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Driving Green Transportation System Through Artificial Intelligence and Automation

Approaches, Technologies and Applications

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Preface

In past years, the idea of making a green environment that has been existing and moving on the society 5.0 being as a country strategy, and today Artificial Intelligence (AI) technology continues its development on this prototype. Indeed, AI has begun actions to resemble a person in a real sense, and the idea of human-liked robotics put forward by scientists has started to be realized and will probably complete its development as living machines in the near future. AI has many subsystems and application in various industries, some of which have automation more accurately and are more integrated in modern industries.

The book "*Driving Green Transportation System Through Artificial Intelligence and Automation: Approaches, Technologies, and Applications*" explores the intersection of many cutting-edge technologies such as AI, automation, software defined vehicles, internet of things, sensors, wireless communication, and their potential to drive the smart transportation system in green environments. This technical description provides an overview of the key concepts, approaches, technologies, and applications covered in the book. The book begins with an introduction to the growing challenges of technologies in green and intelligent transportation environments. It highlights the increasing complexity and interconnectedness of modern systems, leading to vulnerabilities and the need for innovative solutions.

- The book presents a comprehensive overview of AI and automation for driving green transportation system, AI-integrated technologies and their potential to enhance smart transportation system.
- The book covers a wide range of AI-related subjects, such as their approaches, Technologies, applications, and several types of technologies in smart transportation system and green transportation ecosystem.
- The book focuses on using AI and automation in smart transportation system to alter investment and development in improving of green transportation system.

In short, this book is an excellent resource for anyone interested in learning more about how AI and AI-integrated technologies might be used to develop and maintain the green transportation ecosystem. It is a thorough handbook that provides insights into the most recent advancements in AI, AI-integrated technologies, automation, and their applications in development strategy of green transportation ecosystem.

Raleigh, NC, United States

Happy reading!
Alex Khang

Acknowledgments

Artificial intelligence (AI) and Automation are a new direction that has opened a revolution in technology and smart applications, it is also the basis for creating a Green Environment in the Net-zero era. Therefore, machines, devices, self-driving car, and robots controlled by artificial intelligence-based systems are now the model of a smart transportation ecosystem for which all these technologies are referred to as "Green" industries.

The book "*Driving Green Transportation System through Artificial Intelligence and Automation: Approaches, Technologies, and Applications*" focuses on the use of Automation, AI, and AI-integrated technologies in smart transportation and smart city, with the goal of driving Green transportation ecosystem and improving the living environment. The book is also designed to help transportation professionals and construction experts to develop and implement successful smart systems, leveraging the current trends, equipment, and advanced technologies to drive the green transportation system development. This book also targets a mixed audience of specialists, analysts, engineers, scholars, researchers, academics, professionals, and students from different communities to share and contribute new ideas, methodologies, technologies, approaches, models, frameworks, theories and practices to resolve the challenging issues associated with the leveraging of AI, Automation, Autonomous, and Internet of Things (IoT) in green transportation ecosystem.

Planning and designing a book outline to introduce to readers across the globe is the passion and noble goal of the editor. To be able to make ideas to a reality and the success of this book, the biggest reward belongs to the efforts, knowledge, skills, expertise, experiences, enthusiasm, collaboration, and trust of the contributors. To all respected contributors, we really say big thanks for high-quality chapters that we received from our automotive engineers, transportation engineers, experts, professors, scientists, scholars, Ph.D., postgraduate students, educators, and academic colleagues. To all respected reviewers with whom we have had the opportunity to collaborate and monitor their hard work remotely, we acknowledge their tremendous support and valuable comments not only for the book but also for future book projects.

We also express our deep gratitude for all the pieces of discussion, advice, support, motivation, sharing, collaboration, and inspiration we received from our faculty, contributors, educators, professors, scientists, scholars, engineers, and academic colleagues. At last but not least, we are really grateful to our publisher **Springer Nature Switzerland AG** for the wonderful support in making sure the timely processing of the manuscript and bringing out this book to the readers soonest.

Thank you, everyone, Alex Khang

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Alex Khang is a Professor in Information Technology, D.Sc. D.Litt., AI and Data scientist, AI and Data Science Research Center, Global Research Institute of Technology and Engineering, Raleigh, North Carolina, United States. He has achieved recognition as one of the World's Top 2% Scientists in 2024. He has more than 28 years of experience in teaching and researching of computer science and data science at the universities and institutions of computer science and information technology in Vietnam, India, and USA. He has over 30 years of working experience as a software product manager, data engineer, AI engineer, cloud computing architect, solution architect, software architect, database expert in the foreign corporations of Germany, Sweden, the United States, Singapore, and multinationals. He has published many articles, 190+ documents indexed Scopus, 54 authored books (Software development). He has published 30 edited books, 150 book chapters, and calling for book chapters for 5+ edited books in the fields of AI ecosystem.

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Artificial Intelligence (AI) and Automation for Driving Green Transportation Systems: A Comprehensive Review

Derrick Mirindi, Alex Khang, and Frederic Mirindi

Abstract Artificial intelligence (AI), machine learning (ML) and deep learning (DL) have been rapidly transforming and innovating the transportation sector in recent years. This is not only enabling greener, safer and more efficient mobility solutions, but also combating climate change. This comprehensive study explores the current applications, ethical considerations, advantages and disadvantages of AI, machine learning and deep learning in the implementation of green transportation systems. It also highlights the importance of community involvement in promoting ecology in urbanism. Thus, this study examines ML algorithms such as the Genetic Algorithm (GA), Support Vector Machine (SVL), Naive Bayes (NB), k-means clustering, k-Nearest Neighbor (kNN), Classification and Regression Trees (CART), as well as DL algorithms such as Convolutional Neural Network (CNN), Recurrent Neural Network (RNN), Restricted Boltzmann Machine (RBM), and Autoencoder. Grounded in the Unified Theory of Acceptance and Use of Technology (UTAUT), this review examine the application of AI for green transportation such as Autonomous vehicles, Smart Traffic Management, Mobility-as-a-Service (MaaS), Vehicle-to-Grid technology (V2G), Sustainable Public Transit, Micromobility solutions, and Electric Vehicles (EVs). The findings indicate that while AI technologies offer significant potential for optimizing energy efficiency, reducing emissions and enhancing safety in transport, they also present challenges related to data privacy, algorithmic biases and ethical decision-making. As such, this study highlights the need to develop and implement AI responsibly, reconciling technological advances with ethical considerations and community needs. Finally, this work recommends future research to address these challenges in order to develop more transparent and

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explainable AI models, and to explore the long-term societal impacts of AI-driven green transportation systems.

Keywords Artificial intelligence · Machine learning · Deep learning · Blockchain · Green transportation system · Community engagement · Mobility-as-a-service · Vehicle-to-grid technology · Electric vehicles · Smart traffic management · Genetic algorithm · Support vector machine · Naive Bayes · k-means clustering · k-nearest neighbor · Classification and regression trees · Convolutional neural network · Recurrent neural network · Restricted Boltzmann machine · Autoencoder

1 Introduction

About 28% of all emissions in the United States come from the transportation sector; hence, it is a significant contributor to world greenhouse gas emissions [10]. Adoption of ecologically friendly transportation choices has become necessary given the urgent need to solve climate change. Björklund [7] defines green transportation (GT) as "the transportation service with fewer negative impacts on human health and the environment compared to existing transportation services." This covers public transit, active transportation, electric and alternative fuel cars, and intelligent transportation systems that optimize efficiency. Shah et al. [48] underlined the possibilities of GT in tackling several transportation-related issues, including reducing traffic congestion, pollution, and accident prevention, improving energy and resource sustainability; increasing safety and security assurance; and optimizing travel speed and traffic flow.

Fields including medicine [31], water science [40], architecture [32], and economy [44] are progressively integrating Artificial Intelligence (AI), Machine Learning (ML), and Deep Learning (DL) algorithms to develop new technologies. In response to important changes, AI, ML, and DL algorithms have become vital elements in transportation systems, allowing the shift to environmentally friendly mobility. AI, according to [45], spans technology enabling robots to complete activities usually requiring human intelligence, including perception, cognition, learning, and decision-making [21]. In addition, AI has significant potential to improve sustainability, efficiency, and safety in the transportation industry [6].

In fact, ML algorithms, a subset of AI, seek to develop algorithms that complete activities usually requiring human intelligence [35]. Indeed, [11] have illustrated how ML algorithms such as linear regression or logistic regression use statistical techniques to help computer systems learn from data without explicit programming. From traffic pattern analysis to route optimization and vehicle and infrastructure predictive maintenance, ML algorithms find use in the transportation space [38]. On the other hand, [26] claim DL is a subset of ML utilizing artificial neural networks (ANNs) with multiple layers to learn hierarchical representations of data. Indeed, DL algorithms have made great progress in fields including computer vision and natural language processing (NLP), which are directly used in the transportation systems of autonomous vehicles for object detection and collision avoidance and intelligent traffic management systems for congestion prediction and alleviation [3, 43].

The adoption of AI in green transportation raises serious ethical concerns. Techstack [52] emphasizes the urgency of addressing issues related to algorithmic bias, data privacy, transparency, reliability, safety, and job displacement within the transportation system. For instance, the gathering of mobility data for AI applications raises concerns about individual privacy and data security, putting personal privacy and data security at risk. Furthermore, researchers have made significant progress in applying AI, ML, and DL to various aspects of the transportation system. For instance, [56] demonstrated the use of DL algorithm for accurate short-term traffic flow prediction. However, there is a lack of comprehensive reviews that synthesize the diverse applications of AI, ML, and DL algorithms for driving green transportation by studying their ethical considerations, their advantages and disadvantages and their current and future opportunities.

This paper aims to study the application of AI in driving green transportation systems that include Genetic Algorithm (GA), classification and Regression Tree (CART), Support Regression (SVR), k-Nearest Neighbor (k-NN), and k-means clustering for ML with and k-means clustering for ML with Long Short-Term Memory (LSTM), Deep Belief Network (DBN), Convolutional Neural Network (CNN), Recurrent Neural Network (RNN), Delivery Cooperative Network (DCN), Republic Broadcasting Network (RBN), and SAE International (SAE) for DL.

Furthermore, the purpose of this work is to investigate the advantages and disadvantages of integrating AI, ML, and DL algorithms for green transportation systems with their associated ethical considerations, including data sharing and intellectual property, as well as their current and future opportunities. This research hopes to contribute to the current existing literature by providing more information to scholars, researchers, and practitioners within this field [20].

2 Data and Methods

The data and the subsequent methodology used in this research including various databases such as Google, Scopus, Web of Science, IEEE Xplore, and Google Scholar. In order to study the application of AI, ML and DL algorithm for driving green transportation, the search queries were used: “Artificial Intelligence in Driving Green Transportation,” “Machine Learning in Transportation System,” and “Deep Learning Algorithms.“ Our methodology included conducting literature research, performing a preliminary analysis by selecting approximately 250 articles that are identified helpful to respond to our research gap as shown in Fig. 1.

Furthermore, to achieve this work, a deeper analysis was then conducted, which involved identifying and examining the advantages, disadvantages, current and future opportunity of AI applications in the context of green transportation. By adhering to

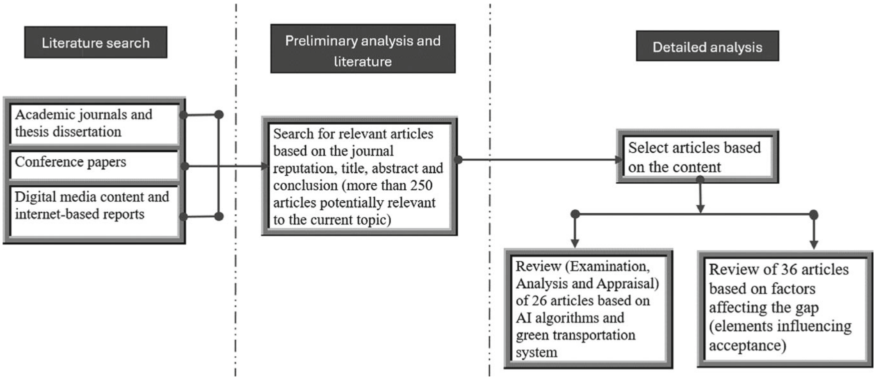

Fig. 1 Schematic representation of the methodology

the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) rules, this guarantees openness and repeatability.

3 Theoretical Framework

In this study, theoretical frameworks are vital since they offer a structured approach to understanding complex phenomena in green transportation systems. In this regard, a theoretical framework provides a conceptual basis for examining the acceptance and application of environmentally friendly transportation technologies and approaches. As described by [30], one of the most prominent theoretical models that is adopted in this research is the Unified Theory of Acceptance and Use of Technology (UTAUT), because it can be served and applied to understand the factors influencing the adoption of green transportation systems with the use of AI, ML, and DL. According to UTAUT, behavioral intention—which is shaped by four main constructions—determines how technology is really used.

Performance expectancy ("the degree to which an individual believes that using the system will help him or her to attain gains in job performance"), effort expectancy ("the degree of ease associated with the use of the system"), social influence ("the degree to which an individual perceives that important others believe he or she should use the new system"), and facilitating conditions ("the degree to which an individual believes that an organization's and technical infrastructure exists to support the use of the system") [54].

Also, the UTAUT model includes moderating elements including age, gender, experience, and voluntariness of usage, which can influence the strength of the interactions between the main constructions and behavioral intention. Applying the UTAUT paradigm to create green transportation systems will help academics and legislators better understand the elements influencing acceptance and use of sustainable transportation technologies, including AI, ML, and DL algorithms to lower carbon dioxide emissions.

4 AI Applications for Driving Green Transportation Systems

AI forms the overarching framework for driving green transportation systems, with Machine Learning (ML) and Deep Learning (DL) as its subsets, as depicted in Fig. 2. Indeed, ML enables computers to analyze data with algorithms used in this study, such as Support Vector Regression (SVR), Classification Regression Tree (CART), Genetic Algorithm (GA), k-Nearest Neighbor (k-NN) and K-means clustering, and create predictive models without explicit programming, while DL, a subset of ML, utilizes artificial neural networks (ANN) to learn hierarchical representations of data. This includes algorithms such as SAE, LTSM, BND, CNN, RNN, Autoencoder, and DCN. These AI technologies are important in revolutionizing green transportation systems because they are used in different applications, such as Autonomous vehicles with self-driving capabilities and AI-powered navigation [20].

Additionally, Smart Traffic Management systems employ adaptive traffic signal control, predictive congestion management, and AI-powered real-time traffic analysis. Sustainable Public Transit uses electric and hydrogen-powered buses with AI-optimized routes, Vehicle-to-Grid (V2G) technology with bi-directional charging, and AI-optimized energy management, while Electric Vehicles (EVs) employ battery-powered, zero-emission capabilities and AI-optimized battery management.

Concerning Mobility-as-a-Service (MaaS) platforms, they offer integrated multimodal transportation and AI-driven route optimization, while Micromobility Solutions like e-bikes and e-scooters are integrated with AI-powered rebalancing systems as shown in Fig. 3. In fact, AI's role in these application systems is important, allowing predictive maintenance, optimizing energy efficiency, enhancing safety through advanced sensors and decision-making algorithms, and improving overall system performance and sustainability.

4.1 Machine Learning Algorithms

4.1.1 Genetic Algorithm

Genetic Algorithm (GA) is an optimization tool used in both supervised and unsupervised learning tasks. GA uses a survival of the fittest type of algorithm to reach solution much faster. GA can also be useful for optimizing various aspects of sustainable mobility [34]. GAs can be used, for instance, to maximize smart grid system

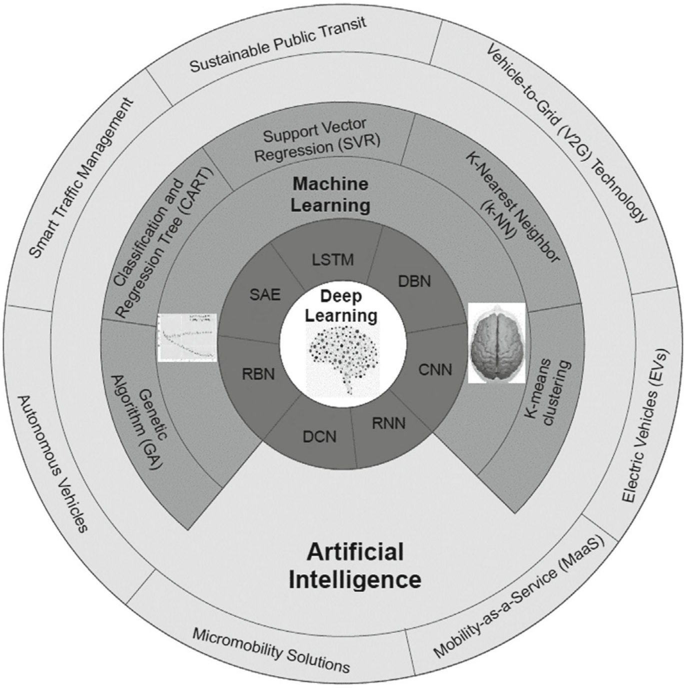

Fig. 2 Schematic representation of AI, ML and DL algorithms for driving green transportation Systems

electric vehicle (EV) charging schedules. This helps to lower environmental impact, balance energy demand, and cut expenses [23].

Following five keys' actions allows GA to be applied for optimal EV charging. First, an initial chromosome representation—each chromosome represents a possible charging schedule for several EVs over a 24-h period—follows definition of a fitness function—fitness is computed based on elements like total energy cost, grid load balancing, renewable energy use, and user convenience. The third step is the choice of fitness (higher fitness individuals with a better charging schedule have a higher chance of being selected for reproduction); finally, the fourth step is using crossover and mutation (combine and somewhat change charging schedules to create new potential solutions); followed by iterations (repeat step 3 and 4 to solve the problem).

Indeed, the fitness function could be expressed as: $f(x) = w1C(x) + w2B(x) + w3R(x) + w4U(x)$, where C(x) is the total energy cost, B(x) represents grid load balance, R(x) is renewable energy utilization, U(x) is user convenience, and w1-w4 are weights for each factor. This innovative application of GAs in green transportation demonstrates their potential to optimize complex systems, balancing multiple objectives to create more sustainable and efficient mobility solutions.

Fig. 3 Key features for driving green transportation systems

4.1.2 Support Vector

Support Vector Machines (SVMs) are powerful supervised learning algorithms that have found innovative applications in driving green transportation systems. In the context of autonomous vehicles, SVMs can be used for real-time obstacle detection and classification, enhancing safety and efficiency. The SVM algorithm finds an optimal hyperplane that maximizes the margin between classes, defined as $\vec{w}\cdot\vec{x}+b=0$, where w$^{\rightarrow}$ is the normal vector to the hyperplane and b is a variable [41]. The objective function for the SVM optimization problem is: $\min_{\vec{w},b}\cdot\frac{1}{2}\vec{w}^2$ subject to $y_i\left(\vec{w}\cdot\overrightarrow{x_i}+b\right)\geq 1\forall$i, where yi is the class label (1 or $-$ 1) for each data point $\overrightarrow{x_i}$.

According to research done by [4] and [39], SVMs have promising applications in green transportation. While they can be useful for Mobility-as-a-Service (MaaS) platforms, SVMs can optimize route selection by classifying options as 'eco-friendly' or 'standard' based on travel time, cost, and emissions, they can also be used in Vehicle-to-Grid (V2G) technology. Indeed, SVMs can predict optimal charging and discharging times by analyzing grid demand and vehicle usage patterns, enhancing grid stability and renewable energy use.

4.1.3 Naive Bayes Algorithm

Based on Bayes' Theorem from eighteenth century mathematician Thomas Bayes, these algorithms are simple yet effective probabilistic classification methods. They assume features are conditionally independent given the class, which simplifies calculations but can still perform well on various tasks. As stated by [53], Naive Bayes (NB) offers an efficient approach for classification tasks in the context of green logistics. The probability of a class Ci given a feature vector x is calculated as: $P(C_i|x) = \frac{P(x|C_i)*P(c_i)}{P(x)}$.

In addition, assuming conditional independence, this simplifies to:$P(C_i|x)\alpha P(c_i)\prod_{j=1}^{n} P\left(x_j \middle| c_i\right)$.

Where n is the number of features and x_j is the j-th feature value.

For continuous features, a Gaussian Naive Bayes model can be used, where the likelihood $P\left(x_j \middle| C_i\right)$ is modeled as a normal distribution: $P\left(x_j \middle| C_i\right) = \frac{1}{\sqrt{2\pi\sigma_{ij}^2}} \exp\left(-\frac{\left(x_j-\mu_{ij}\right)^2}{2\sigma_{ij}^2}\right)$ with mean μ_{ij} and variance σ_{ij}^2 estimated from the training data for each feature j and class C_i.

The class with the highest posterior probability is then predicted: $\hat{C} = \arg\max_{C_i} P(C_i|x)$.

Forecasting EV charging demand is one green transportation application. Based on factors such as time of day, day of week, and local events, naive Bayes can classify time slots as either high- or low-demand periods. This maximizes grid load management and charging station operations, therefore promoting more environmentally friendly urban transportation [9].

4.1.4 K-means Clustering

According to [17], k-means clustering is an unsupervised machine learning algorithm that groups similar data points together into a predefined number of clusters. Indeed, k-means clustering offers innovative applications for optimizing sustainable mobility solutions. Xydas et al. [59] demonstrated that k-means may be utilized to classify EVs in accordance with their charging patterns, energy consumption, and availability for grid support. The algorithm works by initially selecting k random centroids, which represent the center of each cluster. Each data point is then assigned to the nearest centroid based on the Euclidean distance: $\mathrm{d}\left(x_i, c_j\right) = \sqrt{\sum_{p=1}^{n}\left(x_{ip} - c_{ip}\right)^2}$ where $\mathrm{d}\left(x_i, c_j\right)$ is the distance between data point xi and centroid cj, n is the number of features, and x_{ip} and c_{jp} are the p-th features of x_i and c_j, respectively. In light of this, [29] says that the centroids are updated by finding the average of all the data points that are assigned to each cluster: $C_j = \frac{1}{|C_j|}\sum_{x_i \in C_j} x_i$, where C_j is the set of data points assigned to cluster j. Hartigan and Wong [12] observed that this iterative approach is repeated until the centroids no longer suffer significant change or until the maximum number of iterations is reached. This process is repeated until one of these conditions is met.

4.1.5 K-Nearest Neighbor

As [2] emphasizes, k-Nearest Neighbor (k-NN) is a flexible machine learning method fit for both classification and regression tasks in intelligent transportation systems. Regarding green transportation, k-NN presents creative solutions to improve self-driving vehicle decision-making capacity. For autonomous cars, they may include sensor readings, traffic conditions, and meteorological data [62]. k-NN works by identifying the k most similar instances from a dataset of historical driving scenarios. The similarity is typically measured using a distance metric such as Euclidean distance:$d(\mathrm{x}, \mathrm{y}) = \sqrt{\left(\sum (\mathrm{x_i} - \mathrm{y_i})^2\right)}$.

Shalev-Shwartz and Ben-David [49] point out that k-NN's simplicity and interpretability make it especially useful for safety–critical uses in autonomous vehicles. By matching current sensor data to a database of pre-classified situations, it allows cars to rapidly recognize possible risks and choose suitable evasive maneuvers, hence enabling real-time obstacle avoidance [63]. K-NN greatly helps to enhance safety, efficiency, and traffic congestion in green transportation systems [58] despite obstacles like the requirement for vast, varied datasets and possible processing demands in real-time situations.

4.1.6 Classification and Regression Tree

The Classification and Regression Tree (CART) algorithm was first presented by Breiman et al. [8] as a versatile machine learning algorithm used for building decision trees based on Gini's impurity index as the splitting criterion. Bachute and Subhedar [5] point out that CART algorithm has the potential to be utilized in autonomous vehicles in a novel manner for the purpose of accident detection, likelihood prediction, and prevention.

CART algorithm proceeds as follows:

- For each feature, find the best split that maximizes the splitting criterion, which is the Gini impurity index: $Gini(t) = 1 - \sum_{i=1}^{n} p_i^2$, where *pi* is the probability of class *i* at node *t*, and *n* is the number of classes.
- For k distinct values of a feature, there are k − 1 possible splits. Evaluate each split using the Gini index.
- Select the split that maximizes the reduction in impurity, defined as: $\Delta Gini(s, t) = Gini(t) - \sum_{i\in\{L,R\}} \frac{N_i(s,t)}{N(t)} Gini(i)$, where *s* is the split, *t* is the current node, *L* and *R* are the left and right child nodes, and *N* is the number of samples.
- Repeat steps 1–3 recursively for each child node until a stopping criterion is satisfied, such as reaching a maximum depth or minimum number of samples per

leaf. The resulting decision tree can predict accident likelihood based on the input features.

In the context of green transportation, CART algorithm can assess datasets that contain characteristics like as the speed of the vehicle, the conditions of the road, the weather, and the behavior of the driver to forecast the possibility of accidents occurring in autonomous vehicles. Through the enhancement of safety and efficiency in autonomous vehicle systems, this application is in line with the broader goals of sustainable mobility, which are illustrated in the image. Because of its interpretability and efficiency, CART algorithm is a great tool for making decisions in real time in the context of intelligent traffic management and autonomous driving, which contributes to the overall optimization of environmentally friendly transportation programs.

4.2 *Deep Learning Algorithms*

4.2.1 Convolutional Neural Networks

Convolutional Neural Networks (CNNs) have emerged as a powerful deep learning architecture for processing grid-like data in transportation systems. CNNs are innovatively applied to predict traffic flow by treating spatio-temporal traffic data as a 2D image. In the context of sustainable mobility, CNN models typically classify features into two groups: Green Traffic Conditions and Environmental Incidents. The architecture consists of multiple convolutional layers extracting increasingly abstract features, followed by pooling layers for down-sampling. The convolutional operation in a CNN layer can be expressed as: $Y_{ij} = f\left(\sum_{a=0}^{m-1}\sum_{a=0}^{n-1} W_{a,b}.X_{i+a,j+b} + b\right)$ where X is the input green traffic matrix, W is the convolutional filter for sustainability features, b is the bias term, f is a non-linear activation function, and Y is the output feature map of eco-friendly traffic patterns [32].

4.2.2 Recurrent Neural Networks

Recurrent Neural Networks (RNNs) are a class of deep learning models designed to process sequential data by maintaining an internal state or "memory" of previous inputs. In fact, for green transportation uses including time-series data, such as estimating energy consumption patterns in EVs or maximizing sustainable traffic flow, this makes them especially well-suited.

RNNs can have several configurations:

- Vector-to-sequence: Takes a fixed-size vector input and outputs a sequence.
- Sequence-to-vector: Accepts a sequence as input and produces a fixed-length vector output.

- Sequence-to-sequence: Both inputs and outputs are sequences, making this variant popular for many applications.

