be adapted to diverse urban contexts.

2.1.2. Overview of ITS – Intelligent Transportation Systems

Intelligent Transportation Systems (ITS) represent the integration of information and communication technologies with roadway infrastructure and vehicles to enhance the efficiency, safety, and sustainability of transportation networks. Through adaptive traffic signal control, real-time incident management, and collaboration with smart city initiatives, ITS enables the collection and analysis of real-time data, which informs decision-making and improves overall system performance (Pradhan, 2021).

Globally, ITS applications have demonstrated significant benefits in addressing traffic congestion and improving road safety. For example, adaptive traffic signal systems in developed cities have successfully reduced delays, improved fuel efficiency, and decreased emissions by optimizing signal timing to match traffic demand (Creb et al., 2024). Additionally, ITS technologies that leverage roadside infrastructure provide drivers with real-time data, enhancing decision-making and reducing accident rates.

However, ITS faces notable challenges that hinder its widespread adoption. The integration of advanced sensors and IoT technologies with legacy systems often results in inefficiencies. Decentralized data dissemination is another obstacle, as secure sharing of data between devices and stakeholders is crucial to prevent unauthorized access or data manipulation. Moreover, ITS implementation requires significant investment in infrastructure and technology, posing a barrier for regions with limited resources.

While ITS systems in advanced economies have achieved scalability and reliability, developing regions face hurdles in integrating new technologies due to cost and infrastructure constraints. Addressing these gaps requires innovative solutions, such as leveraging cloud-based platforms and edge computing, to improve scalability and accessibility. Integrating IoT-driven methodologies into ITS provides an opportunity to overcome these challenges, enabling traffic flow optimization and more efficient congestion management. This approach aligns with the solutions proposed in this research, ensuring a sustainable and intelligent transportation system.

2.1.3. Key Concepts in IoT and ITS

The convergence of IoT and ITS introduces several key concepts central to modern traffic management. IoT enhances ITS capabilities by enabling vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communication, which are essential for real-time traffic optimization and safety. For instance, ITS leverages IoT to manage traffic flow dynamically, optimizing route choices and preventing congestion propagation (Dui et al., 2024).

Additionally, ITS frameworks emphasize system architecture, including the interaction between software and hardware elements, to ensure seamless integration and operation. The physical and functional architecture of ITS must accommodate emerging trends such as blockchain-based data security and plug-and-play mechanisms for scalability (Daeibal et al., 2019). By addressing these architectural and technological needs, IoT and ITS collectively contribute to smarter and more sustainable urban transportation systems.

2.2. Technical Ingredients: Machine Learning

Machine learning (ML) is fundamentally transforming intelligent transportation systems (ITS) through the application of sophisticated algorithms aimed at improving traffic management, forecasting congestion, and optimizing urban mobility. By discerning patterns within extensive datasets, ML-driven systems facilitate precise traffic predictions and informed decision-making, thereby enhancing the overall effectiveness of transportation networks (Abbasi and Goldenholz, 2019; Pacheco et al., 2019).

2.2.1. Machine Learning Applications in ITS

Examples of ITS ML applications include traffic prediction, congestion management, and system optimization. The algorithms being used by these systems include multilayer perceptron-neural networks, support vector machines, and deep learning models that may lead to adaptive and intelligent decision-making processes.

Supervised learning methodologies, such as NN-ARIMA, have shown considerable advancements in the prediction of traffic states, achieving accuracy enhancements between 8.9% and 13.4% through the integration of neural networks with ARIMA analysis (Ma et al., 2020). Likewise, clustering and reinforcement learning strategies proficiently categorize traffic patterns and regulate fluctuating roadway conditions, highlighting the adaptability of machine learning in tackling urban transport issues (Berlotti et al., 2024; Nallaperuma et al., 2019).

2.2.2. Machine Learning Based Traffic Forecasting

Traffic forecasting is one of the crucial tasks in ITS, enabling proactive methods for congestion reduction and smart routing. The most advanced machine learning methods, above all, deep learning, are competent in finding spatiotemporal dependencies along roads, thus allowing one to make more accurate traffic predictions and find adaptive routes more effectively. (Yin et al., 2022). Two-level ML frameworks-based on unsupervised clustering with supervised learning-effectively predict traffic flows even without sensor data, thus being scalable for urban areas (Berlotti et al., 2024).

In the figure 2 below, the workflow for machine learning-based traffic forecasting in Intelligent Transportation Systems (ITS) begins with analyzing data collection from various sources, including IoT devices, sensors, GPS, and mobile apps (Spiceworks, 2024). This collected data undergoes preprocessing to clean, organize, and standardize it for analysis (Zhang et al., 2024). Subsequently, important features such as time, location, weather, and events are extracted to enhance the model's performance (Singh et al., 2024). Next, deep learning models, including RNNs, LSTMs, CNNs, and GNNs, are trained on the prepared data to learn traffic patterns (Kumar and Patel, 2024). These models are then utilized for predicting traffic flows and estimating variables like congestion levels, vehicle speed, and travel time (Chen et al., 2024). Finally, the predictions support adaptive routing, enabling real-time adjustments to optimize traffic management, reduce congestion, and improve overall transportation efficiency (Zhao et al., 2024). Each stage plays a crucial role in ensuring accurate forecasting and effective traffic optimization.

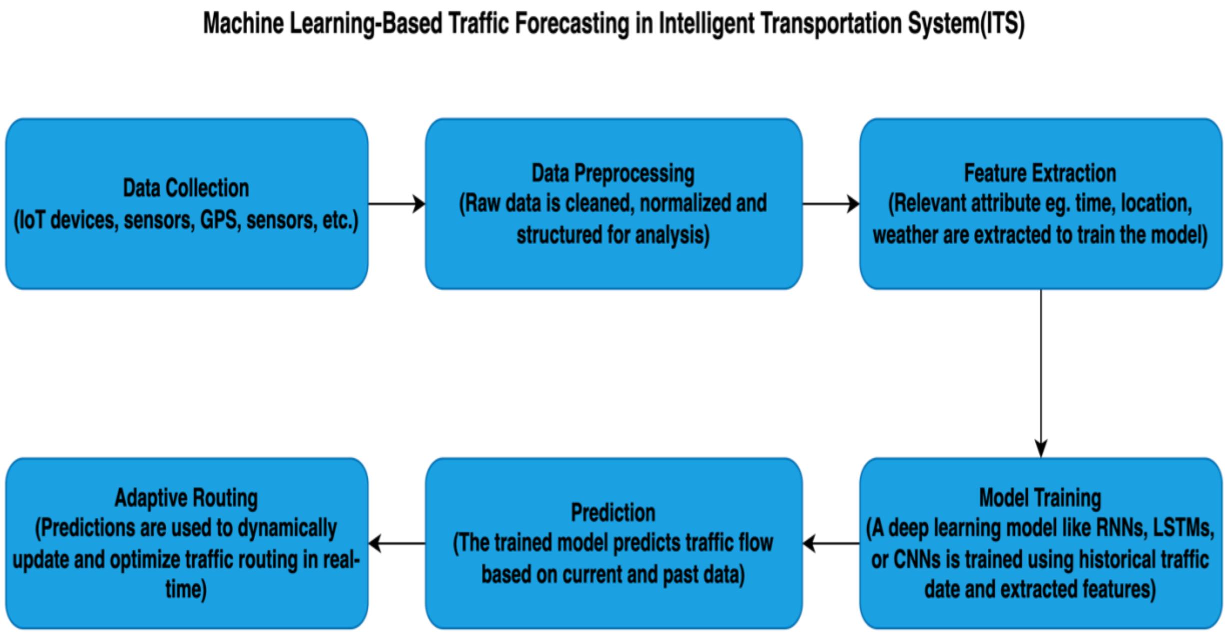

Figure 2: Machine Learning Based Traffic Forecasting in ITS *Source: Authors creation*

2.2.3. Machine Learning Applied to Traffic Management: Case Studies

Proof that machine learning research in traffic management shows the ability to transform urban traffic systems came from an integrated Simple Mail Transfer Protocol (STMP) that utilized deep learning with reinforcement learning in more than 190 million historic traffic records in Victoria, Australia. It accurately predicted traffic flow, incidents that do not recur, improved the plans for traffic control by commuter sentiments analyzed, and data from social media sites were gathered (Nallaperuma et al., 2019)

2.3. Big Data Analytics for Traffic Management

Big data techniques are good at processing traffic data with the "four Vs": Volume, Velocity, Variety, and Veracity, enabling effective responses to dynamic traffic conditions. According to (D'Alconzo et al. 2019), scalable and real-time big data applications enhance network traffic monitoring, detect anomalies, and allow for quick reactions to unpredictable events.

2.3.1. Traffic Estimation and Prediction Using Big Data

Big data in ITS are mainly applied for traffic estimation and prediction, hence congestion reduction, improving travel efficiency. (Jiang and Luo, 2022) discuss the use of big data for estimation and prediction of the states of traffic using big data and advanced tools. The process helps in contributing to the improvement of operational efficiency.

(Fang et al. 2022) propose the Fine-grained Traffic Prediction Method, FTPG, which implements graph attention networks for predicting specific traffic metrics such as flow velocity and queue lengths at intersections. By capitalizing on these spatiotemporal dependencies, they can furnish appropriate and accurate traffic forecasts.

Furthermore, (Dommaraju et al. 2020) introduce the ECMCRR-MPDNL methodology, which is a deep learning framework that achieves an accuracy rate of 98% in predicting network traffic and thus proves important in big data for minimizing prediction inaccuracies.

The flowchart in figure 3 outlines a systematic process for leveraging big data to estimate and predict traffic conditions. It begins by collecting data from multiple sources such as GPS devices, IoT sensors, social media, weather reports, and historical traffic databases (Yuan, Zheng, and Xu, 2020). This data is ingested through real-time streaming or batch processing and stored in scalable storage systems like data lakes or NoSQL databases (Hashem et al., 2015). Following storage, data preprocessing is carried out to clean, transform, integrate, and geo-tag the datasets (Aggarwal, 2015). After preprocessing, the system splits into two main modules:

- Traffic Estimation Module:

Performs real-time traffic estimation by analyzing current conditions and visualizing congestion levels (Ghosh, Basu, & Ganguly, 2016).

- Traffic Prediction Module:

Uses machine learning or deep learning models, such as Long Short-Term Memory (LSTM) networks or ARIMA, to forecast future traffic scenarios based on real-time and historical inputs (Lv, Duan, Kang, Li, & Wang, 2015). Finally, the results are fed into a decision-making layer that delivers actionable outputs like route recommendations, traffic alerts, urban planning insights, and dashboards for traffic authorities (Wang, Yang, & Zhang, 2022).

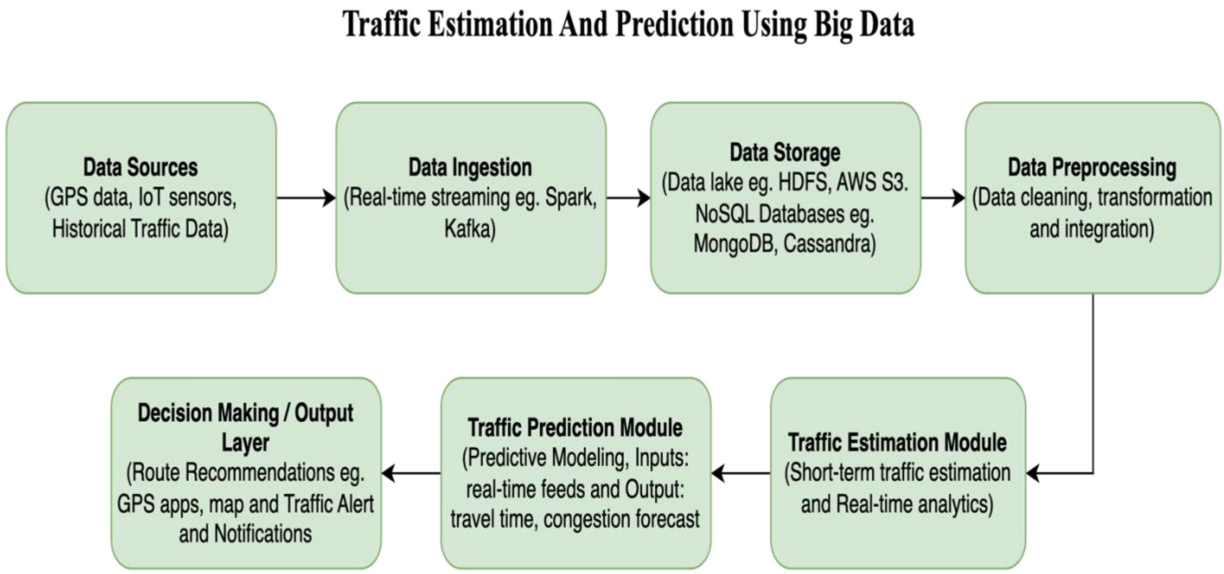

Figure 3: Traffic Estimation Using Big Data. *Source: Authors creation*

2.3.2. Big Data Applications to ITS

It contains big data analytics ranging from traffic flow prediction to public transportation planning, accident analysis, personal route optimization, and improvement in infrastructure safety. (Zhu et al. 2019, Kaffash et al. 2021) further detail some of the uses of big data in ITS: estimating travel time and route planning, rail transportation management, and improving vehicle safety.

In a nutshell, big data analytics is essential to ITS for developing creative solutions through ITS to improve the performance of urban traffic by accurate predictions and real-time decisions. Its wide applications range from traffic estimation to urban planning, including infrastructure safety, proving it crucial in solving modern transportation issues.

2.4. Distributed Ledger Technology in Intelligent Transportation Systems

The new generation of Distributed Ledger Technology has emerged to become a novel tool for ITS, with a guarantee of security, decentralization, and dependability in data handling. However, scalability and responsiveness are yet to be achieved as key challenges toward mass adoption.

FlexiChain 3.0 has been introduced as a Layer0 network tailored for Intelligent Transportation Systems (ITS), demonstrating its capacity to process 2.3 transactions per second while ensuring robust security for the Internet of Vehicles (IoV) (Alkhodair et al., 2023). By tackling the challenges posed by the substantial data influx from connected vehicles, FlexiChain illustrates the promising role of Distributed Ledger Technology (DLT) in facilitating responsive and dependable infrastructures within ITS.

(Zichichi et al. 2020) also pointed out that DLTs are used for creating, storing, and sharing the data emanating from users or vehicles devices by using immutability and traceability features. Applying the case studies of IOTA and Ethereum in their studies, they were able to identify the possibility of using DLTs in the ITSs, which needed further enhancements in response from infrastructure.

2.4.1. Blockchain Applications for Traffic Flow Management

Blockchain technology represents a particular application of DLT in managing traffic: problems that originate from data integrity, privacy, and real-time traffic monitoring. For instance, (Li et al. 2020) developed a blockchain-based traffic management system using permissioned networks along with the Zero-Knowledge Range Proofs (ZKRP) protocol, which could guarantee the integrity of data without the loss of privacy. The performance achieved by this system proved feasible for real-time applications in connected vehicle networks. (Yang et al. 2019) proposed the proof-of-event consensus mechanism, special for vehicular networks to validate the traffic events and build trust in the data that has been shared across the network. This method reduces misinformation and thus helps the monitoring of congestion proactively and enables autonomous driving.

From figure 4, Blockchain technology can significantly improve traffic flow management by offering decentralized, transparent, and secure solutions:

Blockchain Decentralized Traffic Data Sharing enables secure real-time data exchange, improving congestion management and route planning (Ali et al., 2019). Blockchain enhances V2X communication, automates smart traffic signals, and supports autonomous vehicle coordination.