Introduced by [15], Long Short-Term Memory (LSTM) is a specialized form of RNN that solves the vanishing gradient issue compromising conventional RNNs in handling long sequences. Within the framework of transportation, [61] suggested an LSTM-based model for temporal-spatial correlation in traffic data based short-term traffic forecasting. Indeed, the LSTM network for traffic flow can be represented mathematically as: $h_t = LSTM\,(x_t, h_{t-1}, C_{t-1})$, with $y_t = w_y h_t + b_y$ where x_t is the input at time t, h_t is the hidden state, C_t is the cell state, y_t is the output prediction, and w_y and by are learnable parameters.

As Pascanu et al. [42] point out, RNNs and LSTMs remain useful for modeling intricate temporal dynamics in green transportation data despite obstacles including computational complexity and training time. Ma et al. [28] show that their capacity to learn long-term dependencies in traffic patterns makes them essential instruments for maximizing energy economy and lowering environmental impact in mobility systems.

4.2.3 Restricted Boltzmann Machines

Restricted Boltzmann Machines (RBMs) are powerful generative models that can automatically discover patterns in data through unsupervised learning. RBMs show promise for environmentally friendly traffic flow prediction and anomaly detection in clean transportation systems as noted by [13], which uses unsupervised learning to automatically identify trends in data. Salakhutdinov and Hinton [46] characterize the structure of an RBM as comprising visible and hidden layers with an energy function: $E(v, h) = -\Sigma_i a_i v_i - \Sigma_j b_j h_j - \Sigma_{i,j} b_{i,j} v_i h_j w_{ij}$ where v and h are visible and hidden unit states, ai and bj are biases, and wij are connection weights.

Indeed, for low-carbon transit flow prediction, Lv et al. [27] propose representing road segments as visible units and latent traffic patterns as hidden units. Training proceeds through contrastive divergence, as outlined by [14]. In addition, Yu et al. [60] demonstrate that stacking multiple RBMs can create Deep Belief Networks (DBNs), enhancing performance in sustainable transportation prediction by allowing hierarchical feature learning of environmentally friendly traffic patterns.

4.2.4 Autoencoders

Autoencoders, a neural network architecture introduced in 1986 and popularized by Geoffrey Hinton in 2006 consist of two main components: an encoder and a decoder [47]. The encoder compresses input data into a lower-dimensional representation, while the decoder attempts to reconstruct the original input from this compressed form [16] as shown in Fig. 4.

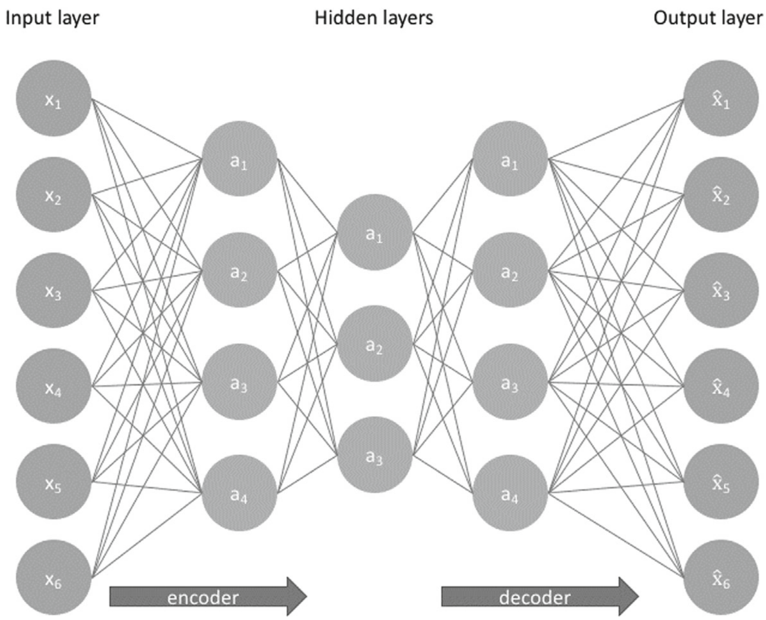

Fig. 4 Autoencoders architecture

Using stacked autoencoders (SAEs), Lv et al. [27] have been used to model hierarchical feature representations of human mobility patterns for traffic incident risk prediction. An autoencoder can be generally expressed as $h = f(w_x + G)$, $\hat{x} = g\left(w - h + b'\right)$ where x is the input; h is the encoded representation; x̂ is the rebuilt output; W and Wx are weight matrices; b and b' are bias vectors; and f and g are activation functions.

While [57] used them for feature extraction in estimating EV charging demand, Sun et al. [50] applied autoencoders for noise reduction in renewable energy-powered traffic data. Zhu et al. [63] also dimensionally reduced high-dimensional sustainable transportation network data using autoencoders. This showed the potential of autoencoders to contribute to driving green transportation. Autoencoders are also used in the Delivery Cooperative Network (DCN) to optimize routing, decrease emissions, and improve efficiency in cooperative transportation networks. This include vehicle-to-vehicle (V2V) communication, vehicle-to-infrastructure (V2I) communication, and real-time hazard warnings.

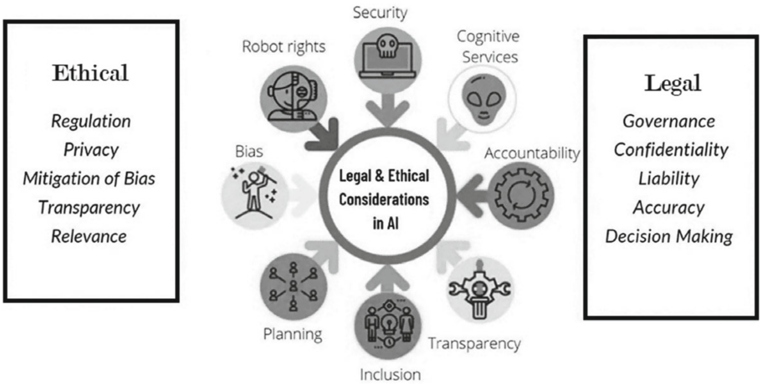

Fig. 5 Key features for driving green transportation systems [37]

5 Ethical Considerations, Advantages and Disadvantages

As Fig. 5 shows, an example of ethical issues such as accountability, confidentiality, liability, privacy, and transparency used in healthcare can also be faced with the integration of AI into green transportation systems [18]. In fact, [25] underline in AI-powered mobility solutions the need for data privacy and security. Mladenović et al. [36] stress the need for algorithmic fairness to prevent bias in access to sustainable mobility and route planning. Transparency and responsibility in AI decision-making for autonomous cars and smart traffic management are underlined by [55]. These ethical considerations must be carefully balanced with the possible advantages (Table) of AI, ML, and DL algorithms for sustainable green transportation.

This comparison emphasizes a complex interaction among the benefits and disadvantages of AI in environmentally friendly transportation systems as shown in Table 1. Although AI presents challenges regarding privacy, fairness, and ethical decision-making, it also offers great possibilities for enhancing sustainability, efficiency, and safety. Responsible development and implementation of AI-driven green transportation solutions depends on careful balancing of these elements.

6 Community Engagement

Community engagement’ is therefore a strategic process with the specific purpose of working with identified groups of people, whether they are connected by geographic location, special interest, or affiliation to identify and address issues affecting their well-being [1]. Indeed, Community engagement is important in driving green transportation systems powered by AI. Furthermore, by empowering communities with AI technology, we can create more sustainable, equitable, and effective mobility solutions that truly serve local needs. Indeed, this approach goes beyond simply

Table 1 Advantages and disadvantages of AI in Green transportation systems

Advantages	Disadvantages
Enhanced energy efficiency through optimized route planning and traffic management [51]	Potential privacy breaches from extensive data collection on travel patterns [24]
Improved safety in autonomous vehicles with AI-powered decision-making [57]	Risk of algorithmic bias leading to unequal access to sustainable transportation options [36]
Reduced emissions through AI-optimized electric vehicle charging and grid management [50]	Cybersecurity vulnerabilities in connected transportation systems [22, 63]
Increased accessibility to sustainable mobility options through AI-powered MaaS platforms [4]	Potential job displacement in traditional transportation sectors [33]
Real-time adaptation to changing environmental conditions for more resilient transportation systems [28]	Ethical dilemmas in AI decision-making for autonomous vehicles in critical situations [55]

implementing new technologies because it involves actively involving residents in the design, deployment, and ongoing management of smart transportation systems.

Participatory planning systems driven by AI, for example, can let citizens provide real-time data and comments on mobility problems, helping optimize various aspects of EV charging station placement to micromobility routes. Moreover, community-led artificial intelligence ethics boards can guarantee fairness and openness by monitoring algorithmic traffic management system decision-making.

Citizen science projects from local communities and professionals utilizing artificial intelligence can also involve citizens in tracking noise pollution from transportation and air quality, so influencing evidence-based policy changes. Combining local knowledge with artificial intelligence powers us to create sophisticated solutions like demand-responsive public transportation that really meets community needs or culturally sensitive autonomous vehicle behaviors. This cooperative approach not only results in more efficient and fair green transportation systems but also fosters public trust and acceptance of AI technologies—essential for general adoption and long-term success in changing to sustainable mobility.

7 Conclusion

This review highlights how AI, ML and DL are reshaping green transportation. Indeed, by studying a range of ML and DL algorithms, from kNN enabling real-time traffic classification and route optimization to CNN used for image-based traffic analysis and autonomous vehicle perception, this study reveals the exciting possibilities of AI for sustainable green mobility [19].

Based on the UTAUT, this research shows that AI can significantly increase energy efficiency and reduce carbon dioxide emissions, which are important to our planet. However, it also raises important ethical issues related to data privacy, potential algorithm biases, and wider impacts on society.

Additionally, this study highlights the importance of community engagement in driving green transportation systems through AI integration. Participatory planning platforms and citizen science initiatives enable residents to provide real-time data and feedback, leading to more efficient and equitable mobility solutions. This approach is essential for building public trust and ensuring the long-term success of sustainable mobility initiatives.

Looking ahead, this study proposes some promising opportunities:

- Developing context-aware AI systems for real-time traffic management and emissions reduction.
- Integrating AI with emerging technologies like blockchain for enhanced security and transparency in transportation data management.
- Expanding AI-powered MaaS platforms to create more inclusive and accessible transportation ecosystems.

For future research, focus areas should include:

- Investigating methods to improve the explainability and transparency of AI decision-making processes in transportation systems.
- Assessing the long-term socioeconomic impacts of AI-driven transportation solutions on employment and urban development.

Moving forward, it is important to keep sustainability, ethics, and community engagement at the heart of AI development in green transportation. This approach can create mobility solutions that are truly inclusive and environmentally responsible, paving the way for a greener future for all.

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Declarations

Conflict of Interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this chapter.

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Application of Automation and Artificial Intelligence (AI) in Green Transportation System

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Abstract Automation and artificial intelligence (AI) are becoming important in the development of green transportation systems.This abstract investigates the varied role of AI-driven automation in improving the efficiency, sustainability, and safety of transportation systems. AI application in green transportation includes a variety of technologies such as self-driving cars, smart traffic control systems, predictive maintenance, and energy-efficient logistics. Autonomous cars, outfitted with powerful AI algorithms, are at the vanguard of this transformation, promising to minimize carbon emissions by optimizing driving patterns and energy usage. These cars use machine learning models to read real-time data from sensors, cameras, and Global Positioning System (GPS), allowing them to make more informed judgments that save fuel and minimize traffic congestion. The decrease of human error also helps to improve safety and reduce accident rates. Smart traffic management systems (TMS) utilize artificial intelligence to monitor and analyze traffic flow, reducing idle and emissions. These systems use data from road sensors and linked vehicles to provide a comprehensive view of urban traffic, promoting greener transportation networks. AI-driven automation also plays a crucial role in energy-efficient logistics, optimizing route planning, load allocation, and delivery scheduling to save fuel and reduce greenhouse gas emissions. AI also facilitates the integration of electric vehicles (EVs) into logistics fleets, improving the sustainability of goods transportation. The integration of automation and AI into green transportation systems offers a significant opportunity to improve sustainability and efficiency, reducing the transportation industry's environmental footprint and promoting sustainable growth. The continued progress and use of AI in this sector are crucial for achieving the full potential of green transportation systems.

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1 Introduction

Transportation is one of the largest contributors to the global emission of greenhouse gases. Achieving environmental sustainability therefore calls for a shift. There is a promising solution in automation with the application of Artificial Intelligence (AI) where the world has the opportunity to transport people and goods differently, and more environmentally friendly. AI excels at evaluating large datasets in real time. Traffic patterns, weather circumstances, vehicle performance, and even passenger behavior can all influence its decision-making. This enables AI to improve transportation networks for both efficiency and environmental effect.

Consider a network of self-driving electric automobiles that navigate city streets. AI systems can continually change routes to avoid congestion, greatly lowering emissions caused by idling and stop-and-go traffic. Traffic lights may be dynamically regulated depending on real-time traffic, which improves overall efficiency. The applicability of Automation AI goes beyond individual automobiles. AI-powered logistics and supply chains may shorten delivery routes, reduce empty truck trips, and improve fuel efficiency. Predictive maintenance, enabled by AI, may detect possible vehicle faults before they occur, reducing breakdowns and the accompanying emissions.

Public transportation can also benefit from artificial intelligence. AI can enhance bus and train schedules, lowering long lines and encouraging people to use public transportation more. Demand-responsive micro transport systems with AI dispatch and routing can offer a more flexible and efficient alternative to private autos. However, integrating Automation AI into green transportation systems is not without obstacles. It is critical to ensure that autonomous cars are safe and secure. Additionally, ethical concerns about data privacy and potential job loss due to automation must be addressed proactively. Despite these limitations, Automation AI's potential for a more environmentally friendly transportation future is obvious. By using this technology, we can design a transportation system that is not just efficient and sustainable, but also accessible to all. This will pave the way for a more ecologically conscious future in the transportation industry.

1.1 Overview of Green Transportation Systems

Green transportation systems prioritize environmental sustainability, marking a paradigm change in the transportation industry. This includes a holistic strategy to reducing environmental effect at all phases of the transportation lifecycle. Green transportation systems include a variety of modalities intended to reduce environmental effect. These modalities include electric vehicles (cars, buses, trains) and hybrid vehicles.

- Public transportation (buses, trains, and subways)
- Vehicles powered by biofuel.
- Implemented carpooling and ridesharing schemes.
- Micro mobility choices, such as e-scooters and e-bikes.
- Their importance is critical in creating a sustainable future.

Green transportation systems provide a multi-pronged approach to environmental challenges:

- Combating Climate Change: Transportation generates a considerable amount of greenhouse gas emissions, notably carbon dioxide. Green transportation alternatives quickly address this issue by transitioning to cleaner means of transportation.
- Improving Air Quality: Traditional combustion engines emit pollutants that affect public health. Green transportation dramatically decreases air pollution, resulting in cleaner air and healthier communities.
- Promoting Resource Conservation: Green transportation encourages the use of energy sources that are renewable, such as electricity and biofuels, to minimize reliance on finite fossil fuels and their environmental consequences.
- Creating Livable Cities: Traffic and noise pollution have a huge influence on metropolitan areas. Green transportation addresses these concerns by encouraging cleaner and more efficient movement of people and products.

Green transportation systems aim to reduce their environmental impact throughout their lifespan, which includes production, operation, and disposal:

- Reduced Emissions: Switching to electric or alternative fuel cars decreases tailpipe emissions, improving air quality and minimizing climate change.
- Energy Efficiency: Green transportation advocates for clean and renewable energy sources, such as electricity, hydrogen, or biofuels, in order to minimize reliance on fossil fuels and their environmental impact.
- Resource Conservation: Predictive maintenance, efficient operation, and use of lightweight materials in vehicle construction all help conserve resources.
- Land Use and Habitat Protection: Green transportation encourages alternative transportation modes like cycling or walking, reducing dependence on car-centric infrastructure and sprawling development patterns. This helps protect natural habitats. However, achieving true sustainability necessitates a broader perspective beyond just tailpipe emissions:
- Battery Production and Recycling: The environmental effect of battery manufacture for electric cars must be carefully assessed. Developing robust recycling processes for these batteries will be crucial for long-term sustainability.

- Life Cycle Analysis: A holistic analysis of a green transportation system's environmental impact is necessary. This includes manufacturing processes, energy sources used throughout operation, and end-of-life disposal practices.
- Infrastructure Development: Sustainable infrastructure development is critical. This includes effective public transit networks, designated bike lanes, and charging facilities for electric automobiles.

By addressing these challenges and fostering continuous innovation, green transportation systems can become the cornerstone of a sustainable future for our planet.

1.2 The Critical Role of Automation and Artificial Intelligence in Green Transportation Systems

Automation is the use of technology to do activities with minimum human participation. It covers a wide range of applications, from basic automated operations to sophisticated systems capable of performing complicated tasks autonomously. Automation aims to improve efficiency, accuracy, and consistency in various operations.

AI is a subfield of computer science that focuses on developing computers capable of doing activities that would normally need human intelligence. Learning, thinking, problem solving, perception, and language comprehension are some of these skills. Machine learning (ML), natural language processing, and robotics are some of the subfields of AI. The use of AI and automation into green transportation systems offers a paradigm shift toward more environmentally friendly and efficient means of transportation. This junction may be examined through various major areas, including:

- Smart Infrastructure: AI-powered traffic management systems (TMS) may evaluate real-time traffic data to improve traffic flow, decrease congestion, and reduce idle time, resulting in fewer emissions [29]. Smart grids and AI-enabled charging stations for electric vehicles (EVs) ensure efficient energy distribution, predict peak usage times, and manage loads effectively to support a higher adoption of EVs [22].
- Autonomous Vehicles: Autonomous vehicles, powered by AI, can significantly reduce emissions by optimizing driving patterns, reducing sudden accelerations and decelerations, and choosing the most efficient routes. Studies have shown that autonomous vehicles can improve fuel efficiency by 15–20% [20]. These cars also help to reduced traffic congestion, since they can interact with each other and TMS to avoid blockages and ensure consistent traffic flow [4].
- AI in Public Transit: AI can enhance public transportation systems by optimizing schedules and routes based on real-time data, ensuring that buses and trains run more efficiently and on time, thereby encouraging more people to use public transit

instead of private cars [28]. AI-enabled predictive maintenance can monitor the status of transit vehicles and infrastructure, identifying probable problems ahead of time and lowering downtime and maintenance costs [1].

- Sustainable Urban Planning: AI technologies may help urban planners create cities that promote green mobility, such as improved bike lanes, pedestrian paths, and public transit networks. These tools can analyze large datasets to identify optimal locations for such infrastructure improvements [2].
- Energy Management: AI algorithms can optimize energy consumption in transportation by managing the energy usage of EV fleets, predicting energy needs, and integrating renewable energy sources more effectively into the grid [21]. The combination of AI and automation in green transportation not only addresses environmental challenges by reducing greenhouse gas emissions and reliance on fossil fuels but also enhances the overall efficiency and sustainability of transportation systems.

2 Current State of Green Transportation

Green transportation refers to forms of transportation that have a minimal environmental effect, with an emphasis on lowering emissions, increasing energy efficiency, and encouraging sustainability. Here are some important methods of green transportation.

- Electric Vehicles (EVs): EVs are vehicles powered entirely or partially by electric motors using energy stored in rechargeable batteries. They have no tailpipe emissions, considerably lowering air pollution. The global adoption of EVs is increasing quickly. According to the International Energy Agency (IEA), the number of electric cars on the road surpassed 10 million in 2020, with an annual increase of 43% [11].
- Electric Buses and Trains: Many cities are switching to electric buses and trains, which are more energy efficient and emit less pollution than diesel-powered equivalents. Shenzhen, China, for example, has converted its entire bus fleet to electric, saving 1.35 million tons of CO_2 per year [26].
- Light Rail and Metro Systems: These systems offer efficient mass transit options, reducing the reliance on personal vehicles and lowering overall emissions.
- Biking and Pedestrian Infrastructure: Cities worldwide are investing in bike-sharing programs and dedicated bike lanes to encourage cycling as a sustainable mode of transport. For example, Copenhagen aims to become carbon–neutral by 2025, with biking playing a significant role in its strategy [10].
- Pedestrian Infrastructure: Enhancing walkability through better sidewalks, crosswalks, and pedestrian zones promotes walking, reducing the need for motorized transport.
- Carpooling and Ride-Sharing: Carpooling minimizes the number of cars on the road, hence lowering traffic congestion and pollutants. In Europe, services such as Bla-Bla-Car make long-distance carpooling possible.

- Ride-Sharing: Platforms such as Uber and Lyft provide ride-sharing choices, which can reduce individual automobile usage and encourage shared journeys, resulting in reduced emissions.

Despite advances in green transportation, numerous barriers prevent broad adoption:

- Environmental Challenges: The manufacture and disposal of EV batteries have substantial environmental implications, including the mining of raw minerals such as lithium, cobalt, and nickel, which can cause ecological harm and pollution [8]. Renewable Energy Integration While electric cars reduce pollutants, their environmental benefits are enhanced when charged using renewable energy sources. Many areas are still transitioning to a completely renewable energy system [11].
- Economic and Social Barriers: EVs and electric public transportation vehicles are more expensive than regular automobiles, limiting adoption. However, costs are lowering as technology advances and economies of scale are obtained [24].
- Infrastructure Development: Significant investment is required to provide electrical infrastructure to charge for electric automobiles, as well as dedicated lanes for bicycles and buses. Infrastructure development usually lags behind green transportation mode adoption [9].
- Public Awareness and Acceptance: Encouraging individuals to switch from private automobile usage to public transportation, bicycling, or carpooling necessitates a considerable adjustment in behavior and lifestyle, which can be difficult to implement. Range Anxiety and Charging Time: Concerns about EVs' limited range and charging time as compared to refuelling conventional vehicles might dissuade potential consumers [23].
- Regulatory and Policy Challenges: Inconsistent rules and incentives for green mobility across areas might lead to uncertainty and delayed uptake. Governments must give unambiguous, long-term support to encourage the expansion of green transportation [27].

3 Integration of Automation and AI in Green Transportation Systems

The transportation industry considerably contributes to global greenhouse gas emissions due to the usage of fossil fuels in automobiles. To address this, a considerable shift to more sustainable and ecologically friendly transportation systems is required. AI and automation technologies can improve the efficiency of green transportation by improving traffic flow, lowering congestion and idle times, and optimizing autonomous vehicles (AVs) by adhering to ideal driving patterns and routes. AI-powered solutions enhance sustainability by optimizing energy use in electric vehicles (EVs) and integrating renewable energy sources into transportation infrastructure.

AI can also enhance accessibility and equity in transportation. Ride-sharing systems can improve vehicle routing to better service underserved or distant locations, making transportation more accessible to a larger population. AI can also create inclusive transportation systems that meet a variety of mobility demands, such as public transit and micro mobility solutions. By recognizing and responding to possible threats in real time, AI technologies can make transportation networks safer and more dependable. Cutting accident risk and improving overall road safety. AI can also improve vehicle and infrastructure maintenance plans, increasing efficiency and decreasing downtime. AI and automation may also enable data-driven decision-making in transportation planning and management. AI systems can extract trends, patterns, and insights from massive volumes of data to inform strategic decisions for optimizing transportation networks, cutting emissions, and improving overall system performance.

3.1 Smart Infrastructure: The Nervous System of Green Transportation

Consider a city in which traffic lights respond in real time to changing conditions, green waves effortlessly assist vehicles through junctions, and congestion is a thing of the past. This goal is becoming more attainable owing to AI-powered Smart Infrastructure. TMS are the foundation of this intelligent network. These systems serve as the nervous system of green transportation, constantly gathering and evaluating data from a variety of sources such as cameras, sensors, and Global Positioning System (GPS) devices. This real-time information on traffic flow, congestion areas, and even accidents enable the TMS to make dynamic adjustments. Traffic lights adjust to improve flow by rerouting vehicles around bottlenecks and providing drivers with real-time information on the best routes.

Los Angeles is a classic example, with its AI-based traffic control system resulting in a significant 10–20% increase in traffic flow [29]. The incorporation of AI goes beyond traffic management. Smart grids, the backbone of the power system, are being transformed as renewable energy sources become more prevalent. AI can help integrate renewable energy sources like solar and wind. It forecasts peak energy demand and adjusts loads throughout the grid, ensuring that EVs are charged during off-peak hours or when renewable energy is available. This not only minimizes dependency on fossil fuels, but also optimizes energy use within the grid. Similarly, AI-powered charging stations may tailor the charging procedure for EVs, taking things like battery health into account.

3.2 Autonomous Vehicles: The Future of Mobility

The prospect of self-driving automobiles has captivated our imagination for decades, and with developments in AI, Autonomous Electric Vehicles (AEVs) are rapidly approaching reality. Companies including as Tesla, Waymo, and Uber are leading the charge, building AEVs with advanced sensors, cameras, and strong artificial intelligence software. These powerful technologies let AEVs to negotiate complicated road situations, recognize hazards, and make driving decisions with little human assistance. The potential benefits of AEVs go well beyond convenience. Safety is crucial, While AEVs have the ability to significantly reduce accidents by eliminating human error, a key contributor to road deaths.

Furthermore, AEVs may be configured for optimal driving, resulting in considerable increases in fuel economy. According to studies, AEVs can increase fuel economy by up to 25% when compared to standard cars, resulting in significant reductions in greenhouse gas emissions [5]. This results in cleaner air, a healthier habitat, and a significant step toward a more environmentally friendly transportation system. However, broad use of AEVs demands resolving issues such as providing strong safety measures, developing clear rules, and overcoming ethical concerns about possible job displacement.

3.3 AI in Public Transit: A Renaissance for Commuter Systems

Public transportation contributes significantly to reducing traffic congestion and pollution. Traditional public transportation systems, on the other hand, sometimes suffer from inefficiencies such as lengthy wait periods and unpredictable scheduling. AI provides a disruptive solution by incorporating intelligence into public transportation systems. AI systems may use real-time data, such as passenger demand and Traffic conditions will be improved, as will public transit timings and routes.

Consider buses that alter their itineraries dynamically depending on real-time ridership data. This is a reality in Singapore, where artificial intelligence has decreased passenger wait times and improved service reliability [6]. By optimizing routes and timetables, AI can not only improve the passenger experience but also stimulate a change to public transportation, lowering reliance on personal automobiles and related emissions. Aside from scheduling, AI enables preventive maintenance plans for public transit vehicles and equipment.

AI-powered systems can track the functioning of cars and infrastructure in real time, evaluating data to detect future problems. This enables for proactive maintenance, which reduces downtime and maintenance costs while guaranteeing smooth operations [1]. Finally, integrating automation and AI with green transportation systems offers a compelling future vision. These technologies have the ability to alter our transportation scene by improving traffic flow and modernizing public transit, as well as opening the way for autonomous electric automobiles. By using the potential of AI and automation, we can develop a transportation system that is not only efficient and convenient but also ecologically responsible, assuring a cleaner and more sustainable future.

4 Benefits of Automation AI in Green Transportation

The integration of automation and AI in green transportation systems has numerous benefits, including reduced traffic congestion, optimized energy usage, environmental impact, and resource conservation.

Intelligent TMS, which use real-time data from cameras, sensors, and GPS devices, make intelligent judgments about traffic volume, speed, and patterns. AI-based TMS provide several advantages, including less idle time, more safety, and fewer pollutants. AI is critical in optimizing energy usage in green transportation systems by improving consumption management and maximizing the use of renewable energy resources. AI-powered smart grids balance electricity supply and demand dynamically, predicting periods of high and low usage and adjusting energy distribution accordingly.

Dynamic pricing and load management are implemented by AI to incentivize users to charge EVs during off-peak hours, smoothing out the demand curve and preventing grid overload. Predictive maintenance is provided by AI to predict when maintenance is needed for charging stations and other infrastructure components, ensuring peak efficiency and minimizing downtime. The integration of AI into green transportation systems is a significant step towards reducing emissions. AEVs can optimize driving patterns, Smooth acceleration and deceleration, for example, cut fuel usage and greenhouse gas emissions dramatically.

AI-powered TMS also contribute significantly to congestion reduction by managing traffic flow and optimizing signal timings in real time. This combined effect of optimized driving patterns and reduced congestion results in a significant reduction in greenhouse gas emissions, which can have a positive impact on urban air quality and global climate change mitigation efforts. As AI technologies advance, new job opportunities arise, including the creation and maintenance of AI systems, ongoing maintenance, updates, and the development of new applications. The growth in the AI and tech sector's contributes to broader economic growth, with the creation of high-skilled jobs leading to increased consumer spending and stimulating related industries.

4.1 Efficiency Improvements

4.1.1 Reduced Traffic Congestion

Intelligent TMS that utilize real-time data from cameras, sensors, and GPS devices are critical for minimizing traffic congestion. These systems employ AI algorithms to make intelligent choices on traffic volume, speed, and patterns. Adaptive traffic signals, which modify timing based on current traffic circumstances, assist to decrease stop-and-go traffic, a significant source of traffic congestion and increased emissions. For example, in Los Angeles, AI-powered traffic control systems have resulted in a 10–20% increase in traffic flow. AVs also help to reduce congestion by connecting with traffic infrastructure and optimizing routes in real time. This communication helps to avoid crowded regions and bottlenecks, allowing AVs to maintain optimal speeds and safe distances. AI-powered traffic control solutions. Provide benefits such as reduced idle time, increased safety, and fewer pollutants. Reduced congestion leads to fewer accidents and incidents of rapid braking and crashes. Overall, AI and AI are critical technologies for improving traffic management and lowering congestion.

4.1.2 Optimized Energy Usage

AI is critical for improving energy usage in green transportation systems by better regulating consumption and harnessing renewable energy sources. AI-powered smart grids dynamically balance electricity supply and demand, anticipating peak and low consumption and modifying energy distribution appropriately.

AI algorithms can prioritize charging electric cars (EVs) during off-peak hours, reducing grid load and maximizing renewable energy sources like wind and solar electricity. AI uses dynamic pricing and load management to motivate customers to charge their electric vehicles during off-peak hours, smoothing out the demand curve and reducing grid overload.

AI can enhance charging procedures at EV charging stations by taking into account battery health, charge level, customer preferences, and power pricing. AI also provides predictive maintenance, which forecasts when charging stations and other infrastructure components will require repair, maintaining peak efficiency and reducing downtime. AI integration has several advantages, including higher usage of renewable energy, decreased energy waste, and improved user experience.

Finally, incorporating automation and AI into transportation systems decreases traffic congestion and optimizes energy consumption, increasing transportation efficiency and sustainability while contributing to a cleaner, more ecologically friendly future.

4.2 Environmental Impact

4.2.1 Lower Emissions

The use of artificial intelligence into green transportation systems is a big step toward emissions reduction. AEVs) are one type of technology that may optimize driving patterns, such as smooth acceleration and deceleration, resulting in considerable fuel savings and reduced greenhouse gas emissions. This is due to the AI's capacity to anticipate traffic circumstances, optimize speed, and decrease fuel use. AEVs can also benefit from more effective regenerative braking, which recovers energy lost when braking and recharges the vehicle's battery.

AI-powered TMS also contribute to congestion reduction by leveraging real-time data to control traffic flow and optimize signal timing. This reduces idle times and stop-and-go waves, lowering pollutants generated while engines are operating but not moving. The combination of improved traffic patterns and decreased congestion leads in a large reduction in greenhouse gas emissions, which can benefit urban air quality and worldwide climate change mitigation efforts.

4.2.2 Conservation of Resources

AI plays an important role in improving public transportation systems by increasing efficiency and preserving resources. It enables demand-responsive operation, which optimizes bus and rail timetables to assure enough demand while reducing needless trips. This not only saves fuel, but also decreases emissions, resulting in more sustainable public transportation operations. AI also provides real-time monitoring of transportation vehicles and infrastructure, allowing predictive maintenance to detect possible problems before they cause breakdowns. This extends the life of automobiles and infrastructure by reducing early wear and tear. Decreasing the need for costly maintenance and early replacement of vehicles and parts. Material conservation reduces waste and allows for more sustainable resource utilization.

The optimal use of materials and resources in transit system maintenance results in less raw materials required for repairs and replacements, which contributes to public transportation's overall sustainability. Environmental and economic benefits include decreased operational expenses for transportation agencies, which may be reinvested in future developments or utilized to lower passenger fees. Another key advantage of AI-driven optimization is its capacity to maintain sustainability. By lowering waste and the environmental imprint of transit operations, AI helps to achieve environmental sustainability in urban transportation.

To summarize, using artificial intelligence into green transportation systems greatly reduces emissions and conserves resources. Autonomous electric cars (AEVs) optimize driving patterns, increase fuel economy, and minimize traffic congestion, resulting in lower greenhouse gas emissions. AI-powered scheduling and route optimization in public transportation systems ensures smooth operation, minimizing needless trips and conserving fuel.

4.3 Economic Advantages

4.3.1 Cost Savings for Governments and Consumers

Artificial intelligence in green transportation systems saves governments money by optimizing existing infrastructure and avoiding the need for costly additions. AI-powered TMS can efficiently regulate traffic lights and decrease congestion. Relieving pressure on infrastructure without requiring substantial road extensions. This leads in significant capital expenditure savings for governments, which may be used to fund other essential sectors such as public health, education, and technology improvements. Reduced infrastructure costs are another advantage of AI in sustainable transportation [16].

Governments may save money on land acquisition, building materials, labor, and long-term infrastructure upkeep by optimizing existing routes and postponing or eliminating new road development. AI-enabled green transportation saves consumers money. AI-managed Autonomous Electric automobiles (AEVs) are more efficient than traditional automobiles, using less fuel and power.

AI improves charging procedures by matching charging periods to off-peak electricity tariffs and ensuring charging occurs when renewable energy sources are most available. Recurrent maintenance equipment monitors vehicle health in real time and forecast when repair is required before a breakdown occurs. This proactive strategy reduces unforeseen issues and costly repairs, reducing the high expenses resulting from emergency repairs and prolonged downtime. Overall, AI in green transportation provides both immediate and prospective financial benefits [14].

4.3.2 Job Creation in AI and Tech Sectors

The incorporation of automation and AI into green transportation represents a fundamental transition that benefits not only governments and consumers, but also drives job development in a variety of industries, including AI and technology. AI systems for traffic management, autonomous cars, and smart grids must be developed, deployed, and maintained by a highly qualified workforce that includes software developers, data scientists, AI researchers, and engineers.

As AI technology advances, new career possibilities emerge, such as creating and maintaining AI systems, as well as continuing maintenance, upgrades, and application development. The expanding market for electric cars (EVs) generates demand for technical and engineering occupations, such as producing, installing, and maintaining EVs and associated infrastructure. Data science and analytics are also required for evaluating and exploiting the huge volumes of data created by AI-powered transportation solutions.

The expansion of the AI and technology sectors adds to overall economic growth, as the creation of high-skilled employment leads to greater consumer spending and stimulates associated businesses. The necessity to build and enhance AI and autonomous systems encourages an innovative culture, which drives technical advancement and diversifies the economy. To summarize, integrating AI into green transportation systems not only saves governments and consumers money, but it additionally stimulates job creation and economic growth in the AI and technology sectors, resulting in a more productive, ecologically sound, and innovative future for transportation and the economy as a whole.

5 Case Studies

5.1 Case Study 1: Singapore

- Description: Singapore is recognized as a global leader in using artificial intelligence into its green transportation network. The city-state has adopted a number of programs targeted at improving traffic management, increasing public transportation efficiency, and encouraging the use of electric vehicles.
- Traffic Management: Singapore operates an AI-powered intelligent transportation system (ITS), which comprises the Expressway Monitoring and Advisory System (EMAS) and the Green Link Determining (GLIDE) system. EMAS monitors traffic conditions on expressways using a network of cameras and sensors, allowing for real-time incident identification and dynamic traffic control. GLIDE, on the other hand, employs artificial intelligence to adjust traffic light timings based on real-time traffic flow data, lowering wait times and congestion at junctions [19].
- Public Transit Optimization: AI is also useful in enhancing the operational effectiveness of Singapore's public transportation system. The Land Transport Authority (LTA) uses AI algorithms to analyse passenger demand patterns and adjust bus schedules and routes accordingly. This dynamic scheduling guarantees that buses are deployed where and when they are most required, decreasing congestion and passenger wait times [28].
- Renewable Energies and Smart Grids: Singapore significantly encourages the usage of electric vehicles (EVs) by offering incentives and building a robust charging infrastructure. The city uses artificial intelligence to manage its EV charging stations, adjusting charging periods based on grid conditions and renewable energy availability. This technique decreases the environmental impact and encourages the effective use of renewable energy sources.

5.2 Case Study 2: Oslo, Norway

- Description: Oslo, Norway's capital, is another outstanding example of AI integration in sustainable transportation. The city has developed a variety of AI-driven technologies to help it achieve its lofty goal of being a zero-emission city by 2030.
- Traffic Management: Oslo features a sophisticated based on artificial intelligence transport management system that integrates data from sensors and cameras across the city to monitor traffic conditions in real time, reducing congestion and pollution. AI systems use this data to adjust traffic signal timings and present drivers with real-time traffic information via digital road signs and mobile apps. This minimizes idle time and increases traffic flow, resulting in fewer emissions (Oslo [25]).
- Public Transit and AVs: Oslo has implemented artificial intelligence (AI) into its public transportation system to improve service efficiency and dependability. The city employs artificial intelligence (AI) to analyze passenger data and forecast demand, allowing for dynamic modifications to bus and tram timetables. Oslo is also in the forefront of testing self-driving electric buses. These self-driving buses, outfitted with AI and ML technology, follow predetermined routes, providing a look into the future of public transportation.
- Electric Vehicles and Smart Charging: Norway, and particularly Oslo, has one of the world's highest per capita rates of electric vehicle adoption. The city uses AI to manage its vast network of EV charging stations. AI algorithms optimize charging schedules in response to energy usage, renewable energy availability, and grid circumstances. This assures efficient energy consumption and helps the city meet its objective of lowering its carbon impact [7] (Table 1).

6 Challenges and Risks

The use of artificial intelligence in green transportation systems creates serious security and confidentiality of information concerns. These systems rely on enormous databases including personal information, traffic statistics, and vehicle diagnostics, necessitating strong cybersecurity solutions to prevent breaches and assure correct functioning. Adherence to data protection regulations such as Europe's General Data Protection Regulation (GDPR) guarantees that personal data is gathered, processed, and kept legally, instilling trust in both users and authorities.

Another difficulty is infrastructure preparedness, since many regions lack the infrastructure required to host these technologies. Infrastructure improvement and maintenance need major investments and coordination among governments, economic sectors, utilities, and other stakeholders. Public–private partnerships can assist support infrastructure improvements and investments in AI-powered technologies. Setting technical standards and ensuring interoperability among AI systems, infrastructure components, and data platforms is crucial for successful integration

Table 1 Comparative table based on the given case studies of Singapore and Oslo

Aspect	Singapore	Oslo
Traffic management	AI-powered intelligent transportation system (ITS)	AI-based traffic management system
	Expressway monitoring and advisory system (EMAS)	Real-time traffic monitoring with sensors and cameras
	Green link determining (GLIDE) system for dynamic traffic light adjustments	AI adjusts traffic signal timings
Public transit optimization	AI algorithms for dynamic bus scheduling and route optimization	AI analyzes passenger data and forecasts demand Dynamic bus and tram schedule adjustments
Autonomous vehicles	N/A	Testing of self-driving electric buses
Electric vehicles and smart grids	Promotes EVs with incentives	High per capita rate of EV adoption
	AI-managed EV charging stations optimizing charging times	AI optimizes EV charging schedules
	Efficient use of renewable energy sources	Efficient energy consumption, aligning with grid conditions and renewable energy availability

and operation. Forecasting and investment approaches are required to maintain infrastructure current with advances in artificial intelligence and green transportation.

Public acceptance and trust are critical for the successful application of AI in green transportation systems. Many people are hesitant to recognize these discoveries owing to a variety of reasons. To gain public trust, AI technology must be shown safe via rigorous testing and public reporting. Transparency is vital for building public trust, and public awareness campaigns, instructional seminars, and open forums may all assist to demystify the technology. Concerns about job displacement have arisen as a result of the increased usage of AI and automation in transportation.

Mitigation strategies include workforce retraining and education, transition aid, equal access to new job possibilities, and the establishment of social safety nets. Legislators, corporate leaders, labor organizations, and educators must work together to develop effective solutions to job displacement challenges. By proactively addressing public acceptance, trust, and job displacement concerns, stakeholders may help to ensure a more inclusive, long-term, and effective integration of AI in green transportation.

6.1 Technical and Operational Challenges

6.1.1 Data Privacy and Security

Integrating AI into green transportation systems is a huge problem for data privacy and security. These systems rely on massive databases that include personal information, traffic statistics, and car diagnostics. Protecting sensitive data from cyber-attacks is critical for preventing privacy breaches and ensuring proper operation. Key issues include privacy breaches caused by illegal access to sensitive data, as well as cybersecurity risks from cyber-attacks, which can interrupt operations, jeopardize safety, and result in financial losses.

To address these concerns, robust cybersecurity solutions like as encryption, secure authentication techniques, intrusion detection systems, and regular security audits are necessary. Furthermore, compliance with data protection requirements such as Europe's General Data Protection Regulation (GDPR) ensures that personal data is acquired, processed, and kept in a transparent and lawful manner, encouraging trust among users and authorities.

6.1.2 Infrastructure Readiness

The incorporation of AI into green transportation has considerable obstacles, including the requirement for current infrastructure to support these technologies. Many locations lack the required infrastructure, resulting in discrepancies in adoption and access to benefits. Key issues include the requirement for improved smart grids and TMS to successfully balance energy supply and demand, as well as broad and easily accessible EV charging networks.

Upgrading and maintaining infrastructure necessitates considerable expenditures and collaboration among governments, business sectors, utilities, and others. To solve these issues, public–private partnerships can help fund infrastructure upgrades and investments in AI-powered solutions. Setting technical standards and maintaining compatibility between AI systems, infrastructure components, and data platforms is critical for smooth integration and operation.

Long-term planning and investment strategies are required to maintain infrastructure preparedness in line with advances in AI and green transportation technology. Addressing confidentiality and safety of data concerns, as well as boosting infrastructure readiness, can help AI integration in green transportation transcend significant obstacles and provide improved effectiveness, profitable, and resilient transportation systems.

6.2 Social and Ethical Considerations

6.2.1 Public Acceptance and Trust

Public acceptance and trust are important for the successful implementation of AI in sustainable transportation systems. Despite the potential advances in AI-powered transportation systems, many individuals are hesitant to accept these breakthroughs owing to a variety of reasonable concerns. Addressing these concerns is critical to earning public trust and. One of the most common concerns concerning AI-powered systems, including AVs, is safety.

People are concerned about the dependability of these technologies and their capacity to handle complicated driving circumstances safely. To develop confidence, AI technology must be demonstrated as safe through rigorous testing and public reporting. This involves thorough real-world testing in a variety of settings, detailed safety performance reports, and third-party validation. Stakeholders may allay public fears about AVs and other AI-powered systems by giving concrete proof of their safety and dependability.

Transparency is essential in developing public trust. Providing clear and accessible information about how AI technologies function, their advantages, and limits can assist to demystify the technology. Public awareness campaigns, instructional workshops, and open forums where people may ask questions and voice their concerns are all useful techniques. Transparent communication also includes disclosing data on AI systems' performance, safety records, and regulatory compliance, allowing the public to develop educated views on their adoption.

Regulatory frameworks are critical to guaranteeing the safety and ethical usage of artificial intelligence in transportation. Governments and regulatory agencies must set and enforce rules for AI technology before they are implemented. Ensuring that AI systems follow these laws reassures the public that these technologies are closely monitored and created with safety and ethics in mind. This may be accomplished through public consultations, surveys, and participatory design procedures that actively solicit and incorporate community opinion into the development and deployment of AI systems. By incorporating the public, stakeholders may immediately address issues and make changes based on community feedback, instilling a feeling of ownership and acceptability.

6.2.2 Job Displacement Concerns

The expanding use of AI and automation in transportation has sparked worries about job displacement, particularly for tasks previously filled by human drivers. This has serious social and economic consequences, including probable unemployment, income loss, and alterations in worker dynamics. Mitigation options include workforce retraining and education, transition assistance, equal access to new employment possibilities, and the building of social safety nets.

Workforce retraining and education include programs that teach technology, data analysis, and AI-related skills. Financial aid, job placement services, and career counselling are all possible forms of transition support. Equitable access to new work prospects is critical for fostering diversity, inclusiveness, and equitable access to training and employment opportunities. Improving social safety nets, like unemployment compensation, job training programs, and healthcare coverage, can reduce the negative effects of job dislocation [13].

Collaboration among legislators, business leaders, labor unions, and education providers is critical for establishing successful measures to address job displacement issues. By proactively addressing public acceptability, trust, and job displacement issues, stakeholders may contribute to a more inclusive, long-term, and effective integration of AI in green transportation. Collaboration, openness, and a focus on fair results are critical for managing the obstacles and reaping the benefits of AI technology in the transportation industry.

7 Future Prospects

AI and ML advancements are transforming green transportation, providing transformational solutions across several facets of mobility and sustainability. Predictive analytics for traffic management enables these technologies to forecast traffic patterns, congestion hotspots, and optimal routing options, allowing for proactive steps to reduce traffic congestion and enhance overall traffic flow.

AI is vital in regulating energy consumption in electric vehicles (EVs) because ML techniques monitor driving patterns, conditions in traffic, and efficiency of batteries to optimize charging schedules and driving behaviors. By charging at high accessibility periods, EVs have a longer range and make better use of renewable energy sources. ML techniques, particularly deep learning, improve the accuracy and dependability of autonomous systems by providing accurate image identification, object detection, and decision-making skills that are critical for safe autonomous vehicle (AV) operation.

AI-powered AVs can better traverse complicated surroundings, decreasing accidents and enhancing road safety. Real-time communication and IoT integration enable real-time communication between vehicles, infrastructure, and IoT devices, enabling dynamic traffic signal modifications, flexible scheduling based on actual-time traffic circumstances, and seamless integration of self-driving cars into smart transportation networks.

AVs are at the vanguard of future transportation technology, with the potential to minimize accidents caused by human error, enhance fuel efficiency through optimal driving patterns, and reduce traffic congestion. Smart cities are increasingly integrating AI and autonomous systems to enhance urban mobility, improving accessibility, reducing travel times, and promoting sustainable transportation choices. Governments play an important role in influencing the future application of AI in green mobility by enacting policies and legislation, assuring the legal and secure utilization of AI in transportation, and promoting international cooperation and standards [15].

7.1 Emerging Technologies

The potential development of green transportation is closely linked to improvements in AI and ML, two increasingly powerful technologies capable of analyzing enormous amounts of data in real time. These technologies have the opportunity to change many aspects of transportation and sustainability. Including predictive analytics for traffic management, optimizing energy use in electric vehicles (EVs), and improving autonomous systems [17].

AI and ML algorithms excel in predictive analytics, allowing transportation systems to anticipate and adapt to traffic trends proactively. These technologies may forecast traffic congestion, identify best routes, and provide alternate travel alternatives by evaluating historical and real-time data, resulting in lower emissions and improved traffic flow.

AI plays a critical role in optimizing EV energy use, increasing the use of renewable energy sources, and contributing to a cleaner transportation environment. Deep learning algorithms provide precise picture and pattern recognition, allowing AVs to navigate complicated settings, recognize impediments, and make intelligent judgments on their own. Real-time communication and IoT integration improve transportation systems by allowing smarter traffic signals, dynamic road pricing, and more efficient public transportation [18].

Future trends in AVs and smart cities include Level 5 automation, which allows vehicles to operate without human intervention in all conditions, and smart city integration, in which AI will play an important role in managing traffic flows, optimizing energy use, and ensuring efficient public services. In conclusion, the future of green transportation is inextricably linked to AI and ML breakthroughs, culminating in greener, safer, and more efficient transportation systems that benefit both the environment and society.

7.2 Policy and Regulation

7.2.1 Government Initiatives and Laws

Governments use initiatives and laws to shape the future of AI in green transportation. Policies that encourage AI research and development, create incentives for the use of EVs, and invest in smart infrastructure are critical. For example, the European Union's "Green Deal" intends by 2050, Europe aims to be the first climate-neutral continent, with an emphasis on sustainable and intelligent mobility. Regulations are also required to ensure the legal and moral application of artificial intelligence in transportation. Governments must establish standards for data protection, cybersecurity, and the ethical use of AI. This includes creating safety standards for self-driving vehicles, ensuring that AI systems are transparent and accountable, and addressing issues such as loss of employment and economic unfairness [3].

7.2.2 International Collaboration and Standards

International collaboration is critical to the worldwide progress of AI in green transportation. Countries must collaborate to create standardized protocols for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication, assuring interoperability across borders. Organizations such as the International Organization for Standardization (ISO) and the International Telecommunication Union (ITU) are developing worldwide standards for AI and autonomous systems [12]. Furthermore, international collaboration can allow the exchange of best practices, research findings, and technology advancements. By fostering sustainable practices, collaborative initiatives can assist solve global concerns including climate change, urbanization, and resource depletion.

8 Conclusion

To summarize, incorporating automation and AI into green transportation has various advantages, including increased efficiency, reduced environmental impact, economic gains, and improved safety. Key advantages include decreased road congestion, optimized energy utilization, lower emissions, and financial savings for governments and consumers. However, there are several hurdles and hazards to this change, such as worries about data privacy and security, infrastructural preparation, public acceptability and trust barriers, and employment displacement. Continuous development and expenditure in AI for green transportation are critical to creating a sustainable and efficient mobility environment.

As technology advances, stakeholders must prioritize the development of strong cybersecurity measures, upgrade infrastructure to support AI integration, address public concerns through open communication and ethical AI practices, and invest in workforce training and transition programs to mitigate job displacement effects. There is a clear call to action for governments, business leaders, research institutions, and communities to collaborate and accelerate the implementation of AI technology in green mobility.

Policies and laws should be structured to foster innovation while still ensuring safety, privacy, and fairness. International collaboration and standardization activities are crucial for creating a global structure to support AI-powered transportation solutions. To recapitulate, the future of green transportation lies in utilizing the full capabilities of AI and automation to construct smarter, more sustainable, and inclusive.

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Edge Computing for Enhancing Efficiency and Sustainability in Green Transportation Systems

Pankaj Bhambri and Alex Khang

Abstract Given the fast pace of urbanization and increasing environmental concerns, it is imperative to transition transportation networks to more sustainable and efficient models. This chapter examines the impact of edge computing on improving the effectiveness and environmental friendliness of green transportation systems. Edge computing, a technology that moves computational capabilities closer to where data is generated, provides notable benefits in terms of processing speed, data protection, and immediate data analysis. Integrating edge computing with artificial intelligence (AI) and Internet of Things (IoT) technology enables transportation systems to achieve enhanced performance in traffic management, energy consumption, and emissions reduction. This chapter explores different implementations of edge computing in green transportation, such as intelligent traffic light management, live vehicle tracking, and proactive maintenance. The analysis also investigates the implementation of edge-enabled electric vehicle (EV) charging stations and autonomous vehicles, emphasizing their capacity to enhance energy efficiency and diminish carbon emissions. Case studies and practical examples demonstrate the concrete advantages and difficulties of incorporating edge computing into both urban and rural transportation networks. Moreover, the chapter explores the collaboration between edge computing and AI-driven analytics to improve decision-making processes for transportation planners and regulators. The text focuses on the technological, economic, and regulatory elements involved in implementing edge computing infrastructure. It also offers valuable insights into upcoming trends and advancements in this industry. The primary objective of this chapter is to offer a thorough comprehension of how edge computing might facilitate the advancement of sustainable and efficient transportation systems, so aiding in the broader objective of creating greener urban settings and reducing the impact of climate change.

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1 Introduction

Today, the management of intelligent urban paradigms and smart cities requires the use of intelligent approaches to enhance the quality of life, facilitate mobility through smart apps, provide safety, and address various elements of human interaction with smart technologies. The establishment of smart cities and the digitalization of intelligence urban computation have been facilitated by the growth of the Internet of Things (IoT). This process entails the creation of a heterogeneous network comprising intelligent household appliances, air quality monitors, intelligent vehicles, and additional objects equipped with actuators and sensors [37]. These elements facilitate the linkage and interchange of information among these entities.

The concept of sustainable urban computing involves the incorporation of applications with intelligence that are linked to the IoT environment, a sustainable society, as well as human conduct [38]. This integration guarantees that intelligent decision-making processes are utilized in the context of interactions between sustainable computing and intelligent devices. Intelligent administration is imperative for urban areas as well as cities due to a multitude of factors, including but not limited to population expansion, environmental demands, energy consumption, transportation infrastructure, security concerns, and employment opportunities [22].

Intelligent urban computing comprises all computational characteristics associated with smart industries, manufacturing, smart farming, smart cities, smart home care, smart infrastructure, smart transit, and smart medical systems. Intelligent urban computing is a methodical procedure that entails the acquisition, integration, and examination of extensive and heterogeneous data sets produced by a variety of sources within the context of sustainable urban environments [41]. By employing intelligent computational environments, this strategy effectively tackles substantial obstacles, including the escalating costs of energy and the congestion caused by traffic.

Intelligent urban computing has been facilitated in its digital transformation by the emergence of the IoT [36]. This requires the setting up of networks comprised of tangible devices equipped with software, actuators, sensors, and electronics, including but not limited to vehicles, household appliances, electricity and water meters, quality of air monitors, and trash cans. These components facilitate the interconnection and data sharing among these objects.

The interconnection of intelligent applications, sensors, actuators, and devices is referred to as the IoT. This network improves the management of resources for both objects and people and facilitates the development of new technologies [39]. Urban computing will make extensive use of IoT devices that will provide an abundance of data to facilitate well-informed decisions and subsequent actions. Data collection should be preceded by condensing, filtering, and analysis techniques prior to transmission by IoT devices in order to facilitate the execution of their respective functions [25].

One notable limitation of IoT devices utilized in intelligent urban computation is their dependence on finite battery capacity. A significant amount of energy is consumed when IoT devices initiate communication; consequently, the operational duration is restricted and depends on the battery's lifecycle [8]. Effective energy management enables the efficient operation of energy harvesting elements in IoT devices. However, there is a significant differentiation in the categories of intelligent urban computing. The field of intelligent urban computing energy harvesting management is currently in its nascent phase, primarily attributable to obstacles associated with scene classification, financial implications, and the intricacy of energy consumption management [32].