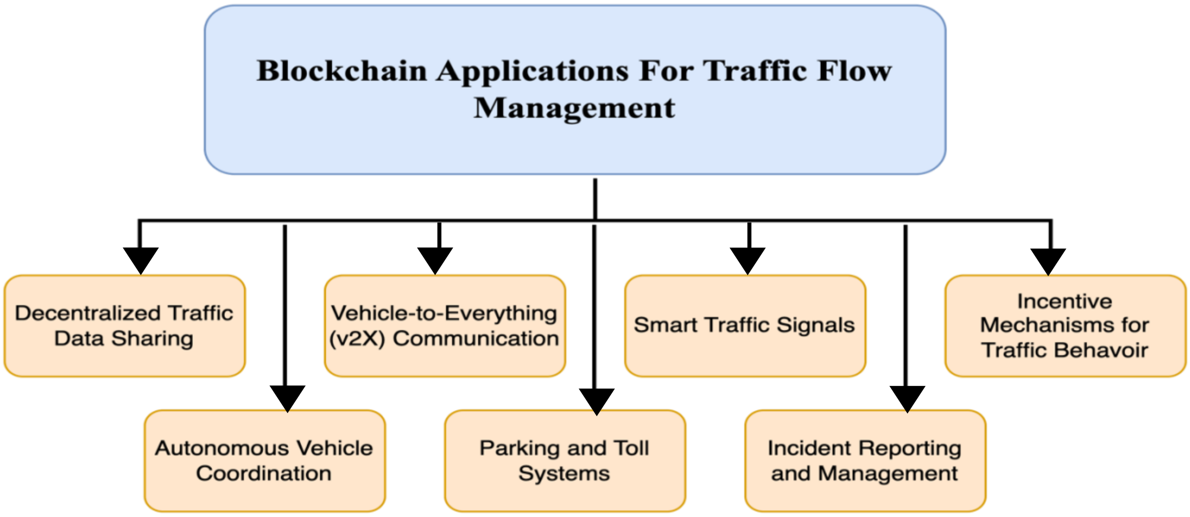

Figure 4: Blockchain Applications for Traffic Flow Management. *Source: Authors creation*

2.4.2. Enhancing ITS Security with Distributed Ledgers

Distributed ledgers form the backbone of ensuring the integrity, availability, and confidentiality of ITS data. (Kokoris-Kogias et al. 2020) presented the Calypso architecture, which leverages on-chain secrets to enable secure and auditable data management. Correspondingly, the architecture reacts to vulnerabilities of both permissioned and permissionless blockchains, therefore ensuring confidential and decentralized data management. This scheme enhances the transparency and safety of transactions without affecting their efficiency; hence, it is one of the most important instruments in the protection of computations within ITS. Collectively, these findings state how distributed ledger technology can revolutionize ITS into more functional and secure systems, despite open challenges in scalability, responsiveness, and adherence to regulations.

2.5. Comparative Table of Technologies in IoT-Based ITS

A summary of features, advantages and challenges of IoT-Based ITS technologies are outline in table 1 below.

Table 1: Description of IoT-Based ITS Technologies

Technology	Key Features	Advantages	Challenges
Machine Learning (ML)	Algorithms like SVM, NN-ARIMA, and reinforcement learning for traffic prediction and congestion management.	Accurate traffic forecasting; adaptability to dynamic conditions.	Limited scalability; computational resource demands.
Deep Learning (DL)	Neural networks and frameworks like CNN, LSTM, and graph neural networks for spatiotemporal data analysis.	High accuracy; ability to handle complex patterns; scalability for large datasets.	Requires significant computational power and large datasets for training.
Big Data Analytics	Processes large volumes of traffic data using the "four Vs" (Volume, Velocity, Variety, Veracity).	Real-time insights; effective anomaly detection; supports urban planning.	Data integration challenges; high infrastructure costs.
Distributed Ledger Technology (DLT)	Blockchain for secure, decentralized data sharing and traffic management.	High security; immutability; transparency.	Scalability and latency issues; high energy consumption.
IoT Frameworks	V2X communication, adaptive signal control, and smart sensors for real-time traffic management.	Proactive incident management; reduced congestion.	Interoperability issues: vulnerability to cyberattacks; high deployment costs.

2.6. Review of Case Studies: IoT Applications in Major Cities

2.6.1. IoT-Based ITS Implementations in Urban Areas

IoT-based ITS has been central to enhance urban sustainability, efficiency, and connectivity. These use real-time data and smart infrastructure in solving some city challenges. For instance, (Tamariz-Flores et al. 2018) presented an exemplary model IoT installation for parking space monitoring with a wireless sensor network, showing how inexpensive hardware combined with free software can support projects in developing regions for smart cities. (Kravchenko 2019) pointed out how IoT can change regular cities into smart cities by using smart services like traffic and resource management. But there are still big problems, such as issues with different systems working together, risks to data security, and the high cost of putting these systems in place.

These case studies illustrate opportunities and challenges. Even as smart city IoT applications hold the potential for improving the flow of traffic and the management of resources, challenges include risks emanating from hacking and slow acceptance of smart technologies by city governments. Whether the true potential of IoT in making cities more sustainable is realized depends on how well these challenges are overcome.

2.6.2. Case Studies of IoT in Traffic Management

Traffic management systems that use IoT technology have shown they can reduce traffic jams, improve road safety, and make travel times better. (Dui et al. 2024) suggested a new traffic control model that uses vehicle-to-everything (V2X) communication to manage congestion by using the best overall strategies, greatly improving how transportation systems work. (Lilhore et al. 2022) proposed an IoT-integrated ATM system the signals of which, using machine learning, would change dynamically depending on congestion and, in turn, reduce time spent traveling and enhance the journey experience.

Apart from controlling traffic flow, IoT systems also come in useful during emergencies. Lalitha and (Pounambal 2020) proposed an IoT-based smart city traffic management system that eases the movement of emergency vehicles using current information on road conditions regarding traffic signals and congestion. Similarly, (Hilmani et al. 2020) developed an intelligent traffic management system based on a wireless sensor network that informs the driver about the traffic condition of the road and where a parking place is available to avoid a delay, thus avoiding traffic congestion.

2.6.3. IoT-Based Smart Traffic Signal Control for Cities

Smart traffic control with IoT uses advanced programs, wireless sensors, and real-time information to solve city traffic problems. (Neelakandan et al. 2021) suggested a traffic prediction system based on IoT that uses the OWENN program and improved traffic control to reach 98.23% accuracy in finding busy traffic areas. This method showed major decreases in traffic jams and better use of resources.

Other new uses include combining Software-Defined Networking with the Internet of Things, as was suggested by (Rego et al. in 2018), whereby one could reduce delays by 33% in getting the emergency resources. Also, the Adaptive Traffic Management System was introduced by (Balasubramanian et al. in 2023) that has accident detection features and safe data dispatch for improving travel time, thereby increasing safety in cities.

Aggregated, these studies show how IoT might alter urban traffic management. IoT applications help reduce congestion, enhance the response to emergencies, and enable traffic forecasting; solutions keep getting better to meet today's city needs. In any case, compatibility, security, and cost remain key concerns that need steady progress if everybody is to use them effectively.

2.7. Gaps in Current Research

IoT can enhance ITS in manifold ways, while the complete dream still stays away from its full potential due to several limitations and challenges.

One of the fundamental problems is the devices' incapacity for proper communication, which is primarily caused using standards that interfere with platform interoperability (Kravchenko, 2019).

For this to be addressed, standard frameworks and communication protocols must be established and universally adopted, whereby one ecosystem of device interaction is facilitated.

IoT systems' susceptibility to data security breaches and privacy infringement is another source of concern. Unauthorized intrusion into private information and cyber-attacks undermine system reliability and users' trust (Lilhore et al., 2022). Advanced encryption techniques, blockchain-based data management frameworks, and strong cybersecurity architectures specific to IoT ecosystems can all help alleviate this.

Furthermore, these challenges are compounded, specifically in developing nations, by the prohibitive expense of IoT infrastructure deployment and the lethargic government adoption of smart services (Tamariz-Flores et al., 2018). Promoting public-private partnerships and embracing low-cost IoT solutions, like low-power wide-area networks (LPWAN), may lower expenses and stimulate wider acceptance.

IoT-based ITS will improve considerably by filling these gaps to provide efficient, secure, low-cost solutions. The enhancements will open doors for integrating high-level technologies like driverless vehicles into the transportation system, enabling real-time traffic management, and improving commuter safety.

2.7.1. Key Areas for Research

Even though the basic architecture for IoT-based ITS has been laid down, there are many aspects where considerable research is required. Firstly, interoperability issues can be overcome by developing some standardized communication protocols, which would make it quite easy for devices from different manufacturers to communicate with each other easily (Neelakandan et al., 2021). Second, it has been suggested that combining blockchain technology with sophisticated encryption techniques would improve data security and stop intrusions (Rego et al., 2018). Lastly, to lower financial barriers and encourage broad adoption, particularly in environments with limited resources, more affordable hardware and open-source software solutions are needed (Tamariz-Flores et al., 2018).