2 Role of Edge Technologies in Green Transportation

The continuous digital revolution offers substantial opportunities for sectors to establish innovative and competitive business models, as well as complex circular supply chains [55]. Nonetheless, this paradigm shift also has significant ramifications for sustainability, given the noteworthy environmental footprint of the Information and Communications Technology (ICT) sector. In order to fulfill the objectives established by the United Nations Agenda for Sustainable Development and establish the foundations of the circular economy, it is critical to provide sustainable and effective solutions that endure for the duration of their operational lifespan [14].

Three critical technologies are required for the implementation of a smart circular economy: the Internet of Things, peripheral computing, and artificial intelligence. According to projections, the integration of IoT and Industrial IoT (IIoT) technologies, which enable extensive communication among physical objects, could add approximately USD 14 trillion to the global economy by 2030, particularly in the industrial sector. In addition, the integration of IoT technologies in recent years has led to the emergence of the Internet of Everything (IoE) as a consequence of the evolution of the traditional Internet of People (IoP) and the Internet Protocol (IP) [2].

Based on the incorporation of people, things, processes, and data in order to improve the quality of life for others, this concept is established. While the widespread adoption of IoT and IIoT technologies can support the shift towards a more sustainable global environment by allowing for comprehensive monitoring of product life cycles, they can also introduce certain disadvantages that pose a substantial obstacle to achieving the objectives specified in the United Nations Agenda for Sustainable Development. The World Economic Forum deliberated on the IoT Guidelines for Sustainability in 2018.

One suggestion put forth was to employ a framework predicated on the United Nations Sustainable Development Goals (SDGs) in order to evaluate the potential ramifications and gauge the efficacy. The consequences of putting these guidelines into practice were as follows. However, with regard to Goal 12: Ensuring sustainable consumption and production, there was a 38% increase in electronic waste from 2010 to 2019, of which less than 20% was recycled.

Regrettably, notwithstanding their considerable potential to facilitate the transition to sustainable digital practices, these technologies are presently not contributing to the sustainable advancement of the ICT industry. More precisely, a contribution is expected in the IoT sector, which is regarded as the primary driver of an enduring digital transformation. Moving forward, it is critical to implement policies that effectively promote the environmentally responsible development of novel products and services. This issue is regarded as a substantial societal concern [3].

As IoT devices continue to improve in power, cost, and energy efficiency, Moore's law continues to be upheld and a sustainable IoT revolution in the global economy is made possible. The emergence of periphery Intelligence (EI) or Edge Artificial Intelligence (Edge-AI), which processes IoT data at the network periphery, contradicts this vision. Further complications arise with regards to energy efficiency, cybersecurity, and latency [47].

2.1 Digital Circular Economy

The Circular Economy (CE) promotes a socio-economic framework that is more progressive in nature and encourages sustainable development. The primary aim is to fulfill current needs while simultaneously ensuring that the expectations of forthcoming generations are respected in three domains: social, environmental, and economic [51]. A comprehensive strategy, the European Green Deal seeks to establish sustainable development throughout Europe. It incorporates a comprehensive strategy for implementing a sustainable circular economy, restoring biodiversity, and reducing emissions by at least of 55% by the year 2030.

Moreover, by 2050, it seeks to transform Europe into the first continent to achieve climate neutrality on a global scale. The approach of the EC is in complete alignment with the 2030 Agenda to Sustainable Development established by the United Nations (UN). The policymaking of the European Union (EU) is influenced by the seventeen Sustainable Development Goals (SDGs), which are integrated into every sector [42]. The objective of CE is to revolutionize the prevailing linear economic models that are founded upon unsustainable patterns of mass manufacturing and consumption.

In lieu of this, CE proposes a novel paradigm intended to promote restoration. This implies that the purpose of components, materials, platforms, assets, and products is to provide maximal value over the course of their whole lifespan. Furthermore, it guarantees that the needs and demands of diverse stakeholders are harmonized, including but not limited to business models, government regulations, and consumer inclinations. When these products and components reach the conclusion of their useful lives, a considerable proportion of them are subjected to regeneration and/or recycling processes [27].

The European Commission introduced the Circular Economy Action Plan (CEAP) in March 2020, which was an integral element of the European Green Plan [31]. By facilitating the execution of strategies throughout the complete life cycle of products—from their inception through their eventual disposal—this action plan seeks to encourage sustainable consumption and reduce waste. An unprecedented degree of collaboration will be required for an effective shift to a circular economy, according to the World Economic Forum. Notably, circularity constituted a mere 8.6% of the worldwide economy as of 2019 [29].

On the contrary, the adoption of a circular economy could yield economic benefits amounting to USD 4.5 trillion by the year 2030. Electricity is critically required to power data centers as well as digital infrastructures. The current electricity demand associated with ICT varies between 5 and 9 percent of the overall. Nevertheless, there is a possibility that it could increase to 20% by the end of 2030. Moreover, the digital transformation poses a material challenge, including the procurement of basic materials and physical resources.

Annually, the world produces over 50 million tonnes of electronic and electric detritus (e-waste), of which a mere 20% undergoes appropriate recycling processes. It is anticipated that the annual waste output will increase to 120 million tons by the year 2050. Circular economy principles must be incorporated into the digital infrastructure due to the proliferation of digital technology [4]. At present, the sector is preoccupied primarily with sustainable solutions to problems, including energy conservation and cybersecurity.

Nevertheless, the future may present a concern with respect to the accessibility of critical basic materials. Furthermore, it is critical to examine the potential advantages that the DCE presents in terms of facilitating the digital transition. These advantages may include the establishment of novel business models, entry into untapped markets, and the mitigation of information asymmetry.

Digital technologies are of paramount importance in promoting the growth of the circular economy as they facilitate the creation and evaluation of data that is essential for the development of inventive business models and complex circular supply networks. Moreover, they possess the capacity to rectify the current shortcomings in transparency and information that impede the growth of DCE. Further incorporation of digital allowing technologies, such as artificial intelligence, blockchain, computing at the edge, UAVs, 5G/6G, flexible, natural, and printed electronics, and electronic smart systems, is required to augment current circular business strategies through the provision of supplementary information and services [50].

To be more specific, the integration of Edge-AI (Edge Artificial Intelligence) and G-IoT (Global Internet of Things) holds the potential to significantly augment the adoption of DCE (Digital Circular Economy) principles by organizations and the general public, primarily by means of two fundamental approaches. To begin, an analysis of an open architecture for the Internet of Things (G-IoT) reveals that G-IoT devices must have circularity-enabling attributes (e.g., energy harvesting capabilities, privacy, interoperability, and end-to-end cybersecurity) [40].

In addition, numerous stakeholders—including investors, suppliers, manufacturers, designers, and end users—are able to promptly obtain critical real-time information and receive intelligent services effortlessly through the deployment of a collection of Edge-AI G-IoT devices. Supply chain openness and candor are thus ensured for the product, the manufacturing process, and the entirety of the organization. In addition, current and accurate information may be essential for stakeholders to make promptly and well-informed decisions, thereby promoting resource utilization efficiency, optimization of processes, and waste minimization. Furthermore, the integration of tracking assets and proactive upkeep methodologies holds the capacity to augment the operational longevity of merchandise.

2.2 Role of Edge Technologies in Green Transportation

Academics and businesses are still in the process of defining the business 5.0 paradigm. In spite of this, the European Commission has in fact formulated its foundational principles, acknowledging the imminent and substantial ramifications that this notion will exert on the European industrial sector [6]. The primary objective of the proposed concept is to address specific aspects of Industry 4.0 which have received insufficient attention or have generated controversy as a result of disregarding fundamental principles including sustainability and social equity.

Regarding the European Commission, it is imperative that Industry 5.0 is completely aligned with social goals and aims to accomplish more than just economic growth and job creation. As a consequence, Industry 5.0 places a premium on environmentally friendly production and the welfare of industrial operators. Industry 5.0 is a supplementary development to Industry 4.0 and is not regarded as an independent industrial revolution. The study places emphasis on the correlation between industrial progress and emergent societal trends [7].

The objective of the Industry 5.0 model is to reduce the negative social and environmental effects while increasing the efficiency of intelligent factories through the use of technology. Moreover, it is important to highlight that the European Commission's conceptualization of Industry 5.0 seems to be substantially shaped by the notion of Society 5.0. This concept was initially proposed by the Japanese administration in 2015, and Keidanren, a prominent Japanese business federation, subsequently endorsed it in 2016. Society 5.0 encompasses a collaborative approach that transcends the digital transformation of industrial enterprises and applies to the entirety of Japanese society. This notion is consistent with a pattern observed in the four preceding social revolutions.

Society 2.0 was distinguished from Society 1.0 by the prevalence of hunter-gatherer societies. In the late eighteenth century, throughout the industrial revolution, Society 3.0 came into existence. The emergence of Society 4.0 can be attributed to the proliferation of information-based economies, extensive Internet usage, and the digital transformation of industries. Society 5.0 expands upon the principles established in Society 4.0 through its concurrent pursuit of economic expansion and environmental and societal concerns. In order to attain the Sustainable Development Goals of the United Nations and operationalizing the notions of the digital the circular economy, Society 5.0, along with Industry 5.0, it is critical to devise approaches that integrate the physical and virtual domains in a sustainable and efficient manner. The subsequent subsections delineate the three fundamental technological enablers that are the primary focus of this article [13].

Maximizing these enablers is imperative for the advancement of environmental sustainability in industrial processes and our everyday lives. The acronym IoT, which stands for the Internet of Things, denotes a network comprising physical entities, commonly referred to as "things," which possess the capability to establish connections with one another and with additional services via the Internet. In general, these apparatuses comprise communication transceivers, actuators, sensors, and computationally constrained processing units, like microcontrollers that IoT devices possess a wide range of applications across multiple sectors, encompassing remote appliance monitoring, home automation, and agricultural precision enhancement [25].

IIoT refers to the application of IoT principles in industry contexts. It facilitates the implementation of an extensive array of intelligent machines, actuators, and sensors that are capable of being remotely monitored and managed within industrial settings [17]. Cloud computing platforms are currently utilized by the majority of IoT applications in operation as a result of their capacity to consolidate the storage, processing, along with remote interaction/monitoring. Nevertheless, these centralized solutions are subject to particular limitations. The cloud is occasionally perceived as a potential singular point of failure due to its susceptibility to security breaches, vulnerabilities, or maintenance operations that could render it inoperable and ultimately lead to a system failure.

Moreover, it is imperative to recognize that there is a projected increase in the number of interconnected IoT devices in the future years. As a result, should the prospective volume of interactions with the cloud not be suitably scaled, it may become inundated. In the past few decades, there have been proposals for novel designs attributable to the constraints that were previously in place.

Edge computing is specifically engineered to mitigate the burden on the cloud caused by operations that can be performed by devices situated in close range to the final IoT nodes, at the outer edges of an IoT network. A multitude of variations on the edge computing paradigm have been introduced, such as Cisco's fog computing, which employs devices with little power at the edge, as well as cloudlets, which are robust computers designed to perform resource-intensive operations at the edge. The field of AI aims to improve the cognitive capacities of machines [49].

Autonomous vehicles that are able to make independent decisions, human voice identification solutions, and recommendation systems are all viable means of demonstrating intelligence. The examples mentioned above have the capacity to collect data from the physical surroundings and analyze it in order to produce a result that could be regarded as a solution to a specific problem. Frequently, AI systems necessitate instruction prior to acquiring the capability to resolve particular problems.

AI systems obtain data from the strategically deployed IoT nodes, frequently through the utilization of the sensors on those nodes. Within traditional IoT topologies, this data is transmitted to a remote cloud for analysis by the AI system. The system then generates a result, which generally comprises a determination that is subsequently communicated to the user or particular devices within the IoT network. The challenge is that real-time IoT systems frequently cannot rely on cloud-based designs due to the response time latency, which impedes their ability to respond promptly.

When faced with such circumstances, the implementation of Edge-AI presents a viable solution: by strategically positioning edge computing devices near the IoT end nodes, latency can be significantly diminished and IoT node queries can be offloaded from the cloud. This effectively prevents any communication bottlenecks that may arise when scaling the system [53]. While Edge-AI is undeniably beneficial for IoT systems, the integration of these technologies might result in energy-intensive systems. Therefore, it is imperative to optimize Edge-AI IoT systems to minimize power consumption.

3 Applications of AI in Transportation

AI is an expansive domain encompassed within computer science, which empowers machines to simulate the complex cognitive functions of the human brain. It is utilized to address issues that are difficult to clarify through traditional computational approaches. The discipline of artificial intelligence was founded in 1956 by John McCarthy. However, the lack of technological advancements impeded its progress and prevented it from successfully achieving its intended objectives, thereby diminishing its potential.

Scholars investigated AI between 1960 and 1970 by employing systems based on knowledge (KBS) and neural network-based systems (ANNs). The KBS methods are computational frameworks that provide guidance by applying pre-established principles and incorporating human-entered knowledge. Analogous neural networks (ANNs) are intricate systems of neurons that are interconnected that emulate the configuration of the brain of a person. They have been implemented in numerous industries, including manufacturing, law, medicine, biology, and language translation engineering. Interest in AI declined during that time period due to the restricted applications of ANNs and the scarcity of evidence until the 1980s.

Considerable scholarly investigation has been devoted to the application of gradient descent, a technique for minimizing prediction errors, since the 1980s. The aforementioned method is referred to as the Back-propagation algorithm [54]. Frequently with a limited quantity of concealed strata, it has been effectively utilized to tackle a multitude of challenges spanning various disciplines. Presently, the existence of data has given rise to the development of machine learning as a subfield within artificial intelligence.

Machine learning entails the development of computational algorithms that emulate the cognitive operations of the human brain, as opposed to being explicitly programmed with task-specific instructions. It facilitates the ability of computers to retrieve substantial features from vast quantities of data with the purpose of resolving intricate situations. Automated neural networks (ANNs) are widely acknowledged as the preeminent form of artificial intelligence utilized in a multitude of applications.

An early and prevalent variety of ANN, the Feedforward Neural Network (Fedforward) operates independently from the input layer to the concealed layer and finally to the resulting layer.

Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs) are two more varieties of artificial neural networks. The RNN is optimized for processing sequences of input data, rendering it applicable to a wide range of applications including writing, speaking, and text recognition, whereas the CNN is more efficient at image processing. These methods are frequently referred to as "Deep Learning Techniques" due to the fact that their structures contain a large number of concealed layers.

Numerous ambiguities and voids exist in the data, which are unresolvable through conventional means. Therefore, artificial intelligence exploits these uncertainties in order to establish a relationship between causes and effects of diverse real-world scenarios through the integration of available data with probabilities and assumptions, which ultimately leads to improved analysis [21]. Transportation-related challenges are considerably complicated due to the complexity of forecasting and modeling travel patterns. Therefore, AI is widely regarded as an ideally suited technology for transportation systems, as it effectively tackles the obstacles presented by increasing travel demand, carbon dioxide (CO_2) emissions, safety concerns, and environmental deterioration [30]. These challenges arise due to the perpetual growth of traffic in both urban and rural areas, which is primarily attributable to the increasing population in developing countries.

The congestion costs associated with the anticipated population increase to 30 million in Australia by 2031 are estimated to amount to 53.3 billion. Prominent thoroughfares spanning more than 640 km in the Australian city of Melbourne encounter substantial traffic congestion during periods of high demand, culminating in the emission of 2.9 tons of carbon dioxide per year.

Amidst the challenges posed by the environment and society at large, a multitude of researchers endeavor to establish a transport system that can be more dependable, employs AI-enabled processes that are both cost-effective and dependable [19]. It is capable of being implemented on vehicles, road infrastructure, drivers, and road users. Understanding the interrelationships among the various components of the transport system can frequently prove challenging.

As a result, AI approaches may be regarded as a sophisticated solution for overseeing these complex systems, which are unfeasible to manage with conventional techniques. Numerous academics have demonstrated the advantageous implications of artificial intelligence within the domain of transportation. To exemplify this notion, consider the transformation of roadside traffic sensors into a smart machine capable of independently detecting collisions and predicting impending traffic circumstances. Furthermore, numerous artificial intelligence methodologies, such as ANNs, find application in the domain of transportation.

ANNs find utility in various domains such as traffic condition prediction, public transit traffic incident detection, and road planning. Learning methods can be broadly classified into two categories: unsupervised and supervised. Support Vector Machine

(SVM), Probabilistic Neural Network (PNN), Radial Basis Network (RBN), K-Nearest Neighbors, and Decision Tree are all examples of supervised approaches. Conversely, unsupervised neural networks are composed of cluster analysis and greedy layer-wise learning.

A multitude of transportation concerns give birth to an optimization dilemma that necessitates the development of specialized algorithms to aid in the successful completion of computational analytics. The sophisticated computational methods referred to as raster algorithms are in question. Such algorithms are exemplified by the Genetic Algorithm (GA). It is founded upon the evolutionary paradigm of biology.

The application adeptly tackles complex optimization challenges through the implementation of the "survival of the fittest" principle. It demonstrates significant utility within the framework of urban design networks. An algorithm known as Simulated Annealing (SA) emulates the metal annealing process. An artificial intelligence program known as the Ant Colony Optimizer (ACO) simulates the navigational process of a swarm of actual ants from their nest to a food source. A computational model known as an artificial immune system (AIS) is specifically engineered to emulate the operations of the human immune system.

Bee Colony Optimization (BCO) is a technique utilized to address a multifaceted optimization problem involving numerous components. The elements of swarm intelligence platforms are the ACO and BCO. Swarm intelligence is a form of AI that draws influence from the cooperative behavior of insects and bees in order to get an optimized resolution. The intelligent computational analytics of the system are capable of efficiently managing concepts that are uncertain, imprecise, or ambiguous. Consequently, these methodologies are implemented to address obstacles related to route optimization in the domain of transportation.

An additional instrument for optimization is the Fuzzy Logic Model (FLM) [35]. It is employed to tackle the challenge of determining the most efficient route. The performance of FLM was evaluated in comparison to the Logistic Regression Model (LRM) during the construction of a route choice model, and FLM exhibited superior performance. Therefore, for tasks requiring prediction, reasoning, and adaptability, intelligent methodologies such as Fuzzy Logic Methods (FLM), GA, ANN, and Ant Colony Optimization (ACO) are highly suitable. Therefore, these are utilized to tackle optimization challenges that involve dynamic traffic conditions and occurrences.

On the basis of AI theories, Agent-Based Software Engineering (ABSE) is an innovative software paradigm that has been introduced. ABSE facilitates the dynamic determination of the shortest path through the evaluation of multiple criteria and scenarios. Furthermore, neural networks were utilized to integrate the system with the aforementioned approaches with the intention of attaining enhanced results.

An additional prevalent technology utilized within the domain of artificial intelligence is the amalgamation of hardware and software components to streamline the process of vehicle automation and itinerary organization. It is imperative that transport authorities give precedence to the strategic implementation of these technologies in order to efficiently mitigate traffic congestion, improve the dependability of travel times for passengers, and maximize the economic and productive capabilities of their critical resources.

Numerous endeavors were undertaken to ascertain the exact moment, site, and magnitude of an incident with the intention of aiding traffic administrators in the mitigation of congestion [52]. These endeavors employ an assortment of techniques, such as neural networks, automated algorithms, and manual reports. The utilization of manually authored reports may result in a delay when incidents are identified and may not be economically efficient. On the other hand, algorithms possess the capacity to evaluate the flow characteristics before and after the event by utilizing data collected from sensors installed along the path.

Statistical techniques, including the California Algorithm, were initially utilized in the implementation of incident detection algorithms. The implementation of algorithms on arterial roads is complicated by the prevalence of traffic signals and street parking. Consequently, algorithms for implementing neural network methodologies have been developed. An evaluation was performed on a neural network classification method designed to detect the occurrence of incidents along a roadway.

Further research was devoted to the identification of a superior software solution that could detect all vehicle objects in real time. It was suggested by the author that AdaBoost software be employed to ensure accurate image detection. The IMM ENKF method is employed to detect instances of hybrid state problems. Following that, an enhanced approach known as the "Efficient Multiple Model Particle Filter (EMMPF)" was developed to detect road incidents through the integration of simulated and real-world data. Moreover, real-time circumstances can be detected via social media platforms. It has been demonstrated that Twitter is an efficient and economical tool for incident detection on arterial and highway roadways [15].

Sophisticated methodologies for forecasting traffic information have become increasingly imperative due to the exponential expansion of intelligent transport systems (ITS). The success of advanced traveler information systems, advanced traffic management systems, advanced public transportation systems, and commercial vehicle operations is dependent on the implementation of these strategies. The development of intelligent predictive systems involves the utilization of historical data acquired from road infrastructure-connected sensors.

Following this, the aforementioned data is fed into machine learning and artificial intelligence algorithms in order to produce forecasts in the short, long, and immediate future. Prior to this, scholarly investigations were focused on the prediction of short-term flow using a fundamental feedforward neural network. A neural network architecture featuring a solitary hidden layer was integrated into the pre-existing urban traffic control system.

The author effectively demonstrated the considerable probability of precisely predicting traffic patterns for a maximum of one minute by employing simulated data. By employing field data that was gathered from a highway spanning 1.5 km in Queensland, Australia. An object-oriented neural network model was constructed utilizing a time-lag recurrent network (TLRN) [12]. The predictive accuracy of the model for the pace five minutes in advance ranged from 90 to 94%. Moreover, the network demonstrated the same degree of accuracy in voyage time prediction (within a 15-min range) when speed and flow were inputs; it achieved the same level of precision as speed prediction.

In another case, a sophisticated neural network was developed to predict traffic movement with an accuracy of sixty minutes in advance. Traffic flow information was collected from freeways throughout California. The SAE model, an unsupervised stack of auto-encoders implemented by the authors, was trained employing a greedy layer-wise approach [34]. By employing feedback and utilizing each output as an input, the network is capable of extracting crucial attributes of the flow of traffic. A supervised logistic regression layer is subsequently applied to generate predictions.

4 Use of Generative AI in Smart Transportation Systems

Significant advancements have been made in the domain of artificial intelligence over the past few decades, specifically in the fields of bioinformatics, computer vision, pharmaceutical design, and natural language processing. The exponential development of intelligent transportation systems (ITSs) and autonomous vehicles (AVs) can be attributed to the expansion of machine learning.

The expansion has generated novel ideas and progress in interconnected sectors, including the automotive industry, the development of 5G infrastructure, and cooperative systems for intelligent vehicle infrastructure. Academics are inclined to apply deep learning, a technique that has demonstrated remarkable efficacy in the domain of computing, to additional sectors. In the domain of transportation, scholars have implemented a range of neural networks, such as the Transformer, long-short term memory (LSTM), recursive neural network (RNN), and feedforward neural network.

With greater precision, we devised an adaptable and expandable deep learning architecture with the purpose of forecasting the volume of individuals boarding and alighting the subway. By effectively incorporating data from multiple sources, we were able to attain an exceptional degree of precision in our prognostications. A model was constructed utilizing a transformer architecture to amalgamate attributes from multiple automobiles. The primary objective of this model is to improve the accuracy of vehicle velocity predictions and assess the influence of adjacent vehicles on the moving vehicle.

In recent years, the generative adversarial network (GAN), a model of deep learning, has shown remarkable efficacy as an unsupervised learning technique applied to complex distributions. Training the discriminative model, which ascertains the likelihood that a sample is from the training set, and the generative model, which represents the data distribution, are both components of the procedure [9].

The primary aim is to generate synthetic samples that exhibit the highest degree of similarity to authentic samples. Given their capacity to generate, modify, and reinstate images and data, GANs offer substantial scientific merit in the field of transportation research, which encompasses a multitude of data-intensive endeavors. At this time, specific scholars have implemented GANs to conduct relevant research in the field of transportation, encompassing autonomous driving, anomaly detection in traffic, and analysis of traffic flow data.

To the best of our knowledge, a considerable number of surveys have been dedicated to investigating the application of machine learning or deep learning in the transportation sector. Nevertheless, a mere fraction of these investigations consider the application of GAN. There are three distinct classifications of deep learning-based urban big data fusion techniques: DL-input-based fusion, DL-output-based fusion, and DL-double-stage-based fusion. Furthermore, certain individuals conducted research on sophisticated deep learning techniques in order to tackle current issues such as autonomous vehicle (AV) detection, traffic network modeling, signal control, and traffic flow forecasting.

Delivered a succinct synopsis of deep learning techniques implemented in the transportation industry and various other domains, with an emphasis on spatial and temporal analysis. A comprehensive analysis was conducted on the machine learning techniques implemented in on-demand ride-hailing services, with a particular focus on their potential to facilitate the planning, construction, management, and oversight of intelligent transportation systems (ITSs) in urban environments.

The user deconstructed the pre-existing frameworks for graph deep learning, compiled a synopsis of prevalent deep learning technologies (e.g., GNNs, RNNs, GANs), and investigated their theories, benefits, drawbacks, specializations, and transportation-related applications. With the exception of a brief section cited by Ye et al. that makes reference to GANs, every single one of these analyses fails to consider the relevant literature.

Nevertheless, there are also exhaustive analyses of the GAN that concentrate primarily on its image processing applications. Although, its application in the transportation sector is limited to a handful of instances. Prior academic evaluations of the GAN have investigated its inception, pragmatic implementations, merits and demerits, as well as potential future developments. Additionally, they have assembled an exhaustive synopsis of the present iterations of the GAN.

A thorough assessment and analysis of the most recent studies concerning GAN models and their practical implementations were provided. Furthermore, an abundance of research has investigated the application of GANs across various fields. In the realm of music, GANs are utilized for sheet music generation, music matching, and additional tasks. It has been discovered that GANs facilitate effective music creation instruction through the use of a collection of midi files.

The representative algorithms of GAN inversions and their applications in image restoration and editing constituted the focus of this work. The primary focus of this research was to investigate techniques for recognizing facial images generated or constructed with GAN models. Additionally, a comprehensive assessment of the most recent developments in GAN-face identification was incorporated [10]. The purpose of the presentation was to provide an overview of the applications of GANs in the domain of ophthalmic images. The objective was to emphasize significant contributions and suggest possible avenues for further investigation.

5 Computer Vision Applications for Green Transportation

Smart city technologies play a crucial role in efficiently managing the fast-paced industrialization of the modern world. They can effectively tackle the economic and environmental challenges arising from the growing urban populations. Smart cities transform the traditional paradigm of urban administration through the integration of technology into conventional public services and infrastructure. This integration results in a system that is not only more sustainable, efficient, and accessible, but also better meets the needs and demands of the inhabitants of the city [24].

ITS are critical components of smart cities as they are specifically engineered to improve the safety and mobility of transportation, reduce the ecological footprint, promote sustainable development of transportation, and increase overall productivity. ITSs offer modern resolutions to transportation challenges such as congestion and collisions. By leveraging data collected from adjacent vehicles, infrastructure, and other networks, ITSs improve the safety of road users. ITS applications are diverse in nature, including but not limited to autonomous driving, cooperative highway movements, and the distribution of road safety information [16].

ITs are sophisticated information processing, data communication, and traffic management technologies. These systems possess the capacity to efficiently analyze and process immediate information from diverse sources in order to support enhanced decision making. Computers have the ability to make decisions that were previously reliant on human experience through the process of digitizing information.

Furthermore, the utilization of state-of-the-art AI algorithms can enhance the accuracy of forecasts and forecasting. AI technologies enable the development of data-driven decision-making systems. These technologies have also brought about significant transformations in several sectors, such as public transportation and transportation systems, and have contributed to enhancing the safety, environmental friendliness, intelligence, and efficiency of numerous transportation modes.

The categorization of AI applications in the field of ITS can be divided into three primary categories: detection/recognition, prediction, and management. Machine learning (ML) approaches, a subset of AI, serve as the cognitive function of ITS and ascertain the precision, dependability, and intelligence of the systems. Recently, there has been a noticeable trend in the effective use of deep learning (DL) methods, a subset of ML methods, for classification and prediction tasks in several domains of ITS [43].

Computer vision (CV) is a branch of AI that allows machines to extract significant data from digital photos, videos, and other visual inputs, and make decisions or take actions based on this data. The CV, which incorporates both ML and DL techniques, tackles image and video processing challenges and provides solutions that can be applied to automate transportation systems and enhance their safety [24].

CV techniques are widely employed in a range of ITS applications. These include automatic identification and recognition of license plates, detection and recognition of traffic signs, identification and classification of vehicles, detection of pedestrians, identification of obstacles and lane lines, detection of anomalies in video surveillance

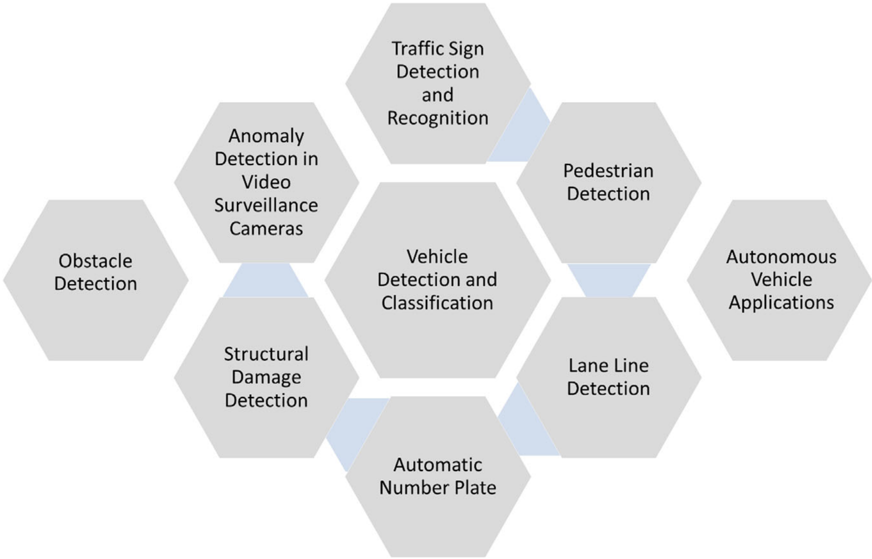

Fig. 1 Computer vision applications in green transportation systems

cameras, tracking of vehicles and passengers, identification of structural damage, and applications related to autonomous vehicles [5]. CV approaches are attractive in these applications primarily because of their cost-effectiveness and the extensive range of applications that CV may facilitate as shown in Fig. 1.

6 Blockchain Technology in Smart Transportation

Blockchain is a versatile technology that functions as a data infrastructure and provides benefits such as monetization, ownership attribution, traceability, and a distributed security architecture. Industries worldwide are finding various uses for it, including financial transactions and infrastructural development. Intelligent transportation systems are a growing field of innovation that many industry observers expect to benefit from the potential of blockchain technology [20].

These technologies facilitate the construction of safer roads for communities, enable authorities to implement more efficient traffic management strategies, and help corporations enhance their transportation operations. By integrating blockchain technology, these processes can undergo significant improvements, leading to the creation of a secure and highly efficient infrastructure that fosters a far greater degree of confidence among all stakeholders. This infographic examines the considerable potential of blockchain technology in the transportation sector, offering valuable data to help you find investment prospects in this domain.

The network characteristics of blockchain render it well-suited for enhancing the efficiency of information technology systems in organizations. An important benefit is its capacity to improve data management through enhanced security measures, which is particularly valuable given the growing economy of the business. For instance, a group of autonomous vehicles might effectively choose its path by utilizing traffic information from IoT sensors that are supported by blockchain technology, as a part of a dependable ITS [44].

IBM collaborated with ZF Friedrichshafen AG and UBS to develop a blockchain-based infrastructure for automotive transactions. The proposal provided drivers with a convenient and secure method to cover typical charges associated to roads, such as tolls, parking fees, and electric vehicle charging stations. This sample only provides a superficial overview of the numerous possibilities.

The adaptability of blockchain technology allows for its secure integration into a wide range of use cases employing ITSs. The intrinsic attributes of blockchain technology offer numerous opportunities for enhancing a data-driven transportation system.

6.1 Streamlines Payment Processes

Traditional payment methods in the transportation industry typically involve intermediaries who oversee transactions and ensure their security. They verify the authenticity of payments and regularly undergo a thorough invoicing procedure. While these roles offer benefits, third parties can result in processing delays and increased expenses [46]. By employing blockchain technology for payments, you or your company can benefit from a far more easy and efficient payment process.

Smart contracts, usually referred to as self-executing agreements, are a commonly employed approach for optimizing payment procedures. Suppose you are in charge of overseeing a logistics company that delegates the task of transporting goods to different carriers in order to deliver them to clients. By employing a blockchain-based Intelligent Transportation System (ITS) integrated with a smart contract, there is no need to individually supervise and remunerate each carrier participating in a successful delivery. The smart contract autonomously does this task, hence improving the efficiency of your business.

6.2 Reduces Expenses

Typical transportation expenses include maintenance of vehicles, fees related to employees, and overseas financial transactions, among other factors. Blockchain-based Intelligent Transportation Systems (ITSs) enable cost reduction in specific domains. Blockchains provide the capability to maintain an immutable record of your vehicle's maintenance history. Furthermore, aside from promoting transparency, it can also enable the anticipation of when the vehicle would necessitate another trip to the auto repair facility. This feature empowers your firm to proactively avoid expensive instances of major vehicle problems.

A study on global marine trade highlights the capacity of blockchain technologies to significantly reduce costs by effectively overseeing transit itineraries and stowage arrangements. The technology possesses the capacity to streamline and automate processes, such as payments. Similarly, land transport can benefit from incorporating blockchain technology into its operations. Employing additional workers as mediators for managing payments or negotiating agreements is unnecessary, as blockchain technology can efficiently fulfill these roles with no danger of human error. Integrating security blockchain technology also reduces potential cybersecurity costs that your company may face without it. Small enterprises may face expenses beyond $3 million as a result of cyber assaults, but larger corporations are exposed to significantly higher monetary damages [18].

The unchangeable and transparent network of blockchain can effectively prohibit crooks from successfully carrying out theft or fraud. Load boards are online platforms that enable the interaction between shippers and freight brokers with available drivers that can transport their cargo. They facilitate the assessment of expenses across different shipments to identify the elements that make up a beneficial transaction. When using load boards, it is valid to have concerns about security and trust. The proof-of-work technique employed by blockchains guarantees security, decentralization, and scalability, for which we are grateful.

Practically, the load board is not governed by a singular entity. Instead, it operates as a network in which multiple shippers, transporters, and stakeholders collectively share responsibility. It improves the effectiveness of freight monitoring procedures, ensuring that everyone has access to the latest and consistent information on transactions, locations, and the condition of commodities. Furthermore, blockchain technology enables enhanced engagement, efficiently expands the workload, and provides expanded opportunities to engage with dependable carriers.

6.3 Introduces Load Board Reliability and Distributed Freight Tracking

Blockchain-based technology can help overcome the numerous challenges associated with onboarding carriers. Carriers often employ specialized technologies and systems that may not consistently interface with Intelligent Transportation Systems (ITSs) in an efficient manner, potentially impacting the exchange of traffic data and unnecessarily complicating the system.

Fortunately, blockchain enables you to make use of smart contracts [48]. When integrating carriers to a system, utilizing blockchain technology and self-executing agreements helps establish consistent data norms and enhance confidence and protection. Smart contracts are inherently self-executing, eliminating the need for institutional oversight to enforce compliance with the agreed-upon agreements between the parties involved. This function enhances the execution of payments, such as fines for contract breaches, by simplifying and making the process more convenient.

6.4 Accelerates Carrier Onboarding and Payment Execution

Blockchain has the potential to improve the efficiency of your ITSs and achieve additional benefits. Moreover, it possesses the capacity to aid your firm in tackling environmental challenges. Studies suggest that blockchain technology can play a significant role in attaining environmentally sustainable development objectives and constructing a reliable and secure smart city [26].

Currently, transportation companies sometimes face a shortage of accurate route information. Inaccurate course information could lead operators to consume more gasoline when they go via inefficient routes or encounter unexpected traffic [45]. Implementing blockchain technology in ITSs has the potential to improve the efficiency of travel routes by facilitating the interchange of traffic condition information among members in the network. This method allows your company to accurately evaluate delivery times and enhance fuel efficiency performance.

7 Future Directions and Research Opportunities in Green Transportation

The global research community has witnessed a substantial surge in the examination of green transportation over the last five years. Scholars and researchers emphasizing the significance of sustainable transportation have increasingly shifted their attention to this critical issue. The notion of transportation sustainability, when applied via green mobility, signifies the urban environment's ability to endure over the long term. It is expected that the implementation of green transportation will help alleviate the adverse effects of climate change and global warming, which have profound implications for ecosystems and life [33].

Nevertheless, this undertaking continues to be considered less desirable. By fostering a smart environment, individuals' well-being can be improved and the long-lasting benefits of a wise lifestyle can be promoted. Presently, a substantial amount of research is being devoted to green transportation in an effort to develop the most current models that can be implemented in various facets of human life. This encompasses continuous endeavors to optimize transportation efficacy and reduce energy consumption. Nevertheless, these developments also introduce a level of environmental unease and pose a risk to ecological balance [28].

Furthermore, efforts are being made to develop intelligent vehicle models in order to contribute to the advancement of smart cities. The escalating energy requirements of electric vehicles mandate the development and deployment of battery energy storage, wind, and solar photovoltaic hybrid renewable sources. This expansion is essential for the transition to electric automobiles, which benefit society by combining energy and mobility. Further advancements are required in the form of electric vehicles equipped with reliable batteries and an all-encompassing public transportation network powered by eco-friendly fuels.

Numerous previous research papers have demonstrated that numerous strategies have been suggested to advance environmentally responsible transportation. However, a number of suggested remedies remain to some extent unfinished, including the establishment of ecologically sustainable modes of transportation in China, Doha, Singapore, and various other countries. An efficacious green transportation schedule system is among the various solutions suggested by a multitude of studies in an effort to advance environmentally friendly transportation [11].

The primary objectives of this system are to diminish transportation expenses, mitigate adverse environmental impacts, and curtail petroleum usage and emissions of greenhouse gases. One strategy for attaining these objectives is through the utilization of the augmented ε-constraint technique. In addition, it is imperative that the Transport Impact Assessment (TIA) procedure devise a plan to alleviate traffic externalities and distribute resources in a manner that encourages the utilization of sustainable transportation alternatives.

An alternative strategy might entail the development of a road pricing system utilizing Electronic Toll Collection (ETC) that prioritizes the perspectives of road users, administrations, and agents. Taking into account potential incidents and environmental impacts, this system endeavors to advance eco-friendly automobile usage. In order to accomplish this, an all-encompassing Green Safety Indicator (GSI) would be deployed. Ecological transportation scheduling can be effectively executed through the utilization of Evolution-Strategy-Based Memetic Pareto Optimization (ESMPO).

To enhance the efficiency of the sorting method, this entails integrating a multi-objective search procedure into the memetic algorithm as an additional multi-objective sorting phase. Electromobility, a burgeoning strategy in environmentally sustainable transportation, addresses mobility challenges linked to environmental and social repercussions in the transportation industry while prioritizing traffic safety. It is anticipated that in the future, electric vehicles will be an essential mode of transportation, causing markets and sectors to undergo a paradigm shift. Electric vehicles are dependent on electricity produced by the energy sector. Therefore, in order to encourage the widespread adoption of electric vehicles, it is imperative to establish policies that foster the concurrent development of the energy and transportation industries. Green transportation is categorized according to the identification of vehicles that employ environmentally friendly technology, such as buses powered by electricity. Clean air is the consequence of the absence of exhaust emissions from these vehicles. There is an expectation that densely populated regions will exhibit a heightened need for clean technology, driven by their pursuit of enhanced air quality and habitability.

Green transportation can facilitate the development of an environmentally friendly world and alleviate the ecological burden. Transport planning is essential for the establishment of a unified transportation network. The evaluation of sustainable transportation may incorporate insights gained from previous traffic planning, such as the models and techniques used for assessment. The expansion of smart cities requires the dissemination of dependable data to support the promotion of energy conservation in urban areas. This dependability is significantly impacted by worldwide urbanization.

Through the implementation of green mobility, managing energy can be made more efficient. The expansion of green transportation necessitates a methodical strategy for integrating data from numerous industries. This requires conducting an exhaustive search of scientific articles in an effort to identify novel concepts of knowledge that can contribute to the development of future knowledge. In order to advance the development of a viable transportation system, the initiative seeks to identify an innovative idea derived from green transportation [1].

8 Conclusion

The integration of edge computing technologies within green transportation systems signifies a pivotal advancement in the quest for sustainability and efficiency in the transportation sector. Throughout this chapter, we have explored the multifaceted roles that edge technologies play in enhancing green transportation. Key highlights include the transformative potential of the digital circular economy, the application of AI in optimizing transportation logistics, and the significant contributions of generative AI and computer vision in developing smart transportation systems.

Edge technologies offer a decentralized approach to data processing, bringing computation and data storage closer to the sources of data generation. This approach reduces latency, improves real-time decision-making, and enhances the overall efficiency of transportation systems. By leveraging edge computing, transportation systems can better manage resources, reduce emissions, and improve energy efficiency, all of which are critical for sustainable development.

Moreover, the integration of blockchain technology presents a promising avenue for ensuring transparency, security, and accountability in transportation networks. Blockchain can facilitate secure data sharing and management, which is crucial for maintaining the integrity of smart transportation systems.

Looking forward, there are several future directions and research opportunities that can further bolster the role of edge computing in green transportation. These include the development of more sophisticated AI algorithms tailored for edge environments, exploring the synergies between edge computing and other emerging technologies such as 5G and the IoT), and addressing the challenges related to data privacy and security. In conclusion, the deployment of edge computing technologies in green transportation systems holds substantial promise for enhancing operational efficiency and promoting sustainability [23]. Continued research and innovation in this domain are essential to overcoming existing challenges and unlocking the full potential of edge computing to drive the future of green transportation.

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Declarations

Conflict of Interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this chapter.

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Electric Vehicles: Paving the Way for Sustainable Green Transportation and Environmental Protection

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Abstract Considering the rise in temperature, regardless of any nation or country, global warming is really becoming a threat to the earth. Many factors are responsible for this global warming, especially the environment, which plays a key role in protecting our mother Earth. Considering the environment and future sustainability, many countries are gradually shifting to zero-emission vehicles. One Hundred Eighty-nine countries agreed to work together on a low-carbon future. It is through lowering greenhouse gas emissions. Transportation is one of the major sectors to lower greenhouse gas emissions. Transportation accounts for 23% energy energy-related greenhouse gas emissions. EVs can be a competitive alternative in the transportation sector, from e-bikes to large trucks. Allowing for a sustainable future and environment, the alternative of electric vehicles (EVs) pops up as a first option. A major chunk of pollution is due to the use of vehicles. With the growing population and customer affordability, the usage of cars has highly increased over the last decade. The extensive use of fuel all over the world forced the automobile industry to develop alternative fuel options or renewable fuel technology. So Electric vehicles are globally promoted by the automobile industry as a sustainable and eco-friendly solution. When you shift to EVs, it brings decarburization and alleviates climate change. As per the projections estimated by the U.S. Energy Information Administration (EIA), the segment of Electric Vehicles is expected to blow up from 0.7 to 31% by the year 2050. According to research conducted by the European Energy Agency, electric cars emit approximately 17–30% less carbon than gasoline and diesel cars. Wide usage of EVs reduces the dependence on non-renewable sources. One of the MIT reports found that a fully electric vehicle emits about 25% less carbon than a comparable hybrid car. To priotarize the environment and sustainability, it is

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need of an hour to reduce carbon usage, whether it is in production or transportation. This chapter deals with green transportation through electric cars and its effect on the environment, and sustainability. It will be a systematic review of the electronic database of Scopus for the duration of 2020–2024 carried out on electronic vehicles the environment, sustainability, governance (ESG) and its impact on green transportation. It is predicted, that e-vehicles will change the automobile market and provide environmental sustainability.

Keywords Battery electric vehicles · Green transportation · Carbon emissions · EV & sustainability · EV & governance

1 Introduction

Fossil fuels remain the dominant source of energy creation, with the automotive sector being the largest consumer of these fossil fuel-based resources. Although the automotive industries are significant contributors to financial efficiency, it is moreover a major source of global greenhouse gas (GHG) releases besides air contamination, leading to increased global warming [50], exacerbated by a rapidly growing world population [42, 46].

The global population surged by 52%, from over 5.3 billion to nearly 8.1 billion. However, CO_2 emissions from the transport sector nearly doubled, rising from 4.61 gigatonnes to 8.22 gigatonnes, making up 17% of global GHG emissions. Given the transport sector's substantial impact on climate change, achieving the global climate neutrality goal by 2050 necessitates reducing its reliance on fossil fuels [25].

As such, transitioning away from fossil-fueled automobiles in addition to switching to battery electric vehicles (BEVs) has emerged as a crucial imitative strategy against climate change. Governments worldwide are increasingly adopting this green transport revolution, recognizing that the transition to electric vehicles is vital for reducing emissions and promoting environmental sustainability. This shift not only promises a cleaner, more sustainable transportation future but also aligns with broader efforts to fight global warming and achieve long-term climate goals.

As climate variation and environmental concerns escalate, the transportation sector faces heightened scrutiny due to its major role in global greenhouse gas emissions [38]. Electric vehicles (EVs) offer a promising solution to mitigate the carbon footprint of transportation and advance environmental sustainability. Recent developments in EV technology, policy frameworks, and consumer adoption illustrate how electric cars are revolutionizing the auto industry and fostering a greener future [66]. Integrating EVs into transportation systems is expected to reduce fossil fuel dependence and stimulate economic growth through green innovation and infrastructure. Ultimately, EVs hold the potential to drive sustainable transformation in transportation and support global ESG goals, contributing to a more sustainable and equitable world as shown in Fig. 1.

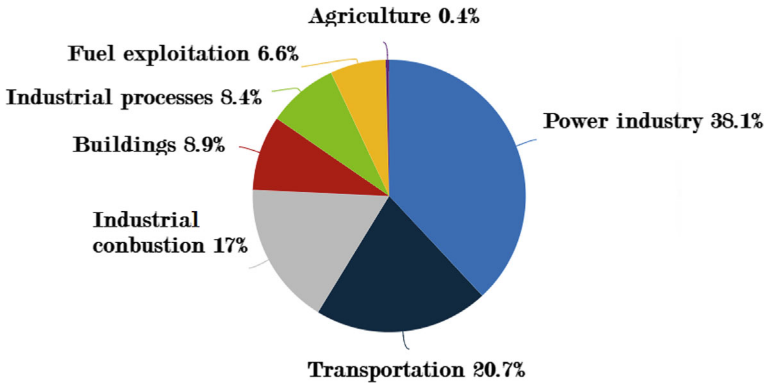

Fig. 1 Worldwide distribution of carbon dioxide releases by sectors in 2022, [64]

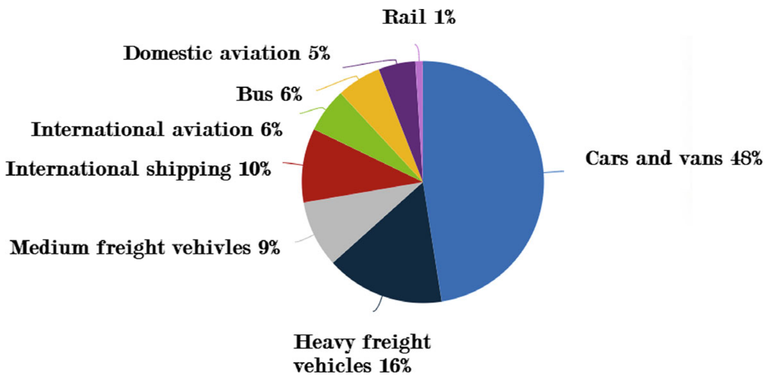

Fig. 2 Worldwide distribution of transportation sector's carbon dioxide releases by sub-sector in 2022 [63]

With the growth of the transportation sector, carbon dioxide emissions are expected to rise as urban road networks become a major source of air pollution, especially in developing countries experiencing rapid vehicle ownership. As reported by [7], there's also an increasing trend of traffic and congestion on roadways, exacerbating emissions as shown in Fig. 2.

In the future, this contribution can increase due to the growth in population and rapid increase in transportation sector models in most of the countries with the highest number of personal vehicle users as reported by [61] in Fig. 2.

1.1 Electric Vehicle

The electric vehicle revolution is fundamentally transforming the transportation landscape. Advancements in battery technology with the development of infrastructure are accelerating the adoption of electric vehicles (EVs) worldwide. Cities across the globe are experiencing a significant shift towards EV-dominated fleets as consumers, businesses, and governments increasingly acknowledge the environmental welfare of plug-in mobility. This evolution extends beyond mere technological advancement, presenting a paradigm shift to a more sustainable as well as robust transport [24]. The growing integration of EVs into our daily lives highlights the potential for clean energy solutions to reshape our cities, reducing urban pollution and contributing to global sustainability goals (Khang and Quantum, 2024).

1.2 Sustainable Transportation

Sustainable transportation refers to modes of transport that prioritize energy efficiency, low- or zero-emission solutions, and affordability [47, 56]. The sustainable goal of transportation is to minimize environmental impact while supporting the mobility needs of society without conceding the capability of upcoming generations to encounter their mobility necessities. It is achieved through various means, including the adoption of alternative fuel and electric vehicles, the utilization of domestic fuels, as well as the development of low-emission community transport.

The viable transportation benefits are manifold, including fuel cost savings, a reduction in emissions of greenhouse gas, and improved air quality [23, 48]. In response to these benefits, governments and organizations worldwide are actively promoting sustainable transportation practices. For instance, the Conference on Sustainable Transport 2021 by the United Nations, held in Beijing (China), intended to advance sustainable transportation initiatives and address the global climate disaster [19]. Adopting sustainable transportation practices is essential for dropping environmental impacts with safeguarding the well-being of future generations.

The transportation industry's environmental issues have led to an agreement that innovative and bold strategies are necessary [14]. Sustainable transportation, which features travel methods to reduce ecological impact as well as emphasize resource protection, symbolizes the future. This paradigm shift is a moral imperative with a strategic necessity in combating climate change. Sustainable transportation encompasses a broad spectrum of alternatives, ranging from advancements in public transit systems to the prevalent acceptance of EVs and the exploration of alternative fuels [16]. As the demand for mobility continues to rise, the transition towards sustainable transportation is not merely an option but a necessity for creating a future where mobility aligns with environmental responsibility [49]. By embracing these sustainable practices, we can ensure a healthier planet and a more equitable society for generations to come.

In the automobile industry, vehicle electrification is a key strategy to contribute to the global thrust for sustainable and green transportation [30]. Several countries are actively working to reduce or even eliminate the production of conventional internal combustion engine vehicles (ICEVs) in favor of promoting the manufacturing and adoption of electric vehicles (EVs). Countries including France, Germany, the UK, and the Netherlands are aligning with the Paris Agreement objectives by evolving plans to halt ICEV production by 2040 [27]. Norway and South Africa aim to upsurge their EV market portion by reducing the sale of petrol engines by 2030 [31].

Governments around the world are implementing various supportive policies, for example, buying incentives and energy grants, to encourage consumers to choose EVs. Nations like Austria, France, Finland, Germany, and Japan are at the forefront of these initiatives [44]. In addition to fully electric vehicles, hybrid EVs are also attaining admiration as an immediate and effective measure toward reducing transportation emissions. Many consumers prefer HEVs due to their extended driving range and the flexibility of using multiple fuel sources compared to battery electric vehicles (BEVs) [67]. In 2023, the diffusion levels of EVs, counting both BEVs and plug-in HEVs, saw significant growth in various regions, highlighting the global shift towards electrified transportation as shown in the table (Table 1).

Alt text: The Table 1 represents the EV market sales in different countries in 2023 with an increase in sales as compared to EV sales in 2022

The global shift towards green transportation is increasingly focusing on electric vehicles (EVs) as a key driver of environmental sustainability. This study aims to conduct a systematic assessment of literature from the Scopus electronic database, spanning from 2020 to 2024, to explore the impact of EVs on the environment, sustainability, and governance (ESG) frameworks. The review will analyze the role of EVs in falling emissions of greenhouse gas, promoting energy efficiency, as well as transforming urban mobility. It is predicted that electric vehicles will significantly alter the automobile market, leading to enhanced environmental sustainability by mitigating climate change impacts and fostering a more sustainable transportation ecosystem. Through this review, we aim to provide insights into the potential of EVs to revolutionize the transportation sector and contribute to broader ESG objectives.

Table 1 Share of various regions in the EV market [26]

Country	EV registration (million)	Increase (%)	Sales share (%)
United States	1.4	40	11
Europe	3.2	20	25
China	8.1	35	45
India	1.5	49	4

2 Problem Statement

The transportation sector expressively contributes to global GHG emissions, with fossil fuel-powered automobiles accounting for about 17% of total emissions. As populations and urban areas grow, the demand for transportation increases, worsening environmental issues like air pollution and climate change. Old ICE (internal combustion engine) vehicles are a major threat to environmental sustainability and public health. EVs offer a promising substitute, with the potential to cut emissions, improve air quality, and boost energy efficiency. However, their widespread adoption faces challenges such as high production costs, limited charging infrastructure, and fluctuating battery metal prices. Despite growing awareness and policy efforts to reduce emissions, the shift to sustainable transportation is slow and uneven.

Thus, it is essential to address the challenges of effectively integrating electric vehicles into the global transportation system to support sustainable green transportation and environmental protection. By analyzing current barriers to EV adoption, assessing technological advancements, and evaluating policy frameworks, this chapter seeks to identify strategies that can accelerate the transition towards electric mobility. Moreover, the integration of Environment, Sustainability, and Governance (ESG) principles into the development and deployment of electric vehicles is crucial for fostering green transportation.