2.7.2. Technological and Methodological Improvements

Researchers have considered how machine learning (ML) and artificial intelligence (AI) can aid in developing more trustworthy IoT-based Intelligent Transportation Systems (ITS). With such aid, the systems will be able to predict prospective traffic patterns, thereby responding quickly to changes and using available resources judiciously (Lilhore et al., 2022). The advent of 5G networks also brings fast data transfer and reduced latencies, which are essential for real-time ITS applications (Dui et al., 2024).

To gain insights into effective practices and further improvement, it is beneficial to compare cities that have implemented different levels of IoT in their ITS. For example, cities like Tokyo, Japan, and Barcelona, Spain, are known for their advanced IoT implementations, while cities in developing regions may still be in the early stages of adopting these technologies. By analyzing and comparing such cities, valuable information can be gathered on good practices and strategies for scaling IoT in ITS (Hilmani et al., 2020). This comparison will help identify the benefits, challenges, and potential improvements needed to enhance city sustainability and transportation efficiency.

2.7.3. Directions of Research and Development

Future research should focus on addressing persistent challenges, such as enhancing the resilience of IoT grids against cyberattacks and establishing standardized communication protocols for devices (Kravchenko, 2019). Also, using distributed ledger technologies like blockchain could change data management considered by making it clear, trackable, and unchangeable in IoT-based ITS (Rego et al., 2018).

We also need teamwork between different fields. This means bringing together knowledge from urban planning, computer science, and behavioral studies to create intelligent transportation system solutions that are strong in technology and include everyone (Balasubramanian et al., 2023).

In essence, Internet of Things (IoT)-based Intelligent Transportation Systems (ITS) possess immense potential, but they require improvement in technology, methodologies, and collaborative research to address the challenges that arise. By working in these areas, we can pave the way for future progress that enhances the efficiency, security, and sustainability of urban transportation systems.

3. METHODOLOGY

3.1. Research Design

Quantitative research design, in this regard, focuses on the role and effectiveness of IoT-based ITS for urban traffic management. A structured questionnaire was developed and used for numerical and categorical data collection among the key stakeholders, which comprised city planners, traffic management professionals, and residents. This approach allowed the research to conduct a statistical test of the efficacy of the prevailing traffic management practices, challenges facing IoT adoption, and the probable benefits that may be achieved using IoT-based solutions. A structured questionnaire ensured consistency, objectivity, and repeatability in the data collection process, enabling the results to generalize to similar settings.

3.2. Data Collection

3.2.1. Questionnaire-Based Data Collection

Quantifiable data of views on various aspects of IoT-based ITS were captured through a structured questionnaire. The structured questionnaire contained six sections: Demographic Information, Existing Traffic Management Practices, Identification of Improvement Areas, Potential of IoT in Traffic Management, Suggestions about Future Improvements, and Closing Questions.

The demographic section outlined the respondents' role, geographical location, and experience about IoT-based ITS. The information herein served to provide background understanding for the responses to enable the comparison between different stakeholder groups. The section evaluates the effectiveness of existing systems for traffic management, awareness of IoT technologies for the same purpose, and identification of main challenges facing traffic such as congestion, accidents, and inadequate infrastructure.

The section Identifying Areas for Improvement identified various aspects that require improvement in the IoT-based ITS, considering scalability, interoperability, data security, and cost-effectiveness. Other major reasons that hamper the integration of IoT in ITS applications are the extremely high costs of implementation, lack of technical experts, and inadequate government support.

The section also assessed the perception of the respondent about the level to which IoT can optimize the flow of traffic, reduce congestion, and make the roads much safer. Furthermore, this section has assessed those most valuable benefits of IoT in reducing travel time, accidents, improving environmental outcomes, and improved public transport integration.

Suggestions for Future Improvements: In this section, the respondents had given ideas about the extra facilities they wanted in IoT-based ITS, including incident detection in real time, analytics that would have predictive qualities, and much better cybersecurity measures. This section then discussed recommendations for policy and stakeholders regarding more funding, clearly defined rules and regulations, and public-private partnership in supporting the adoption of IoT.

Finally, Closing Questions allowed the respondents to make comments or provide some recommendations on IoT-based ITS, or to state opinions about their further involvement in these studies.

3.3. Methods of Analysis

3.3.1. Statistical Analysis Framework

Descriptive and inferential statistical analyses were conducted on data collected to ascertain the IoT-based ITS challenges and opportunities that would help draw on its improvement to effectiveness. Various KPIs used in the measurement of performance implementation of IoT-based ITS include congestion level of the traffic flow, journey time reduction, safety on the road improved, and perception of the public toward IoT.

Descriptive statistics were used to summarize the response distribution, therefore giving an overall view of general trends in responses on IoT awareness, effectiveness of traffic management, and perceptions among stakeholders. In this respect, the measures of frequency distribution, percentages, means, and standard deviation were used for questions with the Likert scale and multiple choices.

The correlation analysis was done to identify the relationships between variables, such as the level of awareness about IoT and perceived improvement in traffic efficiency. This helped in finding out whether familiarity with IoT-based ITS influenced opinions on its effectiveness.

Regression analysis was conducted to determine how different factors were affecting the potential for traffic optimization, including public engagement, government support, and the levels of IoT adoption. This provided quantitative evidence on which factors played the most significant role in the successful integration of IoT into traffic systems.

A comparative analysis was performed to determine how the response varied due to demographic factors, such as the difference in perspective among city planners, traffic management professionals, and urban residents. This helped ascertain whether different groups of stakeholders are showing varying levels of support or concern regarding IoT-based ITS.

3.4. Justification for Methodology

Quantitative methods are preferred in this research study since they objectively measure and statistically validate trends and relationships in the adoption of IoT-based ITS. As opposed to qualitative methods, which depend on subjective perceptions, quantitative approaches will provide empirically valid, generalizable, and replicable findings. A structured questionnaire further ensured that the data was collected in a standardized manner, hence making accurate comparisons across different urban settings and stakeholder groups possible.

In fact, the statistical methods used provide fact-based insight into the effectiveness and future potential of IoT in traffic management to inform policymakers, urban planners, and technology developers. The structured format allowed this paper to be in a format where the collected data was analyzed systematically to give actionable recommendations on how to better implement IoT-based ITS and meet the key challenges.

4. RESULTS

4.1. Demographic Analysis

The demographic analysis has, therefore, provided the profile of the respondents in terms of their roles and geographic distribution, which was very important in contextualizing where the study was conducted. Results are described as frequency counts with their percentage expressions to make sure that clear, comprehensive, and easily interpretable information concerning the sample population is provided.

4.2. Role of Respondents

The main roles the respondents fell into were three: urban residents, traffic management professionals, and city planners. The distribution of the roles is as shown in Table 2.

4.2.1. Distribution of Respondents by Role

The structure of the sample is such that, as presented in Table 2, the highest number of respondents was from urban residents, totaling 77.5%. The next highest proportions were those of traffic management professionals and city planners, respectively, at 13.3% and 9.2%. This ensures a balance whereby the study captures perspectives from both professionals and end-users of IoT-based ITS.

Table 2: Role of Respondents

Role	**Frequency**	**Percentage (%)**
Urban Resident	93	77.5
Traffic Management Professional	16	13.3
City Planner	11	9.2

4.3. Geographic Distribution

Table 3 gives the distribution of respondents according to geographic regions. The sample is drawn from six different regions and hence effectively represents urban areas.

4.3.1. Geographic Distribution of Respondents

It follows from Table 3 that the Prague Region is most heavily represented, with 20.8% of the total number of respondents, followed by the Brno and Pardubice Regions, each accounting for 17.5% of the sample. Hradec Kralove comprises 15.8%, Plzen 15.0%, and the Ostrava Region 13.3% of the respondents. This dispersion is important to ensure that the findings are not biased toward any one region but, in fact, reflect a range of urban contexts and issues.

Table 3: Distribution based on region

Region	Frequency	Percentage (%)
Prague Region	25	20.8
Brno Region	21	17.5
Pardubice Region	21	17.5
Hradec Kralove	19	15.8
Plzen	18	15
Ostrava	16	13.3

4.4. Effectiveness of the Current Systems

In this manner, opinions on the effectiveness of traffic management systems were gathered. As depicted in Figure 5, a significant portion of respondents, approximately 30.8%, rated the systems as “slightly effective,” while 27.5% perceived them as “not effective.” Only 23.3% and 18.3% of the respondents rated these systems as “moderately effective” and “very effective,” respectively.

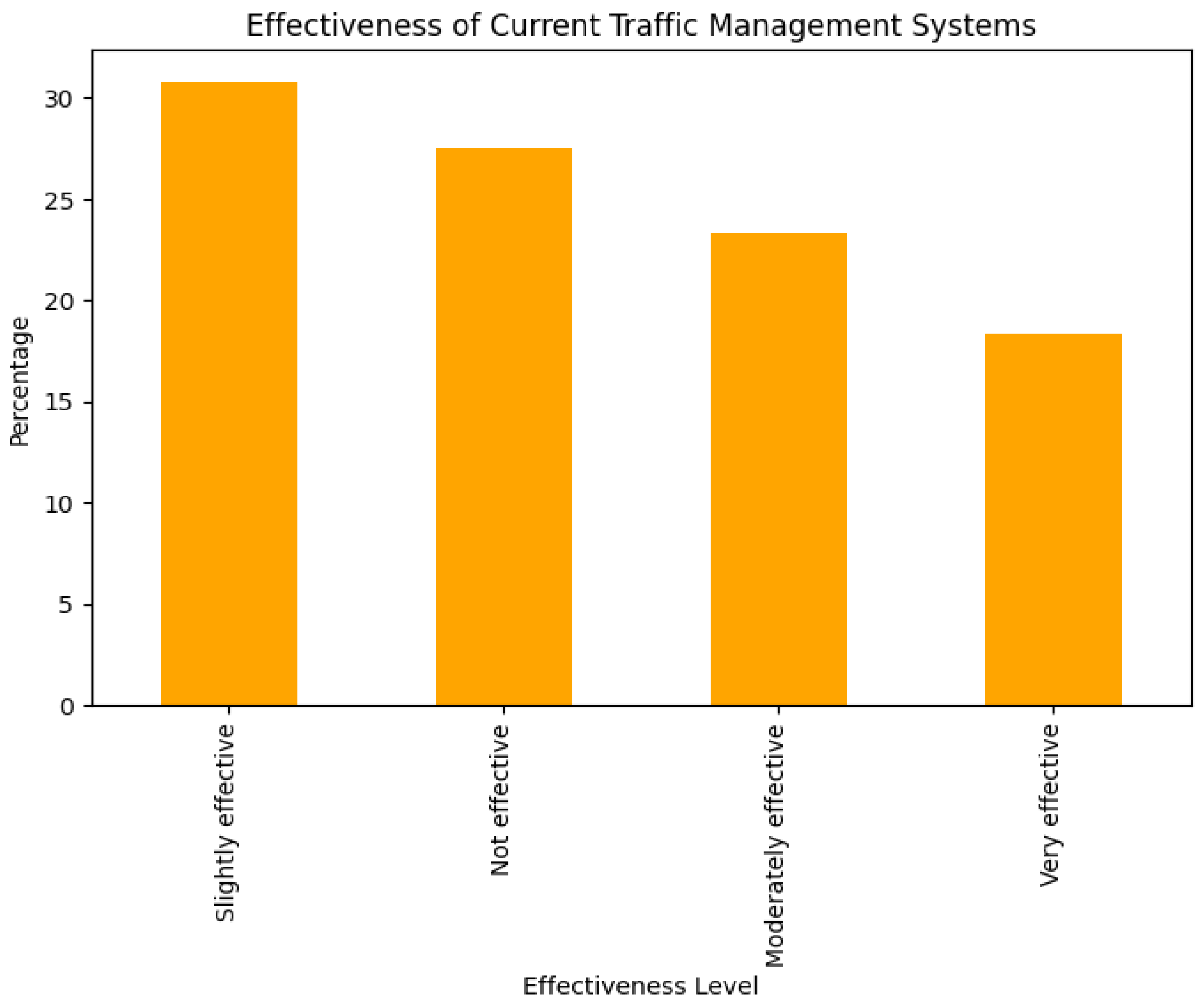

Figure 5:Perceived Effectiveness of Current Traffic Management Systems Source: Authors creation

These findings denote that there is quite a latitude for improvement within the current structures of traffic management, since 58.3% rated them "slightly effective" or "not effective."

4.5. Awareness of IoT Technologies in Traffic Management

It also gauged the awareness of the respondents about IoT technologies being applied in traffic management. Figure 6 shows that a plurality of the respondents, 43.2%, were "not sure" as to whether IoT technologies are used in their area. Another 32.3% of the respondents reported "No" as to the application of IoT in traffic management, while only 24.5% responded "Yes".

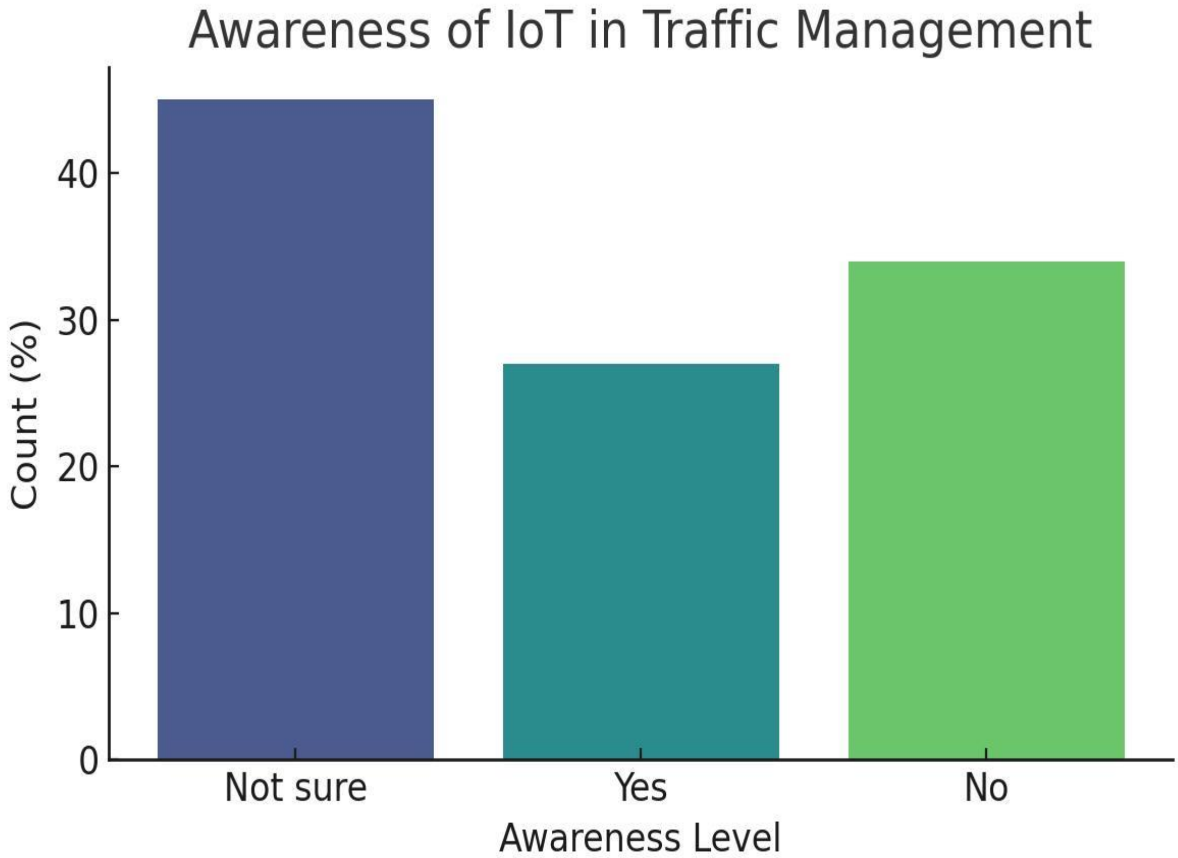

Figure 6: Awareness of IoT Technologies in Traffic Management *Source: Authors creation*

The low level of awareness among the respondents stands as proof that there is an urgent need to educate the public more on the benefits accruable from, and the application of IoT ITS.