The environmental welfare, including a decrease in emissions of greenhouse gas with enhanced air quality, is considered alongside the sustainability of EV production processes and supply chains. Additionally, it explores governance policies that further facilitate this transition by implementing regulations to encourage EV adoption, supporting infrastructure development, and promoting ethical sourcing of materials. Furthermore, the potential impacts of EV adoption on environmental sustainability, public health, and economic growth are important, aiming to provide comprehensive insights into the role of electric vehicles in shaping a sustainable and responsible transportation future.

3 Related Work

Existing studies globally have consistently highlighted the link between transportation and emissions across various regions, including Asia, Europe, and parts of Africa and Latin America [2, 4, 28]. The studies underscore the urgent requirement for combined tactics to endorse viable conveyance. Researchers have also examined factors influencing biological footprints, like economic growth, urbanization, and energy consumption [13]. Despite these insights, there remains a noticeable lack of empirical research specifically addressing the relationship between ecological footprints and green transportation in major energy evolution republics, pointing to a gap in comprehensive studies in this critical area.

3.1 Green Transportation and EV

Green transportation focuses on minimizing environmental impact while meeting urban mobility needs. As urbanization accelerates, the challenge of air pollution from widespread vehicle use has become critical. The expansion of transportation systems must prioritize sustainability to mitigate these environmental issues. Recently, factors essential for implementing green transportation systems have been identified with key barriers and challenges to adopting sustainable practices. The ASI strategy (Avoid, Shift, Improve) proposed by [56] addresses these issues. Applying the Avoid strategy could reduce CO_2 emissions by 146–312 kg/year, the Shift strategy by 0.27 kg CO_2 per vehicle revolution, and the Improve strategy by 12.4% in CO_2 emissions. It also proposes innovative technologies and management approaches for enhancing public transportation sustainability. The successful examples of the ASI strategy provide valuable guidance for urban planners aiming to achieve effective green transportation systems.

Green transportation significantly influences society by addressing economic, social, and environmental impacts. Described as transportation with rarer adverse effects on social health besides the environment, green transportation integrates various technologies, such as efficient electric vehicles, biogas fuels, and improved public transit systems [34]. By prioritizing green transportation in urban planning, cities can achieve sustainability goals through better management of travel demand, vehicle growth, and land use [40]. An effective green transportation system can reduce risks and traffic crowding, enhance energy as well as resource sustainability, lower contamination, and improve protection and traffic flow. This holistic approach not only benefits environmental health but also boosts the overall quality of life in urban areas.

Electric vehicles (EVs), powered entirely by batteries, have gained significant attention from governments due to their low-carbon and environmentally friendly attributes [57, 58]. With substantial policy support, EV sales have surged in recent years [21].

Researchers have used traditional methods to assess the environmental impact of EVs. The ‘well-to-wheel’ approach, which examines emissions from the vehicle’s operational phase, constitutes 60%–90% of the total life cycle emissions [57]. Life cycle assessments, evaluating emissions from material production through recycling, have highlighted that the electric energy mix is crucial for reducing greenhouse gas (GHG) emissions [55]. Studies show that optimizing the electric energy structure can significantly enhance EV environmental benefits, reducing CO_2 and CO emissions by 14% and 37% [10].

EVs are effective tools for GHG reduction, but their effectiveness varies with factors—the energy mix, power economy, and climate. The model of the Modified EV Emissions Index (MEVEI) quantifies the impact of these factors on GHG emissions. For instance, when fossil-fuel electricity exceeds 80% or temperatures are sub-zero, EV emissions can surpass those of fuel vehicles (FVs). However, at temperatures above 25 °C, EVs are more favorable, and reducing the power economy value of

EVs by 20% can lower GHG emissions [38]. This model helps in formulating policy recommendations and provides a solid foundation for accurately evaluating the GHG performance of EVs.

Life Cycle Assessment (LCA) of electric vehicles (EVs) is a detailed approach used to evaluate the environmental impacts associated with every stage of an EV's life, from production to disposal. The assessment begins with the raw material extraction and vehicle production phases. This stage involves evaluating the environmental costs of mining metals for EV batteries, such as lithium, cobalt, and nickel, as well as the energy required to manufacture vehicle components. These processes can have significant environmental impacts, including resource depletion and pollution. The most critical phase of the LCA is the vehicle use phase.

Although EVs themselves generate no tailpipe emissions, their overall environmental impact is heavily influenced by the source of electricity used for charging. If the electricity comes from fossil fuels, the associated greenhouse gas (GHG) emissions can be substantial. Conversely, if the EV is charged using renewable energy sources, the emissions are significantly reduced, showcasing the importance of a clean energy infrastructure [8]. Maintenance and operation also play a role in the LCA. This phase evaluates the efficiency of the vehicle, the lifespan of the battery, and any associated repairs. An efficient vehicle with a long-lasting battery generally results in lower environmental impacts over its lifetime.

Proper maintenance helps ensure that the EV operates efficiently, thus minimizing its environmental footprint. The end-of-life phase examines the environmental impacts related to the disposal or recycling of the EV. Effective recycling of batteries and other components is crucial in reducing environmental harm. However, improper disposal can lead to pollution and loss of valuable resources. This stage of the LCA helps identify strategies for managing end-of-life impacts and improving sustainability. Evaluating an EV's environmental impact compared to traditional vehicles at an early stage of the vehicle's life [5] helps pinpoint areas where environmental impacts can be minimized and informs strategies for enhancing the sustainability of electric vehicles.

3.2 Technological Advancements

Recent advancements in electric vehicles (EVs) highlight significant technological progress in the sector. The design of battery electric vehicles has evolved from traditional vehicles to creating entirely new, integrated designs. For instance, the transition from the EV150 to the ARCFOX αS underscores the growing emphasis on intelligence with electrification. Tesla has set benchmarks with its high-safety intelligent battery management system (BMS) and electric chassis platform, solidifying its leadership in EV innovation [22]. The core component of BEVs is the motor-based electric drive system, offering advantages such as constant torque at lower speeds while continuous power at great speeds. These features provide notable benefits over traditional vehicles with an internal ignition engine.

3.2.1 Charging Technologies

Charging technologies are crucial for EV infrastructure. Various battery types, especially lithium-ion (Li-ion) and its derivatives [5], are preferred due to their high energy density and lightweight characteristics [8]. Charging methods include conductive charging, which uses direct metal-to-metal contact and supports both on-board and off-board charging, with off-board chargers favored for fast charging. Inductive charging, based on electromagnetic induction, offers convenience without the need for precise alignment, though it has a reported efficiency of up to 85% [43]. Capacitive charging uses electric fields to transfer energy, achieving around 90% efficiency at a 1-m range. Emerging technologies like battery swapping, Vehicle-to-Grid (V2G), and smart charging are also advancing the field.

3.2.2 Artificial Intelligence in EV Development

Artificial Intelligence (AI) is transforming EV technology by enhancing driver assistance systems and autonomous driving capabilities. AI applications, such as advanced driver assistance systems (ADAS), increase the security, energy management, and overall efficiency of EVs [60]. Features like adaptive cruise control, departure warnings for lane and automatic emergency braking are becoming standard. Additionally, AI contributes to autonomous electric vehicles (AEVs) by enabling environment perception, path planning, and intelligent decision-making (Khang and Robotics, 2024; [36]).

3.2.3 Autonomous Electric Vehicles (AEVs)

EVs which can operate without human intervention, have become a significant focus for researchers. The SAE International J3016 standard (2014), has facilitated advancements in this area. Testing for AEVs involves unmanned platforms equipped with components like driving motors, sensors, and sub-systems for steering, braking, and speed control [11]. Artificial Intelligence (AI) is key in enhancing environment perception, path planning, and intelligent decision-making in AEVs [36]. Despite concerns like cost, range, and inadequate charging arrangement, the potential of AEVs in developed nations is significant. The future hinges on overcoming energy demand challenges and improving fleet management through data-driven algorithms and smart communication technologies. These advancements collectively drive the evolution of EVs, making them more efficient, user-friendly, and aligned with sustainability goals [33].

4 Environment, Sustainability, Governance (ESG)

4.1 Environmental Impression

EVs offer substantial environmental benefits, particularly in reducing operational emissions. The significant reward of EVs is their zero tailpipe emissions, which notably improve the quality of air, exclusively in urban areas with dense populations. Unlike conventional vehicles that emit large quantities of pollutants such as CO_2, nitrogen oxides, and particulate matter, contributing considerably to air contamination and climate variation, EVs eliminate these harmful emissions [9] during operation.

Additionally, the environmental benefits of EVs are further enhanced when they are powered by renewable energy sources. Charging EVs [69] with solar, wind, or hydroelectric power significantly reduces their overall carbon footprint, making them a more sustainable alternative to vehicles reliant on fossil fuels. This integration with renewable energy is crucial for achieving substantial reductions in greenhouse gas emissions and advancing toward a more sustainable transportation system. As a result, EVs play a pivotal role in addressing environmental concerns and promoting cleaner, greener urban mobility.

The production and adoption of electric vehicles present a complex interplay between economic growth and environmental sustainability. While EVs offer substantial economic benefits by boosting industrial output and creating jobs [17], they also pose environmental challenges due to emissions from production processes [52]. However, the transition to EVs is generally seen as favorable in terms of environmental impact, particularly when considering the reduced emissions during operation and the potential for integration with renewable energy sources. As technology advances and cleaner production methods are adopted, the environmental impact of EVs is expected to decrease further, solidifying their role as a cornerstone of sustainable transportation.

- **Limited Increase in Emissions:** Despite the economic benefits, EV production is not without environmental consequences. The production processes of EVs and their batteries lead to additional emissions, primarily SOx, CO_2, and NOx. However, the increase in emissions is relatively small compared to the significant economic gains [68]. The primary sources of these emissions are the EV sector and the EV battery sector, with emissions stemming from mining and manufacturing processes.
- **Pollutant Sources:** The emissions associated with EV production, while notable, are considerably lower as compared to conventional combustion vehicles when considering the entire lifecycle. The transition to EVs is often justified by their lower operational emissions, which can offset the environmental impact of production. The emissions primarily involve carbon dioxide (CO_2), nitrogen oxides (NOx), and sulfur oxides (SOx), which are typical of industrial production

activities but remain a focus for further reduction through cleaner production technologies and energy sources.

- **Growing Mining Demands:** Many major manufacturers, like Bentley, plan to shift their entire lineup to plug-in hybrid EVs (PHEVs) or all-electric models by 2026, ending tailpipe manufacturing by 2030. This transition demands a steady supply of essential minerals, prompting some automakers to secure mining contracts for EV production. As EVs are increasingly seen as a key solution for decarbonization, the demand for necessary components like batteries and charging infrastructure—requiring lithium, nickel, cobalt, and copper—will increase substantially. This growing demand is expected to rise 30-fold by 2040, posing significant environmental challenges, such as pollution, human rights abuses, and socio-environmental harm. Despite sustainability certifications, the mining sector's troubling legacy raises concerns that increased global mineral demand could worsen existing supply chain issues and biodiversity crises.

These challenges highlight the difficult trade-offs between decarbonization needs and the environmental impact of mining.

4.2 Sustainability

The sustainability of EVs in green transportation is emphasized by their role in reducing energy consumption and GHG emissions. The adoption of EVs offers numerous sustainability benefits that are pivotal for reducing environmental impact and promoting cleaner transportation systems. The substantial gain of EVs is their capacity to condense CO_2 emissions related to conventional ICE vehicles. EVs contribute to lowering GHG emissions and reducing air pollution, which is crucial in the fight against climate change. This shift not only benefits the environment but also plays a crucial role in enhancing public health [9].

Research has shown that air pollution from ICE vehicles is linked to various health issues, including respiratory and cardiovascular diseases. By minimizing harmful emissions, EVs help mitigate the adverse health effects associated with traditional vehicle emissions, thereby fostering a healthier living environment [12]. Another important aspect of EVs is their potential to improve urban environments by reducing noise pollution. Unlike traditional vehicles, EVs operate silently, which can lead to quieter cities and a better quality of life for urban residents.

Furthermore, the incorporation of renewable energy sources, photovoltaic (PV) systems and wind energy with EVs enhances their sustainability [45]. This integration allows EVs to be powered by clean energy, reducing their overall environmental footprint. Optimization models for EVs take into account factors like irregular generation of renewable energy, distribution network features, and management of energy storage to ensure efficient operation. By addressing uncertainties like load demands, solar irradiance, and traffic situations, these models investigate solutions balancing practical, financial, and conservational welfare, making EV charging infrastructure more effectual and sustainable.

In the United States, residential and transportation sectors together account for over half of the total energy consumption. The shift towards EVs in transportation, alongside the adoption of renewable energy in homes, offers a promising path to decarbonization [17].

- **Decarbonization Potential**: EVs are critical for lowering carbon emissions in transportation, while renewable energy sources such as solar PVs offer similar welfares in the residential sector. The combined technologies can significantly reduce reliance on fossil fuels.
- **Current Adoption Trends**: While both EVs and PVs are gaining market share, they are often adopted independently [52]. This separate deployment means potential synergies between the two are not fully realized. Consumers who are interested in one technology may also be inclined towards the other, but this connection is not always leveraged.
- **Behavioral Interdependence**: Research, such as the Study Whole Traveler Transportation Behavior in 2018, shows that buyer acceptance of PVs and EVs is interconnected [62]. This interdependence is influenced by factors like attitudes, values, and personality traits. Recognizing these shared behaviors can help in designing more effective marketing and policy strategies.
- **Integrated Model System**: The study uses a structural equation model to explore how adoption behaviors for EVs and PVs influence each other. It reveals that both direct effects and error correlations exist between these behaviors [20], underscoring the requirement of an all-inclusive method for technology adoption.
- **Policy Implications**: Encouraging the bundled adoption of EV and PV systems through incentives like subsidies could accelerate the uptake of both technologies [53]. This integrated approach not only supports the transition to a more sustainable transportation system but also promotes overall energy efficiency.
- **Need for Integrated Approach**: By considering transport and residential energy-efficient technologies together, policies can be developed that better address consumer preferences and promote the adoption of sustainable solutions more effectively.

EVs contribute to the sustainability of green transportation by lowering emissions and energy use. When paired with renewable energy sources like solar PVs, they offer a powerful solution for reducing carbon footprints in both the transportation and residential sectors. Understanding and leveraging the interconnected nature of consumer adoption of these technologies can lead to more effective strategies for promoting green transportation and achieving broader sustainability goals.

The use of energy storage solutions with clean energy is vital for curtailing the EV charging impact on the environment, significantly reducing the carbon footprint of charging stations [39]. This transition to renewable energy supports greener transportation and aligns with broader environmental goals by decreasing dependency on fossil fuels. Beyond environmental benefits, the rising demand for EVs can stimulate economic growth through job creation in renewable energy and manufacturing sectors [61]. Additionally, EVs reduce emissions and noise pollution, enhancing urban environments and public health. By integrating renewable energy, EVs are important in proceeding with sustainable transportation and achieving a more environmentally friendly future.

4.3 Governance and Policy

The governance and policy framework surrounding electric vehicles (EVs) plays a pivotal role in driving sustainable green transportation and environmental protection. As nations worldwide strive to reduce GHG emissions and shift to clean energy sources, governments have adopted various strategies to encourage the EV market. These strategies encompass economic plans such as subsidies and taxes, as well as non-monetary incentives like access to bus lanes as well as reduced tolls and parking payments. These measures aim to make EVs more attractive and accessible to consumers, thereby accelerating their adoption and contributing to environmental sustainability. However, these policies also present complex challenges and necessitate careful consideration of their broader impacts on other industries and the transportation ecosystem.

Governments have implemented a range of strategies to advance the electric vehicle (EV) market, using both economic policies and political objectives. Fiscal measures such as subsidies and tax incentives are common, as are non-monetary policies like easy bus lane access and reducing tolls or parking charges [6, 7]. These measures aim to make EVs more appealing and accessible to consumers, thereby boosting their adoption.

However, these strategies can have broader implications. For instance, while subsidies can stimulate the EV market, they may become economically unsustainable as the market grows. Non-monetary incentives can encourage EV adoption but may also contribute to increased traffic congestion and impact the efficiency of public transit systems like Bus Rapid Transits (BRTs) [54]. Therefore, a balanced approach that considers the integration of diverse transportation modes, such as cycling and walking, is essential for effective policy formulation.

The global acceptance and success of EVs hinge on several factors, including vehicle quality, affordability, charging infrastructure, government incentives, and public perception [26]. Governments need to develop strategies that not only promote EV adoption but also align with broader sustainability goals. This involves assessing the impact of policy decisions on various stakeholders and adjusting strategies accordingly [59].

Two key strategies, Ttf and SB, are used to optimize the adoption of EVs and achieve sustainability objectives. The Ttf strategy (Transport Tax and Fuel Strategy) focuses on adjusting subsidies for EV purchasers and public fleets buses, while the SB (Subsidy) strategy involves optimizing fossil-fuel vehicles and fuels taxes even though maintaining consistent subsidies for EV buyers [59].

Studies have highlighted various EV acceptance barriers and the role of government in overcoming these challenges. It is found that while fiscal incentives are crucial in the initial EV market development, their effectiveness diminishes as the market expands, necessitating additional policy measures to maintain consistent adoption rates as shown in Table 2.

Alt text: The Table 2 represents the EV promotional policies with details of incentives offered by different governments in the world to increase in sales as compared to EV sales in 2022

In conducting a comprehensive policy analysis, it is crucial to evaluate various scenarios under each strategy to determine the most effective combination of incentives and regulations. This involves considering multiple constant values for each fixed factor, leading to the development of eight different scenarios. Through such evaluations, policymakers can identify the strategies that maximize environmental and economic benefits, ultimately fostering a supportive environment for electric

Table 2 Details of incentives for various countries [1]

Country	Incentive details
Norway	Registration taxes are exempt. Exemption from VAT, sales tax for EVs
Italy	Annual circulation tax exempted for five years
New Zealand	Road User fees exempted
Denmark	CO_2 emission-based tax for Vehicle license
Austria	EV registration and ownership taxes exempted
Greece	Registration tax exempt
Netherlands	Release from yearly circulation and sales tax, VAT Tax for vehicle license rendering to CO_2 emission
USA	\$1000–\$2220 rebate, \$7500 tax credit, \$750–\$900 wall connector rebate Tax reduction on vehicle licenses, sales tax, and Carpool lanes
Belgium	EV VAT exemption 30%, less income tax
Canada	\$600–1000 wall \$3000–8000 rebate, connector rebate
Germany	€3000 rebate for HEVs, €4000 rebate for EVs Sales tax exempt, Exemption from circulation tax for ten years
China	€4200–7200 rebate
Sweden	€4500 rebate. Road tax exemption
UK	€5800 maximum (25% of car price)
Japan	€6300 maximum rebate Exempt from annual tonnage and sales tax, less automobile annual tax
France	€7000 maximum (30% of EV price including VAT)
Slovenia	€7500 rebate
Croatia	€9300 rebate for EVs, €6700 rebate for HEVs

*EV - Electric Vehicle, HEV - Hybrid Electric Vehicle, VAT - Value Added Tax, $ - US dollars, € - euros.

vehicles and contributing to sustainable green transportation and environmental protection.

Norway's success in electric vehicle (EV) adoption is largely due to its extensive and evolving incentive package, which began in the early 1990s. The government, supported by various political coalitions, introduced a range of incentives to accelerate the shift to EVs [37]. Consequently, the highest adoption rate of EVs is in Norway, with the replacement of 20% of passenger cars by EVs while fresh electric car sale is approximately 80% in 2022. The rule has set an ambitious goal to transition to solely zero-emission passenger cars by 2025. The market share of EVs surged from 64.5% in 2021 to 79.3% in 2022 [15]. Additionally, the government's support has been instrumental in expanding charging infrastructure, exemplified by the Transova (Enova) Project, which funded the primary setup of over 1850 charging stations [53].

Government policies for electric vehicles (EVs) include a range of fiscal incentives aimed at promoting widespread adoption by offering financial benefits to consumers. These incentives often encompass tax reductions, rebates, and reduced parking fees, making EVs more accessible and financially appealing to a broader audience [18].

- **Development of Charging Infrastructure:** Governments can support the expansion of high-power charging networks by providing incentives to businesses and property owners for installing charging stations [52]. This not only increases the availability of charging points but also helps in upgrading the electrical grid to handle higher demands.
- **Reducing Ownership Costs:** Lowering the total EV cost can be achieved through subsidies, reduced registration fees, and other financial measures. Conversely, increasing the ICE-associated costs—such as higher registration fees and gasoline taxes—can further incentivize the switch to EVs.
- **Fleet Acceptance:** Offering incentives for industries to electrify their fleets can significantly impact EV adoption. These incentives might include lower registration fees, tax exemptions, and free access to congestion zones [3]. This strategy not only benefits businesses but also sets a precedent for broader societal acceptance.
- **Support for Manufacturers:** To overcome the reluctance of manufacturers to shift from ICE to EVs, governments can provide grants, tax benefits, and research partnerships. These measures reduce uncertainty and support the transition to EV production.
- **Integration of Clean Energy:** Incentives for using renewable energy (RE) for EV charging can mitigate potential grid instability and enhance sustainability. Benefits might include reduced utility bills or tax breaks for using solar panels or other green energy sources.
- **Assistance for Low-Income Households:** To ensure equitable access to EVs, targeted financial assistance can be provided to low-income families [52]. This helps make EVs more accessible across different income brackets, promoting broader adoption and sustainability.

Non-fiscal incentives aim to boost electric vehicle (EV) adoption without providing direct financial benefits. These strategies enhance the appeal and retention of EVs through offering tools and incentives making EVs more striking to patrons [1].

- **Gamification:** Applying gamification to EV ownership seeks to create a more engaging and rewarding experience. This approach encourages environmentally aware besides competent driving conduct, helping users maximize the benefits of their EVs while contributing to sustainability efforts. Various gamification techniques are outlined in Table 2, which details methods to improve the EV ownership experience and motivate increased use.
- **Educational Campaigns:** Unfamiliar or new technology often faces consumer resistance, making it challenging to address distress after technical issues are set. Public awareness campaigns are crucial for educating potential buyers about EV benefits. Advertisements [51], online content, and workshops can clarify errors and then deliver precise information on environmental impact, cost savings, and differences between EV models. Educational programs and community outreach can further help inform consumers about EV charging options and ownership benefits.
- **Research and Development Grants:** Research and development is vital for EVs in evolving battery technology with reduced charging time and rapid charging infrastructure. Rules can deliver contributions to funding these areas, fostering innovation and accelerating EV adoption [65]. However, R&D grants must be carefully audited to ensure funds are used effectively for technology enhancements rather than diverted to general business expansion, which can impede progress.

4.4 Impact of EVs on Green Transportation

As discussed above, the acceptance of electric vehicles (EVs) is significant in advancing green transportation and aligns with Environmental, Social, and Governance (ESG) principles [29]. EVs contribute to condensed CO_2 emissions and improved air quality, directly addressing climate change concerns by decreasing reliance on fossil fuels and promoting renewable energy use. Their silent operation also minimizes noise pollution, enhancing urban living conditions.

Additionally, EVs improve community health with reduction in cardiovascular and respiratory syndromes due to air pollution decrease, making their socio-environmental impact significantly positive compared to traditional transportation. Furthermore, the growth of the EV industry spurs economic opportunities, fostering job creation in the renewable energy and automotive sectors, and contributing to a sustainable economy. The shift towards EVs necessitates the implementation of supportive policies, regulations, and infrastructure development to ensure a smooth transition to greener transportation systems. Consequently, several countries have adopted policies to promote EV adoption and address barriers to EV utilization [35]. Overall, the integration of EVs supports ESG objectives by promoting sustainable development, improving quality of life, and fostering economic innovation, ultimately leading to a more sustainable and equitable future.

Green transportation based on EVs significantly impacts environmental sustainability and protection by enhancing energy efficiency and reducing emissions. A novel approach using Grey Correlation Analysis (GCA) has shown promising results in predicting green transportation energy demand and calculating GHG emissions. According to Lv and Shang [41], the GCA-based approach achieves up to 93% energy savings and reduces GHG emissions to just over 210 tons, demonstrating its effectiveness in energy conservation and emission reduction (ECER).

Additionally, advanced Intelligent Transportation Systems (ITS) infrastructure provides high-resolution traffic data, offering detailed insights into traffic dynamics and emission patterns that surpass traditional emission inventories. Meanwhile, a machine learning technology [60] for predicting PM 2.5 and PM 10 concentrations further refines traffic emission assessments. Overall, these innovations in green transportation contribute to better environmental sustainability and protection by optimizing energy use, reducing emissions, and improving air quality in urban areas.

Overall, green transportation driven by electric vehicles (EVs), along with innovative methods and advanced technologies, represents a pivotal advancement in achieving environmental sustainability [56]. These technologies significantly reduce emissions, optimize energy use, with clean air in urban settings. Integrating renewable energy sources into EV infrastructure further enhances these benefits, aligning with governance policies aimed at promoting sustainability. Addressing these issues through effective policies and innovations not only fosters a cleaner environment but also supports a more resilient and equitable future.

5 Research Gaps

Existing studies are widely focused on EV transportation and its environmental benefits whereas there are only a few research focusing on the long-term impact of EVs on the social and economic field. The environmental impacts are studied in very few studies. The research gap in these studies can be identified as below.

- There is a need to evaluate the cumulative environmental benefits and drawbacks of widespread EV adoption and renewable energy integration over extended periods.
- Inadequate research exists on the economic impacts of transitioning to EVs and integrating renewable energy, including job creation, economic growth, and social equity, as well as their effects on different socioeconomic groups and overall economic stability.
- There is a lack of exploration into integrating EVs with renewable energy and existing infrastructure, insufficient data on consumer behavior and policy effectiveness, and a need for detailed lifecycle assessments of EVs, including their environmental impacts.
- Limited research exists on emerging technologies and their potential to enhance green transportation and sustainability, particularly in exploring advanced battery chemistries and smart grid solutions.

- EV adoption benefits for health, such as reductions in respiratory and cardiovascular diseases, need to be studied across different geographical and demographic contexts.

There is a need for global comparison and scalability studies, as insufficient comparative research exists on the implementation and benefits of green transportation technologies in different countries and regions. Comparative studies are required to understand how different governance models and policies affect the success of green transportation initiatives globally. Addressing the abovementioned research gaps helps for a comprehensive understanding of the impact of green transportation technologies and guides effective policies and practices for sustainable development.

6 Conclusion

The embracing of electric vehicles is significantly advancing sustainable green transportation through cutting-edge technologies. EVs are increasingly recognized as an eco-friendly alternative to high-emission traditional transportation methods. Green transportation plays a crucial role in addressing economic, social, and environmental impacts, with environmental protection being a key measure of EV efficiency in the context of climate change. Technological advancements, such as advanced charging technologies, artificial intelligence, and autonomous EVs, are enhancing the efficiency and sustainability of EVs, contributing to their growing popularity [32].

Despite these benefits, challenges remain, including high costs, efficiency issues, and the need for improved EV charging infrastructure. Additionally, concerns about the environmental impact of EVs, such as increased mining demands for battery materials, highlight the need for a balanced view of their benefits and drawbacks. While EVs show limited emissions compared to traditional vehicles, integrating renewable energy sources has further increased their sustainability and acceptance.