4.6. Potential of IoT to Optimize Traffic Flow

Another related area of research was the ability of IoT to streamline and manage traffic. As per Figure 7, there has been a divided opinion on this matter. While 40.0% of the respondents believed that IoT could significantly optimize traffic flow, 19% thought it could optimize traffic moderately, and 11.5% believed it could not optimize traffic at all. On the other hand, 29.5% felt that IoT could help optimize traffic slightly.

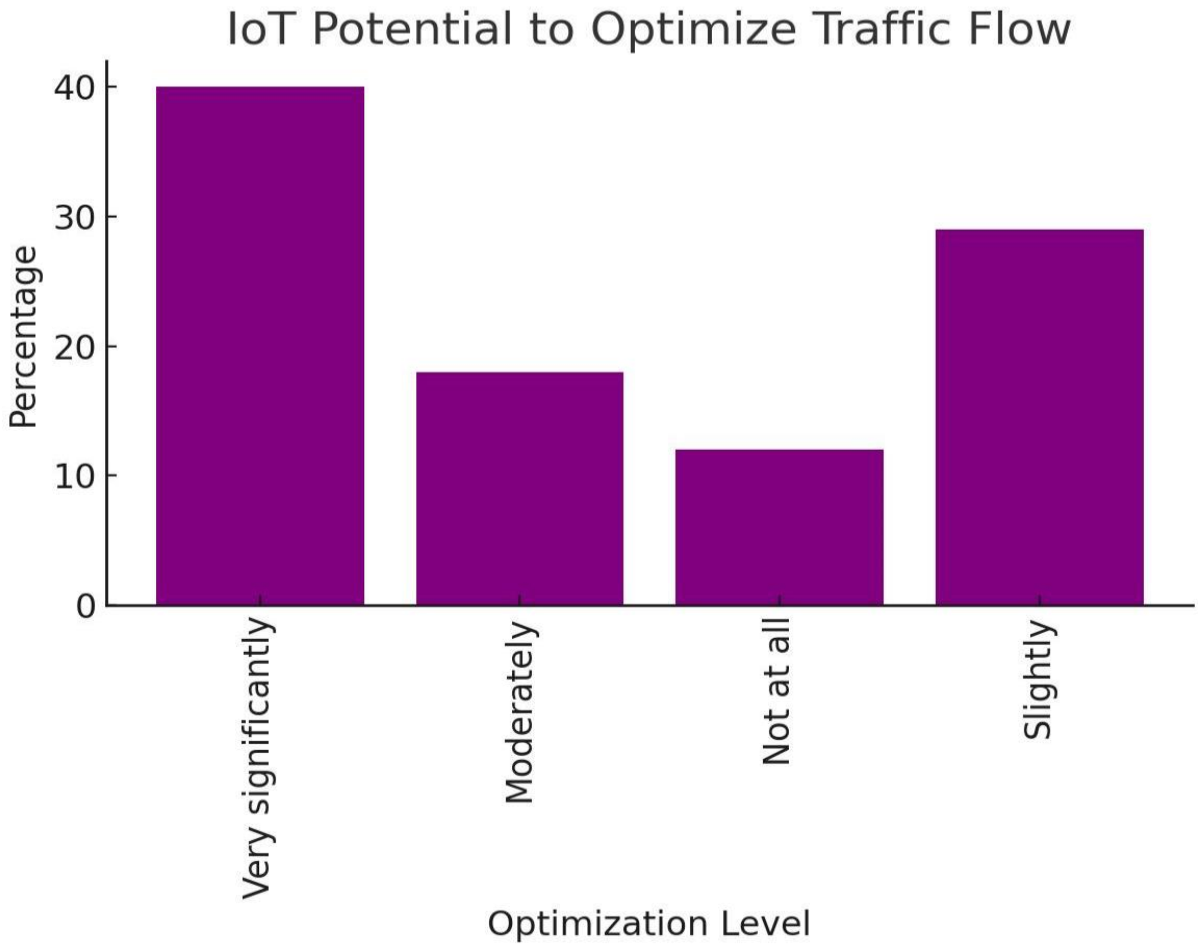

Figure 7: Perceived Potential of IoT to Optimize Traffic Flow *Source: Authors creation*

These results depict a mixed perception of the potential of IoT, as a significant portion of the respondents are still skeptical whether it can cause any major difference in traffic flow. This underlines that the tangible benefits of IoT-based ITS should be demonstrated through pilot projects and case studies.

4.7. Key Benefits of IoT-based ITS

Many respondents identified multiple benefits of IoT-based ITS. These benefits include improved road user experiences, reduced traffic accidents, shorter travel times, improve traffic management, and reduced fuel consumption and emissions.

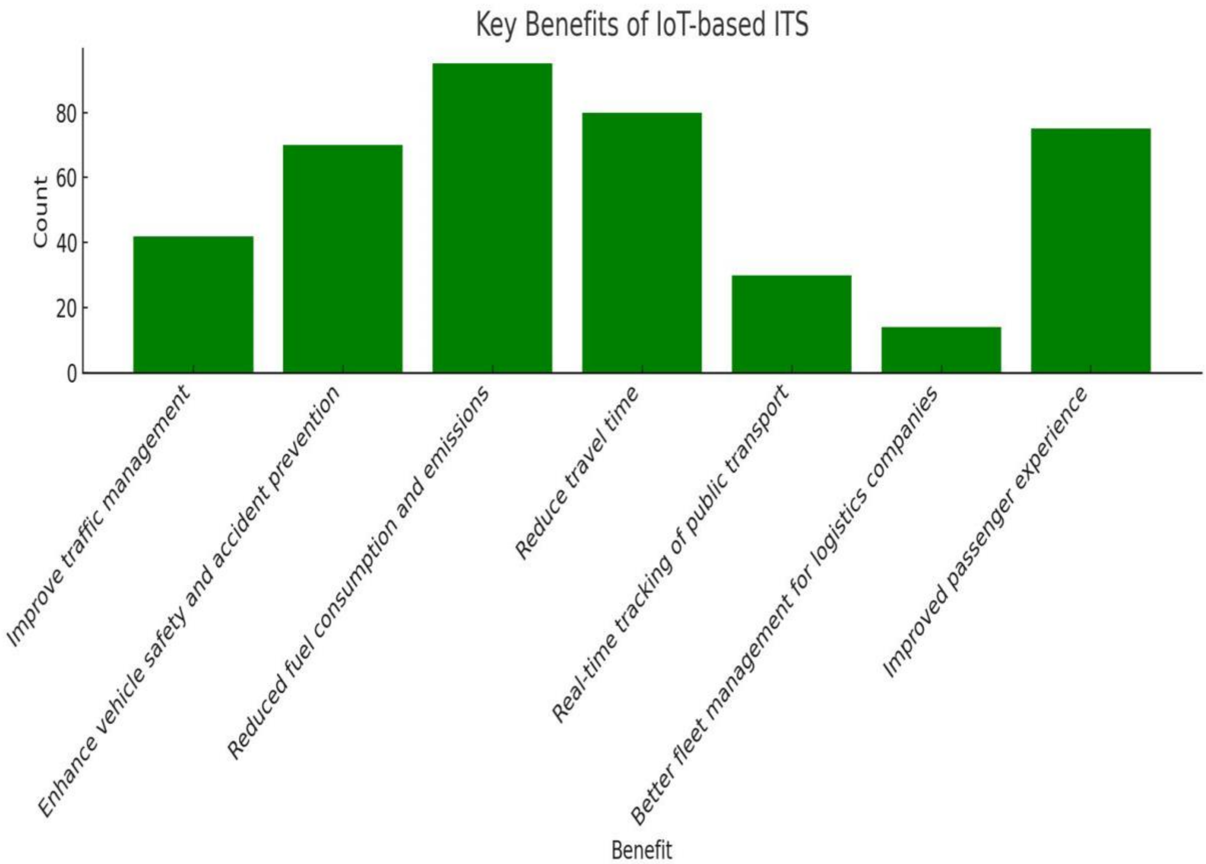

Figure 8: Key Benefits of IoT-based ITS *Source: Authors creation*

According to Figure 8, reduced fuel consumption emerged as the single most significant benefit, as reported by 93 respondents. It was often accompanied by other advantages, such as reduced travel time and fewer traffic accidents. Reduced travel time was the second most important benefit, mentioned by 80 respondents. It was frequently combined with enhanced vehicle safety, accident prevention, and improved passenger experiences.