The current adoption trends underscore the decarbonization potential of EV technologies, with consumer adoption driving the development of integrated model systems and related policies. Governance and policy frameworks for EVs emphasize sustainable green transportation and environmental protection by reducing GHG emissions in addition to transitioning to clean energy resources. These frameworks include various fiscal and non-fiscal motivations to inspire EV adoption, enhance appeal, and ensure long-term retention. Thus, EVs are paving the way for a more sustainable green transportation future and advancing environmental protection.

7 Future of Work

This study can be further extended to address several key areas where it will evaluate the cumulative environmental impacts of widespread EV adoption and renewable energy integration. In-depth economic analyses are needed in future works to understand the impacts on job creation, economic growth, and social equity. Practical solutions for integrating EVs with renewable energy and existing infrastructure must be explored.

Additionally, more research will focus on consumer behavior and policy effectiveness, detailed lifecycle assessments of EVs, as well as the potential of emerging technologies. Examining the health benefits of EV adoption and conducting global comparisons will also provide valuable insights into enhancing sustainable transportation and environmental protection (Khang, Hajimahmud, Alyar et al., 2024).

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Declarations

Conflict of Interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this chapter.

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Industrial Sensors in Smart Transportation System

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Abstract Issues with traffic, safety, and pollution are just a few of the major transportation-related concerns that modern civilization must contend with. Information and communication technology are playing an increasingly essential role in modern transportation networks. Car companies are working on sensors that may be installed inside vehicles and used for many purposes, such as safety, traffic control, and entertainment systems. Cameras and sensors installed along roadways are helping government agencies monitor traffic and environmental factors. Intelligent transportation systems may be realized by the seamless integration of vehicles and sensing devices, which allows for the exploitation of their sensing and communication capabilities. We discuss the potential benefits of sensor technology for transportation infrastructure connectivity, entertainment applications, and traffic control in an STS, as well as the ways in which a network of sensors embedded in different components of an STS may enhance these areas over time. We wrap up by outlining some of the obstacles that must be overcome before an STS environment can be completely operational and cooperative.

Keywords Applications · Smart transportation systems · Sensors · Vehicle management

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1 Introduction

All countries' economic development now rests on their transportation infrastructure. However, the unchecked increase of traffic in many cities throughout the globe is leading to major issues including gridlock, surges in fuel costs, more carbon dioxide emissions, accidents, crises, and a general decline in contemporary society's quality of life.

There are new possibilities for creating an intelligent transportation system that is both sustainable and technologically advanced because to developments in ICT in areas like software, communications, and hardware. The adoption of Smart Transportation Systems (STS) may improve and secure transportation by integrating transportation infrastructure with information and communication technology (ICT) and focusing on four key standards: supportability, reconciliation, security, and responsiveness. Adhering to these rules will assist Clever Transportation Frameworks with accomplishing their fundamental targets, which incorporate greater openness and versatility, less natural effect, and more financial turn of events [14].

For STS to be a success, the platform must be able to access, collect, and analyze accurate environmental data. As a rule, there are two sorts of detecting stages. For the first time, there is an intra-vehicular sensor platform that can monitor a vehicle's health. Urban sensing systems, the second kind, gather data on traffic situations. When it comes to vehicles communicating with each other and with infrastructure, sensor technology is crucial. In order to facilitate further processing, analysis, and decision-making, transportation management systems receive these data. Fuel price spikes, CO2 emissions, traffic jams, and poor road conditions are only some of the problems that smart and intelligent STS aim to address [8, 30].

2 Technological Advancements in Sensors

There has been a lot of buzz and widespread adoption of sensor technology in the last decade. Healthcare [2, 29], agriculture [6]. Ojha et al. [21], forests [29], automotive and marine [3, 13] monitoring, and many more fields have made use of sensors. Countless transportation-related applications, including those for safety, entertainment, and traffic management, have been designed and developed with the help of sensor technology. Vehicles and intelligent transportation systems are now required to include sensors and actuators like tire pressure sensors and back view perceivability frameworks to further develop street wellbeing, decrease traffic congestion, and increase driver and passenger satisfaction (as a result of federal regulation in the US (USA [23]). Manufacturers provide additional sensors as an optional extra to track the vehicle's health and performance, boost economy, and aid drivers. The typical number of sensors in a car is between sixty and one hundred at the moment, but that might increase to two hundred in "smarter" cars [5].

The author of [12] divides sensors into three groups according to where they are introduced in the vehicle: the power plant, the skeleton, and the body. Additionally, there is research that sorts car sensors into four groups according to the function they are meant to serve: safety, diagnostics, convenience, and environment monitoring [1].

2.1 Sensors Installed Inside the Car

Finding the right sensors to build apps that tackle issues like (1) traffic jams and parking problems, (2) increased CO emissions, (3) longer commute times, (4) more road accidents, and more is crucial for enhancing vehicle execution and the driving experience as shown in Fig. 1.

U.S. tire-pressure monitoring applications are required by the National Highway Traffic Administration to alert drivers by audible, visible, or vibratory warning systems when the tire air pressure meets a certain threshold [9].

Electronic, ultrasonic, and proximity sensors are used by applications that assist with parking and reverse warning. Cars often include proximity sensors that detect when they are getting close to objects. As an ultrasonic sensor employs a kind of sonar to ascertain the distance, it will emit an alert should a vehicle go dangerously near to an object.

The driver is alerted by electromagnetic sensors whenever an object enters the field produced by the front and rear bumpers. The IIHS has established standards,

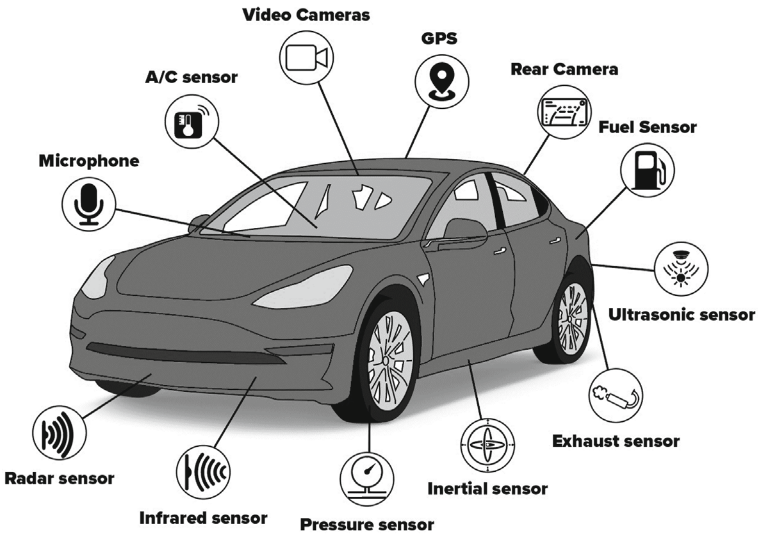

Fig. 1 Uses for vehicle-based sensors

and a system based on proximity sensors has been created to meet those standards. A rectangular capacitive closeness detecting exhibit is the foundation of this device, which measures the exact position of the person's head [31]. The precision of these sensors is, however, often diminished by environmental factors like temperature and humidity.

Safety applications constantly monitor the road for frontal, side, and rear collisions using RADAR and laser sensors. So that the driver may modulate the accelerator and brakes appropriately, these sensors use radio waves to find out the distance among themselves and any impediments. The software will notify the driver and immediately apply the brakes if it senses an item close, preventing a crash.

Inertial navigation systems (INS) utilize the whirligig and accelerometer sensors to discover the area, direction, and speed of the vehicle, among other factors. To get the most precise results, INS are used in tandem with GPS.

When a driver's speed or lane change is detected, a warning system might kick in to alert them of possible danger. It is common practice to alert the driver either audibly or by vibrating the seat or wheel.

For one, cameras can keep an eye on the driver's head, neck, and eye movement for any signs of fatigue or erratic driving behavior (such as veering off the road or unexpectedly merging into oncoming traffic) and, secondly, they can activate night vision assistance systems, which allow drivers to see further ahead and identify obstacles like trees, animals, or people that could cause an accident.

Light Detection and Ranging, or LIDAR, has emerged as an essential tool in the development of driverless cars. Self-driving cars, or any robot, may use LIDAR to see the environment in a unique way, with features like precise depth information and continuous 360-degree vision. Long-range imaging and detection radar (LIDAR) systems constantly pulse laser light and record the amount of time it takes for that light to bounce back to the system [15].

Despite the increased number of sensors in vehicles, a major obstacle to their widespread use is the difficulty in integrating them with other parts of the vehicle and the absence of industry-wide standards across manufacturers [18]. On the other hand, the capabilities of present automated systems are somewhat restricted. In order to keep drivers, riders, and pedestrians safe, Volvo, for one, has imposed a 50 km/h minimum speed limit in urban areas. For a city safety system to work in low-light situations, the vehicle's headlights and taillights must be turned on and visible to the system's laser unit [24].

2.2 As It Relates to Lane Monitoring

The backbone of every contemporary economy is its transportation network, which must be strategically invested in if a nation is to continue growing. Governments throughout the globe pour a substantial amount of money into transportation every year. Annual investment in the US is around 1.6% of GDP [7], whereas in Europe it was about 102 billion Euros in 2014, with road infrastructures receiving 52% of that amount [10].

Intelligent transportation systems have a significant problem in collecting traffic data from mechanisms situated along roadsides, despite significant investments in vehicle-based sensors to improve safety, performance, and comfort. New administrations, such brilliant leaving (which coordinates vehicles with accessible spaces) and marked down estimating in view of road congestion levels, become accessible to drivers when sensors are deployed inside a transportation network. In order to strengthen transportation networks and make them more robust, sensors are constantly gathering data about their surroundings. This data is then processed and analyzed.

The placement of a sensor determines whether it is considered invasive or non-intrusive. Surfaces of pavements have intrusive sensors attached to them. The installation and maintenance expenses are considerable, but their accuracy is great as well. There are essentially three types of invasive sensors, as shown in Fig. 2: Installed detached attractive sensors that are associated with handling machines by cables or wireless links and placed on highways secondly, inductive loops—coiled wires implanted in roadways that feed data to processing equipment; thirdly, pneumatic cylinder sensors—set across streets that send information via wired or wireless means. When it comes to traffic control systems, this category of sensors is heavily used [20].

The high level of technology used by road sensors is one of its main advantages. Their accuracy in detecting automobiles is good, and they have been extensively used. However, road sensors have a few major downsides, the most notable of which are the high installation costs and the traffic interruptions that they generate during both the installation and maintenance periods. The intrusive sensors have been replaced by wireless, battery-operated sensor nodes that are put over the pavement. This might be a solution to the problem highlighted before. The transportation sensors are set to undergo a transformation with this new technology, which is anticipated to reduce costs while simultaneously improving the amount, quality, accuracy, and reliability of data gathered from roadways and avenues [30].

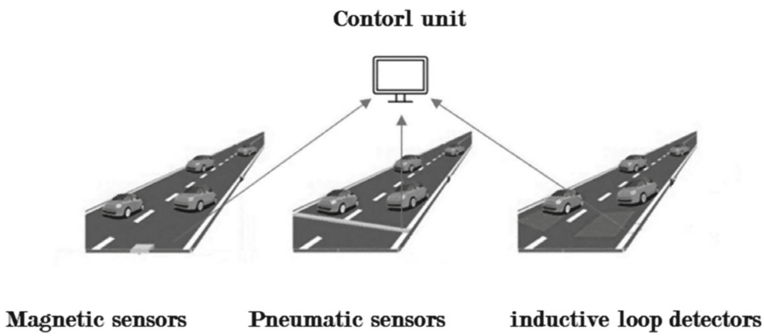

Fig. 2 Three types of invasive sensors

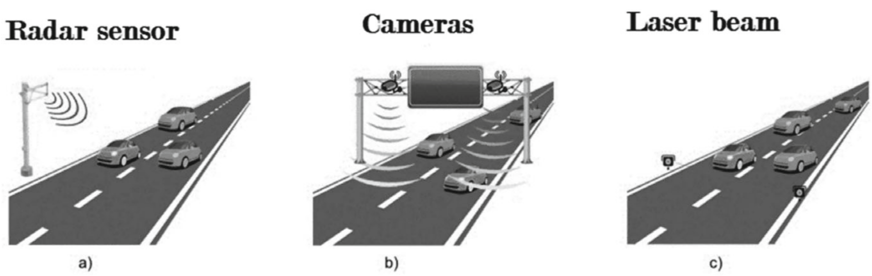

Fig. 3 Non-intrusive sensors on the road of Non-intrusive sensor groups, **a** roadside mast-mounted, **b** bridge mounted and **c** across roadside

Figure 3 shows the placement of non-intrusive sensors on the road, rather than above it, in order to determine a vehicle's transit, speed, and lane coverage, among other parameters. Nevertheless, their cost is high, and they are susceptible to environmental factors. In most cases, apps that gather data on a specific area—like traffic conditions, road and pavement weather, or queue detection at a traffic light—are built using non-intrusive sensors. A number of sensors can keep tabs on a predetermined region by positioning themselves on a mast. A monitoring area is located just below the sensors that are positioned on bridges. Finally, there are ground-level sensors that employ a pillar that traverses the street; they are frequently saved for single-path, one-way flows due to their sensitivity to interference from nearby objects.

While intrusive sensors can accomplish a lot, non-invasive sensors are more convenient and may even do many of the same tasks. But they are quite susceptible to the effects of weather such as snow, rain, and fog. In order to make educated judgments on how to enhance traffic conditions, precise traffic data is crucial. When drivers see non-intrusive sensors, they respond differently and quicker, for example, by reducing their speed and shifting to the right lane. The placement of these sensors is just part of the problem; another is making drivers' responses faster using the data they gather and giving them a clearer picture of the road or avenue's actual condition (Table 1) [31].

Using one or more tubes installed across lanes of traffic, pneumatic road tube sensors may count and classify vehicles. As the tyre goes over the cylinder, the sensor delivers an explosion of gaseous tension, which then, at that point, transforms into an electrical sign. A sign is shipped off the handling unit via electrical means.

Among the many sensors used for traffic control, the Inductive Loop Detector (ILD) stands out. It measures things like traffic volume, vehicle occupancy, distance traveled, and speed. A sensor that detects when a vehicle drives over it sends a signal to a processing unit via a long wire twisted into a circle that is either laid into the street or placed under it. The sensor detects when the circuit's electrical characteristics change.

When an anomaly in the World's attractive field is identified, attractive sensors may identify moving vehicles. Bridges are an ideal location for installing magnetic sensors, which may measure traffic, occupancy, vehicle length, and speed.

Table 1 Classification of transportation-related sensors

Category	Sensor type	Applications
Intrusive	Pneumatic road tube	Designed for use in maintaining records of vehicle counts, types, and classifications
	Inductive loop detector (ILD)	Applied for the purpose of detecting the location, number, occupancy, and motion of vehicles. An apparatus placed by the side of the road records the produced signals
	Magnetic sensors	Used for detecting the presence of vehicles, both moving and stationary
	Piezoelectric	Segmentation of vehicles, tally of vehicles, and measurement of vehicle mass and velocity
Non-intrusive	Video cameras	Vehicles may be detected across many lanes, sorted according to their length, and then each class's existence, flow rate, occupancy, and speed can be reported
	Radar sensors	Applications that track vehicle volume and speed, determine the direction of travel, and utilize this information to manage traffic lights
	Infrared	Speed, vehicle length, volume, and lane occupancy may all be measured with this application
	Ultrasonic	Monitoring the quantity of cars, the presence of vehicles, and the occupancy rate
	Acoustic array sensors	Used in the creation of apps that track the location, speed, and presence of vehicles
	Road surface condition sensors	Designed to gather data on a variety of meteorological factors, including surface temperature, dew point, water film height, road conditions, and grip
	RFID (Radio-frequency identification)	Mainly used for toll control purposes, it tracks vehicles

With a voltage change, piezoelectric sensors can detect cars crossing over them (at speeds of up to around 112 km/h) and can keep an eye on up to four lanes at once. When combined, piezoelectric and ILDs sensors produce a piezoelectric system.

Multiple video cameras, an image processor, and sophisticated algorithm-based software are the main parts of a Video Image Processor (VIP) system, which can interpret and transform the recorded images into traffic data. By keeping an eye on things like traffic volume and occupancy, video cameras placed along highways may capture and analyze footage of a traffic scene to detect changes between shots. A big problem with VIP systems is that they could not work as well in bad weather.

Everything in the radar's detecting zone reflects the low-energy microwave radiation that the sensor sends out. In order to precisely track the quantity of vehicles and decide their speed, Doppler frameworks utilize the recurrence shift of the return. One more sort of radar sensor framework, recurrence adjusted constant wave radar, utilizes ceaseless gearbox ability to gauge stream volume, speed, and presence. Radar sensors are frequently simple to introduce and provide highly precise readings. Both day and night operations are possible with their support for several detecting zones. One major drawback is how easily they may be affected by electromagnetic interferences.

Vehicles, road surfaces, and other things may be detected using infrared sensors. Sensors essentially relay electrical signals to the processing unit by converting the reflected energy. Infrared sensors may be either passive or active. Passive infrared (PIR) sensors detect vehicles via their infrared light emissions or reflections, and they collect data on flow volume, vehicle presence, and occupancy. Light Emitting Diodes (LEDs) or laser diodes are used by Active InfraRed (AIR) sensors to track the reflection time as well as volume, velocity, classification, vehicle presence, and traffic density data.

The time it takes for an item to reflect a sound wave produced at 25–50 kHz allows ultrasonic distance detectors to determine how far apart two things are. The processing unit receives its electrical energy from the transformed incoming energy. Vehicle flow and speed may be measured with the use of ultrasonic sensors. This kind of sensor is quite vulnerable to outside influences, which is its biggest drawback.

A collection of microphones assembled into an array, an acoustic array sensor can detect when the sound level rises when a vehicle approaches and passes within its detection range. The use of attractive enlistment circles is being supplanted, one small step at a time, by acoustic sensors, which can ascertain average vehicle speed, occupancy, and traffic volume.

To monitor the road's temperature and traction, as well as to carry out maintenance schedules, road surface condition sensors use infrared and laser technology. On the other hand, regular servicing is necessary for this kind of sensor to keep working properly. First, smart parking, which uses radio-frequency identification (RFID) sensors to detect cars in order to allot parking spots, and second, automatically recognizing and collecting data from vehicles on highways.

Despite the widespread deployment of sensors, transportation authorities, automakers, road users, and other STS stakeholders are disappointed by the data collected due to inaccurate calibration and cluster integration, which slows down the system's evolution and development. The goal of STS is to enhance transportation conditions by collecting data quickly from a variety of integrated sensors, which will allow for scenario assessment systems and quick decision-making.

3 Important Sensors

Even while sensors are common and easily accessible, they only make up a fraction of the machinery that will be required for the self-driving car of the future. Autonomous, automated, or self-driving cars will be safer and more efficient thanks to redundant sensors and their integration. Radar, cameras, backup sensors, and control software are already standard in modern automobiles. It is anticipated that such components will evolve in the next years, although high-resolution, inexpensive LIDAR systems with ranges of 300 m and beyond are still in the early phases of research.

For ADAS and semi-autonomous driving, modern camera systems integrate machine vision with other sensors (such RADAR) and use CMOS image sensors. When it comes to camera systems, the biggest drawbacks are the limits of computer vision for accurate identification and the fact that objects may be hard to see in dim or otherwise unlit environments. Quick picture capture and effective image processing methods for real-time analysis are the main obstacles of camera systems [17].

Radial acceleration radar (RADAR) sensors use radio waves to consistently measure distance from an object. When used in conjunction with other controls, they adjust the throttle as needed.. While RADAR's portability and adaptability to various environments are its greatest strengths, the technology's narrow range of view is its biggest weakness, making it unable to identify smaller vehicles like bikes and motorcyclists that aren't staying in their lanes.

LIDAR is a cutting-edge technology that the car industry is using to estimate distances to both moving and fixed objects. LIDAR utilizes specific cycles to produce 3D pictures of the discovered items. Since LIDAR relies on light spectrum waves, its primary drawbacks are their size, expense, and inability to function well in poor weather (such as snow, fog, rain, and airborne dust particles). LIDAR produces subpar visual recognition because it lacks the ability to discern color or contrast. Lastly, large-scale productions using LIDAR equipment are quite unusual nowadays. Therefore, due to concerns about availability and cost, the full potential of this technology has not been completely realized just yet.

Decreasing their size to permit straightforward reconciliation in vehicles and expanding their opening point locations are two of the biggest difficulties for LIDAR technology in terms of lowering the cost of deployment in all vehicles. While Google's Waymo initiative favors LIDAR technology, companies like Tesla are concentrating on developing new cars in view of frameworks that simply consolidate cameras and RADAR sensors [25].

The installation of support systems in automobiles does not provide a singular answer. Integrating multi-sensor systems is crucial to the success of the next generation of vehicles. Integrating camera systems with radar systems, which are positioned on the front and back of the vehicle to follow traffic, works on the precision of speed and distance readings, making it easier to recognize obstacles and moving objects. Although LIDAR offers finer resolution, radar and LIDAR work well together and both have great potential.

4 Difficulties and Possibilities

Below, we have outlined some of the future challenges that should be addressed to further develop transportation frameworks, portability, and the wellbeing of the two drivers and travelers via the use of intelligent transportation systems.

Organizations tasked with traffic management are cognizant of the fact that smart transportation frameworks stand up to the issue of how to improve versatility. So, they're always putting smart sensors that rely on computational vision into things like automobiles, physical infrastructure, and mobile sensing units and systems. However, sensors aren't enough to solve the mobility problem by themselves.

The integration of new gadgets and technology is crucial for transportation system improvement. These include data analytics, tools for automated operations and decision-making, as well as social and mobile networks. Capturing, analyzing, and sharing real-time information with the right people from all the different sources requires this integration. In intelligent transportation systems, tracking the range of sensors installed on roadways, in cars, and in transportation infrastructures is a major obstacle.

Inadequate or nonexistent infrastructure, such as transit lines that are either blurry or erased, traffic signals that are either too weak or nonexistent, and hazardous road conditions, such as openings in the street, sudden changes in street surface from asphalt to another material, street floods, or other natural risks that could endanger the vehicle's occupants, are currently challenges for sensing systems. But we need to zero in on the exact locations of the actual limitations (such as the algorithms that handle the data from the sensors or how easily we can access the sensors).

For example, if the front sensors distinguish an item or vehicle while the vehicle is going at a fast, however the calculations' handling time to pick the advance notice connection point or control framework is excessively lengthy, we may not get the right reaction before the crash. Decreased mishap rates could be the aftereffect of further developed vehicle reaction times in every single atmospheric condition and better traffic and hazardous road condition identification on maps made possible by interfacing different sensors, infrared and photogrammetric frameworks, and proficient calculations for multisource information combination [26].

Integrating data fusion methods with AI would enable the vehicle to comprehend its present status and respond appropriately, including predicting various circumstances and settings, similar to how a person might [11]. Take this scenario: a motorist sees a bouncing ball and instantly thinks of pulling over since there's likely a kid running after it. A more rapid reaction from the vehicle to a possible accident scenario may be possible in the future with the coordination of thought induction into the vehicle's control framework, made conceivable by this converging of sensors and artificial intelligence.

Applying machine learning and data fusion, in addition to sensors, may enhance the measure of information created by transportation frameworks. This data can then be used by applications to learn transportation behavior from both historical and real-time data, thereby improving STS performance [27]. In order to study and forecast many situations (such traffic dynamics or driver behavior), fusion techniques integrate data from several sources [28].

In order to discover valuable trends and patterns in various traffic data sources, machine learning is used, with the help of association rules [4]. The goal here is to improve the efficiency of the transportation system by developing learning-driven algorithms that are good at detecting and predicting traffic trends. Problems arise when trying to create algorithms that can process data samples from a wide variety of sources using a wide variety of media (wired or wireless) (cameras, sensors, etc.). These algorithms must be able to: (i) clean the data by removing any abnormal information from the sources; (ii) (i) keep the original feature space's interpretability intact while removing unnecessary features; and (iii) combine and compare data from various sources.

Vehicle privacy and security need a two-pronged approach to minimizing intrusiveness. First, we need to ensure that drivers and passengers do not reveal any personal information while using our vehicles. This is because sharing data in a network can make users identifiable. To further safeguard drivers' and passengers' privacy while using our vehicles' networks, we ought to integrate security and protection conventions into the specialized gadgets that are upheld by them [19].

Furthermore, when new gadgets are integrated into automobiles, their proper placement is crucial. These devices should not distract the driver but also enhance their solace by conveying all the important data about the different segments of the vehicle. Second, think about the best way to notify the driver via the interface. One approach may be to develop tools that help drivers concentrate more on the road by reducing the number of distractions they face, such as notifications and data on roadside infrastructure. This could be achieved, for example, by using AI to automate functions that rely on human judgment [16].

Integrating several devices inside the vehicle to enhance the detecting range and detection accuracy utilizing many sources of information is necessary to provide 360° vision for the driver. Nevertheless, substantial investments in both software and hardware will be required to accomplish this goal. There will also be a great deal of data produced.

Calculating the warning could demand a lot of computing resources. Therefore, in order to choose the most appropriate interface to notify the driver, we need to create efficient processing algorithms. Because excessive prices will damage sales, we need to carefully balance the quantity of detecting gadgets with the quantity of cautioning gadgets while keeping the vehicle's pricing reasonable. Raising the vehicle's detection speed and enhancing its field of view are two possible solutions [22]. With these upgrades, we can respond to crises more quickly and effectively.

5 Conclusions

For STS to succeed in the future, sensors are going to be crucial. Use of these allows for a multitude of applications related to traffic safety, entertainment, and driver support. Incorporating sensor data on the vehicle's environment (including traffic, road conditions, and vehicle status) into existing transportation systems can help alleviate some of the issues that have plagued these systems in the past and in the present.

The practicality of sensor-STS integration is shown by the use of statistical and analytical methods. As a possible area of research, this integration might pave the way for the development of several next-generation smart applications that improve the security and traffic management of existing and future transportation systems.

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Internet of Things (IoT) Smart Sensing Traffic Lights for Revolutionizing Urban Traffic Management

Alex Khang and Khushwant Singh

Abstract The escalating vehicular population in urban areas has reached critical levels, leading to heightened concerns regarding traffic congestion and safety. In response, this research paper proposes an innovative solution "smart sensing traffic lights" as a transformative measure to overcome the limitations of traditional traffic signal systems. Unlike conventional systems relying on pre-defined signal timing, the smart sensing traffic lights integrate a network of advanced sensors, including cameras, radar, and vehicle-to infrastructure communication, to capture real time traffic data. The core functionality of the smart sensing traffic light system lies in its dynamic adjustment of signal timings and sequences based on the analysis of real-time traffic data. This adaptability enables the system to respond to changes in traffic patterns, congestion levels, and overall urban activity. Notably, the system prioritizes emergency vehicles and provides adaptive crossing times, contributing to a safer and more inclusive urban environment. The simulation-based evaluation methodology follows a meticulous series of steps to ensure a robust analysis. Initially, a detailed model of the urban road network is constructed, considering factors such as road geometry, intersections, and traffic flow patterns. Real-world traffic data, encompassing vehicular density and movement patterns, is seamlessly integrated into the simulation environment to enhance the accuracy and realism of the evaluation. The smart sensing traffic lights system is then implemented within the simulation, incorporating parameters reflective of its real-world capabilities. Diverse scenarios are simulated, including peak traffic hours, emergency vehicle interventions, and unexpected traffic fluctuations. Performance metrics are precisely defined to measure traffic flow efficiency, delay reduction, and the system's adaptability to dynamic conditions. The research paper concludes by engaging in a comprehensive discussion of the implications derived from the simulation results and their practical relevance to real-world urban traffic management. The findings offer valuable insights into the

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potential of smart sensing traffic lights as a transformative solution for addressing contemporary traffic challenges. By contributing to the development of more efficient, adaptive, and inclusive urban transportation systems, this research lays the groundwork for future advancements in the field of intelligent traffic management.