Improve traffic management was recognized as a separate benefit by 42 respondents, but it was more commonly mentioned in conjunction with other benefits, such as real-time tracking of public transport and enhanced passenger experiences. Real-time tracking of public transport was noted as a standalone benefit by 30 respondents, but it was also frequently associated with improved experiences for road users and reduced travel time. In contrast, better fleet management for logistics companies was the least recognized benefit, with only 14 respondents mentioning it.

The multifaceted potential of IoT-based ITS in addressing urban traffic management challenges is evident in the benefits it offers. For instance, respondents highlighted the synergistic effects of reduced travel time and enhanced road user experiences, as well as the combined impacts of fewer traffic accidents and improved traffic management.

These findings highlight the multi-dimensional and interrelated benefits of IoT-based ITS, thus indicating that its implementation is likely to result in significant enhancement of traffic management, user satisfaction, and environmental sustainability.

5. DISCUSSION

5.1. Effectiveness of Current Traffic Management Systems

The survey results revealed that a substantial 58.3% of respondents perceived current traffic management systems as either “slightly effective” or “not effective.” In contrast, a smaller percentage of 23.3% and 18.3% rated these systems as “moderately effective” and “very effective,” respectively. These observations underscore the substantial room for improvement in the existing traffic management systems.

Such a claim is supported in a study conducted by (Lilhore et al. (2022), in which an Adaptive Traffic Management System with IoT technology and integration with machine learning reduced congestion and increased efficiency in smart city travel significantly. Authors argued that conventional approaches in controlling traffic have failed to respond effectively to urban traffic's growing requirements—a failure that mirrors respondents' poor assessments of current systems' effectiveness in terms of performance.

(Avatefipour and Sadry 2018) countered that conventional approaches in controlling traffic, including static traffic lights and radio-frequency identification (RFID), cannot respond effectively to current urban traffic requirements, and therefore, integration with IoT technology is imperative. In a similar stance, a study conducted by (Muzzini and Montangero 2024) showed an auction-based coordination model for controlling traffic lights outpaced traditional fixed-time controls in terms of reduced waiting times and overall trip times. In contrast to such high-tech IoT implementations, our survey showed that most current systems have yet to implement such cutting-edge technological capabilities. Such a contrast could shed light on why a high proportion of respondents rated a high proportion of such systems as not effective, or even in no case effective at all.

5.2. Awareness Level of IoT Technologies in Traffic Management

The respondents' awareness level for IoT technologies showed significant discrepancies. 43.2% of respondents showed uncertainty about IoT use in their immediate environment, 32.3% showed a lack of explicit awareness, and 24.5% showed familiarity with IoT-related applications relevant to traffic management. This lack of awareness about IoT is a significant barrier for effective IoT-facilitated Intelligent Transportation Systems (ITS) adoptions.

As such, these observations concur with similar studies that have captured a persistent awareness and comprehension deficit for key stakeholders regarding IoT's transformative impact in traffic management (Masek et al., 2016; Lilhore et al., 2022). Several studies have pinpointed numerous complex integration and infrastructure-related challenges for root causes of such unawareness. For instance, (Bratulescu et al. 2023 and Lalitha and Pounambal 2020) showed that many urban spaces lack key high-tech communications infrastructure, including 5G, critical for real-time IoT operations.

On top of that, financial and organizational barriers for such technology adoptions compound the low adoptions' rates. With such concerns in view, the study emphasized developing public awareness and education, supported with policy interventions, for raising awareness and ease in IoT integration in traffic management.

5.3. IoT Potential for Traffic Flow Optimization

The examination of IoT's potential to optimize traffic flow has been fraught with uncertainty. As evident in Figure 7, respondents' perceptions of IoT's contribution to improving traffic flow varied significantly. A substantial 40.0% of respondents perceived IoT as "very significantly" contributing, while 19% perceived it as "slightly" contributing. Another 11.5% perceived it as "moderately" contributing, and 29.5% perceived it as "not at all" contributing. These empirical observations suggest that a considerable portion of respondents harbor doubts about IoT's transformative role in managing traffic.

In contrast to the optimistic portrayal in academic literature, other studies in the field have confirmed IoT's high potential in providing efficient solutions. For instance, (Moumen et al. 2023) highlighted IoT's ability to enable real-time observation and management of traffic, leading to reduced congestion through sophisticated sensor and communication technology. Similarly, (Dui et al. 2024) argued that IoT networks optimize traffic motion, preventing spatial-temporal expansion of congestion through V2X communications. Additionally, studies by (Ranganathan et al. 2024) explored the potential of incorporating edge computation and deep reinforcement algorithms to enhance traffic light efficiency and automobile throughput. These factors, coupled with predictive analysis techniques, have demonstrated significant improvements in curbing congestion and enhancing urban settings, as evidenced by studies by (Igorovich Rozhdestvenskiy & Poornima 2024 and Khandelwal et al. 2024).

The discrepancy between the optimistic picture presented in the literature and the mixed perception of respondents in this study could stem from various factors. Firstly, pilot projects and public outreach in the study area may not have effectively conveyed the benefits of IoT-based ITS. Secondly, skepticism might arise due to infrastructural and implementation challenges, such as the need for advanced communication networks and seamless integration with existing systems.

Despite the literature's support for IoT's capacity to significantly improve traffic flow, the findings from this study underscore the necessity of more real-world demonstrations and educational efforts to bridge the gap between technological promise and stakeholder perceptions.

5.4. Key Benefits of IoT-Based ITS

The study also explored the significant advantages of Internet of Things (IoT)-based Intelligent Transportation Systems (ITS). The survey participants highlighted several benefits, including an improved road user experience, fewer traffic accidents, reduced travel time, enhanced traffic management, and decreased fuel consumption and emissions. Figure 8 illustrates the results, indicating that reduced fuel consumption and emissions, improved road user experience, and fewer traffic accidents were among the highest-rated benefits. Additionally, other aspects, often in combination, were advanced, such as reduced travel time, better traffic management, and improved real-time tracking of public transport. This demonstrates that a substantial number of respondents recognized the wide range of benefits that IoT-based ITS offers.

The findings in this study concur with past studies in the field. (Bhattacharya et al. 2020) stated that Intelligent Transportation Systems (ITS) empowered through the Internet of Things (IoT) can maximize traffic flow through real-time information dissemination and control techniques, minimizing jams and optimizing journey times. In addition, (Chavhan et al. 2022) showed that combining IoT with artificial intelligence (AI) and edge processing maximizes predictive routing analysis, enhancing the efficiency of transportation networks. (Oladimeji et al. 2023) and (F. Zhu et al. 2020) showed that IoT helps to promote road security through information interchange between automobiles, infrastructure, and fellow road users, and therefore reduces collisions.

According to (Manjunath HK 2024 and Muthuramalingam et al. 2019), current studies confirm that IoT-powered technology promotes public-private integration through interoperability between public and private transportation networks, enhancing passengers' overall journey experiences.

Overall, positive feedback captured in the survey reflects the complex and interconnected character of urban traffic issues. Frequent mentions of numerous consequences in respondents' feedback confirm IoT-powered ITS' capability to tackle several concerns at a go, enhancing passengers' satisfaction and moving towards a path towards a sustainable future. On the other hand, variation in feedback can imply considerable variation in actual consequences of IoT-powered technology, determined by geographical factors and technological infrastructure present in a location.

As a result, in view of positive forecasts in current studies, current work re-emphasizes contextual factors and proposes future studies for confirming such consequences in a variety of urban environments.

5.5. Association between IoT Awareness and ITS Effectiveness

The correlation between IoT awareness and perceived effectiveness of Intelligent Transportation Systems (ITS) was negligible, with a correlation coefficient of -0.08 ($p = 0.3563$). This shows a lack of significant statistical relationship. Such an outcome implies that in our sample, the level of IoT awareness did not influence how respondents rated the effectiveness of current traffic management systems.

Some research literature, however, posits that increased IoT awareness is a driver for enhancing the effectiveness of ITS. For instance, (Dui et al. 2024 and Moumen et al. 2023) demonstrate how IoT-supported traffic monitoring and control systems enable optimized flow, especially when supplemented by artificial intelligence that leverages real-time information and dynamic control approaches. In the same vein, (Saranya et al. 2024) show how IoT-based traffic light control systems enhance traffic flow efficiency by responding to real-time changes in conditions. Several factors could explain the discrepancy between these findings and our results. One possibility is that our respondents lacked real-world experience with IoT-based systems.

Alternatively, the overall level of awareness about their effectiveness may have been insufficient to influence their assessments. This discrepancy underscores the need for further empirical studies and demonstration projects to clearly demonstrate the benefits of IoT integration in traffic management.

5.6. Association between Role and IoT Awareness

The chi-square test performed to investigate the roles of the participants and their awareness level regarding Internet of Things (IoT) technology resulted in a chi-square value of 4.83 with a p-value of 0.3049. This indicates that, in the population under study, the association between role and IoT awareness level is not statistically significant; instead, it seems to be uniform across the different categories of stakeholders involved.

This observation is contrary to many hypotheses reported in recent literature, for example, those claiming that professionals—especially city planners and traffic management professionals—are more likely to exhibit a higher technical awareness level than urban citizens (e.g., Dui et al., 2024; Ranganathan et al., 2024). However, it’s possible that our observations are influenced by widespread awareness campaigns and information dissemination about IoT in society. This could lead to a convergence of awareness among different groups. Alternatively, traffic management professionals may not yet have the necessary knowledge and expertise to build a level of expertise surpassing that of the general public.

The consistency of awareness across different roles suggests that customized awareness programs tailored to each stakeholder group could enhance understanding of IoT’s capabilities in managing urban traffic systems. These observations imply that, based on existing literature, the integration of IoT into traffic management has not yet been practically realized, particularly in terms of system efficiency and stakeholder awareness. In fact, conducting investigations and focused efforts toward practical implementation are crucial to bridging the significant gap between technology’s potential and the actual operational effectiveness observed in urban Intelligent Transportation Systems (ITS).

CONCLUSION

This thesis discussed the concept of IoT with an emphasis on applying it to Intelligent Transportation Systems. The study examines the effectiveness of current traffic management systems through a quantitative survey analysis, awareness of IoT technologies, the potential of IoT to optimize the flow of traffic, and perceived benefits of IoT-based ITS. These findings give good pointers into the challenges and opportunities surrounding IoT implementation in urban traffic management.

Summary of Main Findings

The response revealed that a substantial portion of 58.3% of the respondents rated the current traffic management systems as “slightly effective” or “not effective.” Moreover, most respondents were unfamiliar with IoT technologies for traffic management, as 43.2% expressed uncertainty about their applicability in their area. Despite this, several key benefits of IoT-based ITS were highlighted, including improved road user experiences, reduced accidents, decreased congestion, fuel waste and travel time, enhanced traffic management, and improved real-time tracking of public transport.

However, the statistical analysis did not establish a significant relationship between IoT awareness and perceived ITS effectiveness. Additionally, the data failed to reveal a statistically significant correlation between respondents’ roles and their awareness of IoT technologies. These findings suggest that at this stage of development, IoT awareness does not significantly impact perceptions of ITS effectiveness, and awareness levels remain relatively consistent regardless of professional or residential status.

Implications

These findings have significant implications for various stakeholders, including policymakers, urban planners, and technology developers. Firstly, the low ratings on the effectiveness of current traffic management systems underscore the urgent need for innovation in addressing urban traffic challenges through Internet of Things (IoT)-based Intelligent Transportation Systems (ITS).

Secondly, the low levels of awareness regarding IoT technologies highlight the importance of public education and outreach initiatives aimed at enhancing public understanding and acceptance of IoT applications in traffic management.

The identified benefits of IoT-based ITS, such as improved road user experiences and reduced accidents, present a compelling business case for investment in IoT technologies. However, mixed perceptions regarding the potential of IoT to optimize traffic flow suggest that more evidence-based demonstrations and pilot projects are necessary to instill confidence in these systems.

Recommendations

Based on the findings, the following recommendations are suggested:

1. **Enhance Public Awareness**: Governments and stakeholders should launch awareness campaigns to educate the public about the benefits and applications of IoT in traffic management.
2. **Invest in Pilot Projects**: Pilot implementations of IoT-based ITS should be conducted in diverse urban settings to demonstrate their effectiveness and build public trust.
3. **Encourage Interdisciplinary Collaboration**: Collaboration between city planners, traffic management professionals, and technology developers is required to design and implement IoT solutions that address real-world challenges.
4. **Create Conducive Policies**: Policymakers should put in place clear regulations and mechanisms for funding to support the adoption of IoT technologies in urban transportation systems.
5. **Emphasize User-Centric Design**: IoT-based ITS should be designed with the user in mind, ensuring systems are accessible, intuitive, and beneficial for all road users.

IoT-based Intelligent Transportation Systems (ITS) can address urban traffic congestion, but cities must overcome implementation challenges to achieve sustainable and efficient transportation systems. Future research will explore long-term impacts and effective implementation strategies.

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APPENDIX

This questionnaire aims to assess public perceptions of IoT in transportation, highlighting both its benefits and challenges.

Your response will be kept confidential and will be used only for academic research purpose.

Section 1: General Information

1. Where do you live in the Czech Republic? (please write)

____

2. What is your age group?

Mark only one oval.

- Under 18
- 18-25
- 26-35
- 36-45
- 56+

3. What is your primary mode of transportation?

Mark only one oval.

- Private car
- Public transport (bus, train, tram, metro)
- Bicycle/scooter
- Walking
- Ride-sharing services
- Other (please specify)

4. How familiar/aware are you with IoT (Internet of Things) in transportation?

Mark only one oval.

- Very familiar
- Somewhat familiar
- Not familiar

4. How effective is the current Traffic Management System?

Mark only one oval.

- Very effective
- Moderately effective
- Slightly effective
- Not effective

Section 2: Advantages of IoT in transportation

5. In your opinion, which of the following are the biggest advantages of IoT in transportation? (Select all that apply)

Check all that apply.

- [ ] Improve traffic management
- [ ] Enhanced vehicle safety and accident prevention
- [ ] Reduced fuel consumption and emissions
- [ ] Reduce travel time
- [ ] Real-time tracking of public transport
- [ ] Better fleet management for logistics companies
- [ ] Improved passenger experience (e.g., smart ticketing, real-time updates) Other
- [ ] (please specify)

6. How much do you agree with the following statements? (Rate on a scale of 1-5: = Strongly disagree, 5 = Strongly agree)

a. IoT can help reduce traffic congestion *Mark*

only one oval.

1	2	3	4	5
○	○	○	○	○

b. IoT improves vehicle safety through real-time monitoring and alerts.

Mark only one oval.

1	2	3	4	5
○	○	○	○	○

b. IoT helps reduce environmental impact by optimizing fuel consumption.

Mark only one oval.

1 2 3 4 5

7. Have you ever used IoT-based transportation services (e.g., smart parking, GPS enabled ride-sharing apps, connected public transport systems)?

Mark only one oval.

- Yes
- No

Section 3: Disadvantages of IoT in Transportation.

8. What do you think are the biggest disadvantages of IoT in transportation? (Select all that apply)

Check all that apply.

- [ ] Privacy concerns due to constant data tracking
- [ ] High costs of implementation and maintenance
- [ ] Cybersecurity risks (e.g., hacking, data breaches)
- [ ] Dependence on technology, which may fail or malfunction
- [ ] Increased unemployment due to automation

9. Have you ever experienced issues related to IoT in transportation (e.g., GPS failures, security concerns, unreliable smart ticketing systems)?

Mark only one oval.

- Yes
- No

Section 4: Future of IoT in Transportation

10. Do you believe IoT will have a mostly positive or negative impact on transportation in the future?

Mark only one oval.

- Mostly positive
- Mostly negative
- Neutral

11. What suggestion or comment will you provide for future improvement of IoT-based ITS? (please write)