Keywords Smart sensing traffic lights · Traffic congestion · Safety · Urban traffic management · Real-time traffic data · Simulation-based evaluation · Emergency vehicle prioritization

1 Introduction

The escalating vehicular population in urban areas has intensified traffic congestion and safety concerns, prompting a need for more intelligent transportation systems. This research paper introduces the innovative concept of "smart sensing traffic lights" as a solution to address the limitations of traditional traffic signal systems. Unlike pre-defined signal timing, this proposed system integrates a network of sensors—cameras, radar, and vehicle-to-infrastructure communication to capture real-time traffic data [1, 2].

The core functionality of the smart sensing traffic light system lies in its ability to dynamically adjust signal timings and sequences based on the analysis of real-time traffic data. This responsiveness allows the system to adapt to changes in traffic patterns, congestion levels, and overall activity [3]. Notably, the system prioritizes emergency vehicles and provides adaptive crossing times, contributing to a safer and more inclusive urban environment. To evaluate the effectiveness of the smart sensing traffic lights system, a simulation-based approach is employed using real-world traffic scenarios [4].

The methodology involves creating a detailed virtual environment that replicates diverse traffic conditions and scenarios. The system's performance is then compared to that of conventional traffic signal systems to measure improvements in traffic flow efficiency, reduction in congestion- related delays, and overall enhancement of the urban traffic experience [5, 6]. The simulation-based evaluation methodology comprises several key steps [7, 8, 9, 10].

Firstly, a comprehensive model of the urban road network is constructed, incorporating factors such as road geometry, intersections, and traffic flow patterns [11, 12]. Real-world traffic data, including vehicular density and movement patterns, is integrated into the simulation environment to ensure a high degree of accuracy. The smart sensing traffic lights system is implemented within the simulation, with parameters reflecting the real- world capabilities of the proposed system [7–14].

Various scenarios are simulated, encompassing peak traffic hours, emergency vehicle interventions, and unexpected traffic fluctuations. Performance metrics are defined to measure traffic flow efficiency, delay reduction, and the system's adaptability to dynamic conditions [15, 16]). Comparative analyses are conducted by simulating the same scenarios using traditional traffic signal systems [2, 17–19].

The results of these simulations provide quantitative insights into the advantages of the smart sensing traffic lights system [20, 21]. Key performance indicators, such as reduced travel times, minimized congestion, and improved emergency vehicle response times, are utilized to assess the system's efficacy.

This chapter concludes by discussing the implications of the simulation results and their relevance to real- world urban traffic management. The findings offer valuable insights into the potential of smart sensing traffic lights as a transformative solution for addressing contemporary traffic challenges, ultimately contributing to the development of more efficient, adaptive, and inclusive urban transportation systems. The paper also outlines future research directions and considerations for the practical implementation of smart sensing traffic lights in urban settings [22].

2 Literature Review

Hurtado-Gómez, Romo et al. [23] designed a new model, the article: Machine Learning Based Adaptive Traffic Signal Control for Intelligent Transportation Systems. The research aims to create to collect data for machine learning models. The methodology proposed an adaptive traffic signal control system using machine learning techniques. Data from traffic sensors, cameras, and historical traffic patterns were collected and used to train machine learning models. The models were then deployed to make real-time traffic light timing decisions based on current traffic conditions. This Machine Learning Based Adaptive Traffic Signal Control offers advantages like it allows for data-driven, adaptive adjustments in real-time. Can potentially optimize traffic light timings based on complex, dynamic patterns, but has limitations such as requires significant computational resources and data collection infrastructure.

Models may need frequent retraining to adapt to changing traffic conditions. Nimburkar, Ghodmare et al. [24] developed a model for traffic light synchronization, as detailed in their 2022 article titled "Traffic Signal Synchronization System for Highway Corridor in Urban Area". The research aims compared various traffic light synchronization techniques. The methodology included field data collection, such as traffic volumes and travel times, and the implementation of different traffic light synchronization algorithms. The effectiveness of these techniques was evaluated based on traffic flow and congestion reduction. It objectively provides a practical comparison of different techniques for traffic light synchronization.

Field data collection ensures real world relevance. But Field studies can be time-consuming and costly. Results may be specific to the studied locations and conditions. Xie, Smith et al. authored a paper titled "Real-time traffic control for sustainable urban living" in 2017. The study aims to employed a simulation-based approach using traffic modeling software. Real world traffic data were collected and used to model traffic flow, and various traffic light control strategies were tested to optimize traffic light timings for reduced congestion and improved traffic flow in an urban area. Simulation based approaches allow for controlled experimentation without affecting

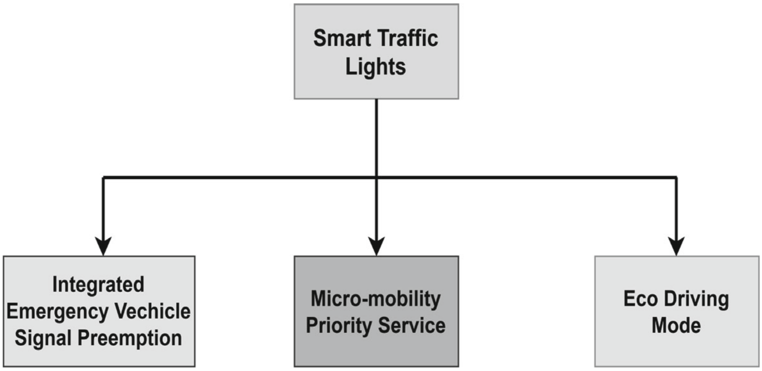

Fig. 1 Classification of smart traffic light

real traffic. Results can be obtained quickly and at a lower cost compared to field studies. The accuracy of simulations may depend on the quality of input data and model assumptions. Real-world variations and unexpected events may not be fully captured in simulations.

Designed a model for implementation, the article. Smart Traffic Management System using IoT Enabled Technology. The research focused on implementing IoT technology for smart traffic lights. The methodology involved installing IoT sensors at intersections to collect real-time traffic data. These data were then processed in a cloud based system to adjust traffic light timings. However, it relies on data, involves IoT sensors can provide real-time data for adaptive traffic light control. Centralized cloud based systems enable remote monitoring and control [25].

Emre, Mohammad et al. [26] designed a new model the article: Pedestrian safety at signalized intersections: Spatial and machine learning approaches. The research aims to focus on improving pedestrian safety at signalized intersections. The methodology involved a combination of field surveys, pedestrian behavior observations, and traffic light timing adjustments. The study aimed to optimize traffic light timings to enhance pedestrian safety while maintaining efficient traffic flow as shown in Fig. 1.

However, addresses a critical safety concern at signalized intersections. Combines field observations with practical traffic light adjustments as shown in Table 1.

Table 1 depicts the literature review comparison of various researchers.

3 Proposed System

In 1912, In Salt Lake City, a young police officer named Lester Wire introduced an innovative concept for traffic control. Tired of officers enduring harsh weather for hours at intersections, he devised a solution: Wires attached to a wooden box on a pole. This box featured two light bulbs, one red and one green, connected to electricity for seamless switching with the press of a button. Patrol officers could now

Table 1 Literature review comparisons

Author	Paper Title	Methodology	Advantage	Disadvantage
Ferrer et al., 2016	Innovative transportation case validation for automated traffic light tests for programs	This study employed a simulation-based approach using traffic modeling software. Real world traffic data were collected and used to model traffic flow, and various traffic light control strategies were tested to optimize traffic light timings for reduced congestion and improved traffic flow in an urban area	Simulation based approaches may allow for controllable experimentation without affecting real traffic	The accuracy of simulations may depend on the quality of input data and model. Real world result variation can be unexpected
Liang et al., 2008	Machine learning based adaptive signal learning techniques in the biomedical	This paper proposes adaptive system data driven techniques. Real time data from transportation system has been used from the biomedical	Machine learning allows for signal control computational resources of data	It requires significant resources and infrastructures for the signal conditions
Sharma et al., 2020	IoT-Enabled Smart Traffic Lights for Urban Traffic Management	This research IoT sensors can Initial setup and provide focused on real time data infrastructure	Implementing IoT for adaptive traffic costs can be light technology for smart control. It is more vulnerable centralized to traffic lights	The cyber security cloud based systems methodology involved risks and data enable remote privacy installing IoT sensors at concerns. monitoring and control
Jain et al., 2022	Comparative study of traffic light techniques	This study compares various traffic synchronization techniques	The methodology included field data collection, such as traffic volumes and travel times, and the implementation of different traffic light	It provides a practical field studies. Comparison of different techniques time is quite time consuming for traffic and costly

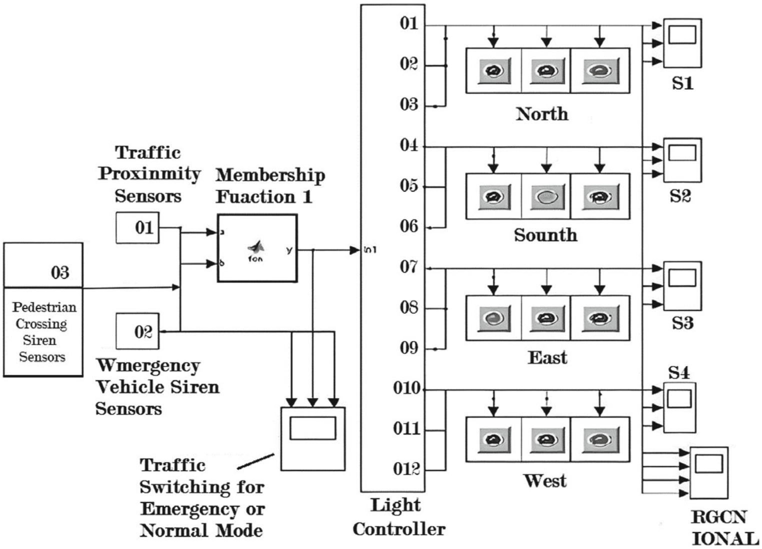

Fig. 2 Block diagram for smart sensing traffic lights

manage traffic signals from a sheltered booth at the roadside. Although modern traffic light signals have evolved with the introduction of the yellow light and automation, the fundamental idea remains intact-traffic lights continue to change based on a pre-programmed schedule or specific time intervals [27].

In this research chapter, the proposed system is Censored Based Light System in which there are sensors installed for integrated emergency vehicle, micro mobility vehicle, pedestrians, and eco driving mode (reducing vehicle idle time). Consideration should be given to revisiting traditional approaches and embracing a more advanced and intelligent traffic light system that aligns with the evolving and expanding global landscape [28]. The evolution of traffic lights and signals persists through the integration of innovative technologies or the synergistic use of existing ones as shown in Fig. 2.

4 Methodology

4.1 Urban Road Network Modeling

Create a detailed virtual model reflecting the complexities of an urban road network. Incorporate factors such as road geometry, intersections, and traffic flow patterns. Integrate real-world traffic data, including vehicular density and movement patterns, ensuring a high degree of accuracy in the virtual environment.

4.2 Smart Sensing Traffic Lights System Integration

Implement the proposed system within the virtual simulation, mirroring real-world capabilities. Define system parameters reflecting the responsiveness and adaptability of smart sensing traffic lights. Simulate diverse scenarios, including peak traffic hours, emergency vehicle interventions, and unexpected traffic fluctuations.

4.3 Performance Metrics Definition

Establish key performance metrics to quantitatively assess the system's effectiveness. Define indicators such as traffic flow efficiency, reduction in congestion-related delays, and adaptability to dynamic conditions.

4.4 Comparative Analysis with Conventional Traffic Signal Systems

Conduct comparative analyses by simulating identical scenarios using traditional traffic signal systems. Evaluate travel times, congestion levels, and emergency vehicle response times to quantify the advantages of the smart sensing traffic lights system.

4.5 Quantitative Assessment

Use simulation results to quantitatively assess the benefits of the smart sensing traffic lights system. Analyze reduced travel times, minimized congestion, and improved emergency vehicle response times as quantitative indicators.

5 Result and Discussion

Classifying smart traffic lights based on their purpose, they can be categorized into different types: that integrated emergency vehicle signal preemption, give priority to micro mobility priority vehicles or traffic lights that dynamically adapt their scheduling based on the presence and volume of pedestrians.

5.1 Unified Emergency Vehicle Traffic Priority System (EVTPS)

Ensuring priority access for emergency vehicles is paramount, given that a delay of just one minute in medical assistance can reduce the chances of survival by 7% to 10%. The critical nature of timely arrivals extends to police, firefighters, and other emergency services, where delays can have severe consequences. Despite the urgency, emergency vehicles often face challenges navigating heavy traffic. Introducing a smart emergency vehicle traffic light changer addresses this concern comprehensively: Enhance signaling to expedite the movement of emergency vehicles. Adjust grid signals to divert regular traffic away from affected areas. Implement prioritized signaling in proximity to emergency vehicle garages, parking lots, or stations. Provide advance notification to drivers about approaching emergency vehicles, allowing for extra time to maneuver safely.

Case in point: An insightful examination of smart traffic signal preemption for emergency vehicles in the United States revealed compelling findings. In Fairfax County, Virginia, the implementation of a preemption system facilitated faster passage of emergency vehicles through busy areas, resulting in time savings of 30–45 s per intersection. The city of Plano experienced a remarkable reduction in the average number of emergency vehicle intersection crashes, decreasing from 2.3 per year to less than one every five years, following the deployment of a similar solution. Notably, the city of Plano achieved consistent response times despite a reduction in the number of fire and EMS stations in the vicinity.

5.2 Nano-Transportation Preference Service

The rise of Nano-Transportation Preference or micro-mobility, encompassing bikes, e-bikes, and e-scooters, has become integral to the Mobility as a Service (MaaS) landscape. However, this expansion introduces additional road safety challenges for both pedestrians and drivers. Startlingly, in the initial half of 2021, escooter accidents in London surged by an alarming 2800%, a staggering increase compared to the entire year of 2018. With the escalating adoption of personal and shared micro-mobility solutions, it becomes imperative to enhance their regulation.

Intelligent traffic light systems should adapt to the presence of these dynamic road participants, necessitating the establishment of more sophisticated controls tailored to their movements. To ensure optimal safety, a two-step approach is recommended. Employ smart traffic light video systems to detect and recognize vehicles, enabling precise traffic signal adjustments. Notify nearby drivers of micro-mobility riders by leveraging V2X-based updates or Signal Phase and Timing (SPaT) messaging, enhancing awareness and responsiveness on the road. Revolutionary Mobility Innovations has pioneered a cutting-edge solution to enhance safety and efficiency for cyclists and pedestrians. Their innovative smart mobility system seamlessly integrates all road users through an intelligent traffic control platform accessible via a dedicated mobile app. Through this app, real-time data is transmitted to a smart traffic light control system, enabling adaptive signal adjustments. For instance, if a pedestrian is about to cross a street, the app prompts the connected traffic light to automatically modify signal durations. Similarly, the system can anticipate approaching cyclists, optimizing signal timings to enhance their flow. This dynamic approach not only prioritizes safety but also promotes the appeal of cycling by introducing responsive traffic lights, ultimately reaping numerous benefits [29].

5.3 Fuel-Efficient Mode

Roaring engines at bustling intersections generate a blanket of both noise and air pollution. Plus, they contribute to diminishing the appeal of urban locales with bustling intersections, impacting the economic development of neighborhoods as well. Intelligent traffic signals have the potential to decrease idle time for vehicles and encourage the adoption of environmentally friendly driving behaviors. A team of Taiwanese researchers meticulously recorded a series of eco-driving traffic light regulatory models designed for integration into sensor-based traffic light systems [30]. Their discoveries have been swiftly implemented by the PTV Group in Taipei, where the PTV Balance software platform is adept at recognizing shifts in traffic dynamics and recommending intelligent signal adjustments for cars, cyclists, and pedestrians.

Table 2 depicts the comparison of normal and smart sensing traffic lights.

The Effectiveness of the platform was validated through extensive testing in two Taipei districts, Neihu and Nangang, yielding remarkable results: An impressive 7.9% enhancement in average travel time. A notable 12.6% decrease in travel delays on both weekdays and public holidays. A substantial annual fuel has done the savings of 318,269 L and significant CO emission reductions of 101.1 metric tons per year.

Table 3 depicts the comparative analysis of various eco driving model.

6 Conclusion & Future of Work

Smart Traffic Lights represent a technological breakthrough poised to address congestion challenges and mitigate road accidents. This paper examines the methodologies and technologies employed in the development of smart traffic lights, focusing on the reduction of traffic density, pedestrian issues, and the efficient detection of emergency vehicles and micromobility (two-wheelers). The future outlook envisions highly evolved smart traffic lights capable of independent, efficient, and effective traffic management, thereby mitigating human error and minimizing time wastage in extensive traffic jams.

Table 2 Comparison table between normal and smart sensing traffic lights

Normal traffic lights	Smart sensing traffic lights
The data you provided indicates that traffic light upgrades have been made over the years, resulting in a reduction in clearing time. These upgrades may involve changes in signal timing, infrastructure enhancements, or other manual improvements	Smart sensing traffic lights, on the other hand, use real-time data from sensors to make dynamic adjustments to signal timing based on current traffic conditions. This approach is more responsive and adaptive than traditional upgrades based on historical data
The data-driven traffic light upgrades likely involve static changes in signal timing based on past traffic patterns. These changes might not account for sudden traffic surges, accidents, or road closures effectively	Smart sensing traffic lights constantly monitor traffic conditions through sensors and can adjust signal timing on the fly, responding to real-time events and traffic fluctuations. This dynamic approach leads to more efficient traffic management
The data you provided focuses on specific major cities (Delhi, Mumbai, and Chennai) and the corresponding traffic light upgrades in these locations	Smart sensing traffic lights can be implemented in a broader network, covering a larger geographic area and multiple intersections. This allows for a more comprehensive and coordinated traffic management system
The data suggests a gradual reduction in the number of traffic light upgrades over the years, implying that improvements may reach a point of diminishing returns	Smart sensing traffic lights require ongoing maintenance and updates but have the potential to continuously optimize traffic flow, offering sustainable and long-term benefits
With smart sensing traffic lights, adaptive algorithms can make real-time decisions to improve traffic flow, such as giving priority to the busiest directions or responding to emergency vehicles, without the need for manual intervention	Traditional traffic light upgrades may rely on manual intervention or scheduled adjustments, which are less flexible and responsive to changing conditions

Contrasted with conventional traffic light systems, smart traffic lights excel in handling variable traffic flow at junctions, diminishing waiting times and proactively preventing large-scale traffic congestion. Their implementation contributes to a significant reduction in road accidents by preventing signal violations and collisions between vehicles. Smart sensing traffic lights represent a paradigm shift in urban traffic management. By leveraging advanced sensor technologies, data analytics, and artificial intelligence, these systems offer a dynamic and responsive solution to address traffic congestion and improve road safety. While challenges exist, the potential benefits far outweigh the obstacles. This research paper aims to contribute to the understanding of smart sensing traffic lights, providing valuable insights for policymakers, engineers, and researchers working towards the future of intelligent urban transportation networks [16].

The future scope of smart sensing traffic lights is promising and includes several advancements and benefits. As AI and machine learning algorithms become more sophisticated, traffic lights will be able to predict traffic patterns and adapt in real-time to optimize traffic flow further [31]. As more vehicles become connected to the internet and equipped with vehicle-to-infrastructure (V2I) communication, traffic

Table 3 Comparative analysis of various eco driving model

Eco driving model	Concept	Actions	Benefit	Applications
MaxTM, MinADM	Max, Throughput and Min. acceleration and deceleration	OBU suggest eco-driving speed	Reduce carbon emission, fuel consumption, travel time	Standalone intersections
VANATE-based coordinated signal control model	Forecasting and decision making	RSU determines traffic signal plan	Reduce carbon emissions, fuel consumption	Multiple intersections
EDAS System	Calculate number of intersections that can be passed and can different modes	OBU suggest eco-driving speed	Reduce carbon emissions, fuel consumption, travel time	Multiple intersections
TTA & RS	Travel time predictions and path recommendations	OBU forecast travel time and suggest path	Reduce computational complexity and reduce travel time	Multiple intersections

lights can communicate directly with vehicles to optimize traffic flow, reduce congestion, and enhance safety. Smart traffic lights can contribute to reducing carbon emissions by optimizing traffic flow, thus reducing idling time and fuel consumption. These systems can automatically give priority to emergency vehicles, clearing the path quickly and efficiently.

Smart traffic lights can prioritize public transport vehicles, reducing wait times for buses and improving overall public transportation efficiency. Advanced pedestrian detection systems can enhance crosswalk safety by extending green times when pedestrians are present. The data collected by these systems can be used for urban planning, traffic management, and policy decisions. Dynamic lane assignment can be implemented to adapt to changing traffic patterns and accommodate different modes of transportation such as bicycles and scooters. In summary, the future of smart sensing traffic lights is focused on improving traffic efficiency, safety, and environmental sustainability through advanced technology integration and real time data analysis.

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Declarations

Conflict of Interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this chapter.

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Quantum Computing: Revolutionizing Green Transportation Through Advanced Optimization and Simulation

Pankay Bhambri and Alex Khang

Abstract Quantum computing, a nascent paradigm in the field of computation, offers the potential to profoundly transform green transportation through its unparalleled powers in optimization and simulation. Conventional computing approaches frequently face difficulties when dealing with the intricacy and magnitude of problems associated with optimizing transportation systems to achieve environmental sustainability. Quantum computing, utilizing concepts like superposition and entanglement, provides a significant advancement in computational capability, allowing for the effective manipulation of large datasets and intricate models. This chapter explores the ways in which quantum algorithms can improve different areas of environmentally friendly transportation, including optimizing routes, managing traffic flow, designing energy-efficient vehicles, and controlling autonomous systems. Through the examination of practical implementations and theoretical progress, we emphasize the capacity of quantum computing to tackle the pressing issues of carbon emission reduction and operational efficiency improvement in transportation networks. Moreover, this chapter provides a thorough examination of the collaboration between quantum computing and artificial intelligence (AI) within the framework of sustainable mobility. This study investigates the impact of quantum-enhanced artificial intelligence on the creation of prediction models for transportation demand, the optimization of logistics in supply chains, and the enhancement of transportation infrastructure's resilience to environmental effects. By combining quantum computing with AI and automation, we can discover novel approaches to developing more intelligent and environmentally friendly transportation systems. The topic encompasses the analysis of specific instances, prospective advancements, and the moral implications of implementing quantum technologies in transportation.

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The purpose of this investigation is to offer a clear plan for researchers, practitioners, and policymakers to utilize the potential of quantum computing in facilitating the shift towards a sustainable, environmentally friendly future in transportation.

Keywords Artificial intelligence · Route optimization · Traffic flow management · Energy-efficient vehicles · Autonomous systems · Sustainable mobility

1 Introduction

1.1 Overview of Quantum Computing

Quantum computing is a transformative change in how we process information, using the fundamental concepts of quantum physics to revolutionize computational methods [1]. Quantum computers differ from classical computers in that they utilize qubits, which are quantum bits, to represent data instead of the traditional binary system of 0 s and 1 s. Qubits have the ability to be in the state of superposition, meaning they can simultaneously represent both 0 and 1 [9]. Additionally, qubits can get entangled in other qubits, resulting in immediate correlations of their states across any distance. Quantum computers possess certain characteristics that allow them to solve specific types of problems at an exponentially quicker rate compared to classical computers [11].

1.2 Relevance to Green Transportation

The transportation industry has a substantial role in the generation of worldwide carbon emissions and the deterioration of the environment. Conventional methods for improving transportation systems are restricted by the intricate and extensive nature of the networks involved [12].

Quantum computing presents a hopeful opportunity to tackle these difficulties by utilizing sophisticated optimization and simulation methods. Through the utilization of quantum algorithms, we may create more streamlined routes, optimize traffic flow, devise energy-efficient vehicles, and improve autonomous systems. These technological breakthroughs have the potential to result in significant decreases in carbon emissions and enhancements in overall sustainability [20].

1.3 Objectives and Structure

This chapter aims to explore the intersection of quantum computing and green transportation, highlighting the potential benefits and applications of quantum technologies in creating more sustainable transportation systems. The chapter is structured as follows:

- Introduction: An overview of quantum computing and its relevance to green transportation.
- Fundamentals of Quantum Computing: Basic concepts and principles underlying quantum computing.
- Challenges in Conventional Transportation Optimization: Current limitations and sustainability issues in transportation.
- Quantum Computing for Transportation Optimization: Specific applications of quantum algorithms in optimizing transportation systems.
- Quantum Computing in Autonomous Systems: Enhancing autonomous vehicle technologies with quantum computing.
- Quantum-Enhanced Artificial Intelligence in Transportation: Integrating quantum computing with AI for improved transportation systems.
- Case Studies and Practical Implementations: Real-world examples of quantum computing applications in transportation.
- Prospective Advancements in Quantum Computing and Green Transportation: Future technologies and trends.
- Ethical and Societal Implications: Addressing the broader impacts of quantum computing on society and the environment.
- Conclusion: Summarizing key findings and outlining future directions.

2 Fundamentals of Quantum Computing

2.1 Basic Concepts: Qubits, Superposition, and Entanglement

Qubits, the quantum equivalent of classical bits, are the fundamental building blocks of quantum computing. Qubits can simultaneously occupy many states due to the concept of superposition. Quantum computers possess the capability to simultaneously execute many calculations [19]. Entanglement, a fundamental notion, allows qubits to be linked in the manner that classical bits are unable to. When qubits are entwined the condition of one qubit has an immediate and simultaneous effect on the condition of another qubit, irrespective of the distance among them. This phenomenon is crucial to the efficacy of quantum computing [15].

2.2 Quantum Gates and Circuits

Quantum gates serve as the fundamental components of quantum circuits, similar to how logic gates function in classical computing. These gates modify quantum bits (qubits) via unitary operations, which allows for the creation and advancement of quantum algorithms. Quantum circuits execute computations by developing the quantum behavior of qubits between a starting states to a final state using sequences of quantum gates. Quantum computations commonly utilize several specific gates, such as the Pauli-X, Pauli-Y, Pauli-Z, Hadamard, and CNOT gates [22].

2.3 Quantum Algorithms and Their Potential

Quantum algorithms exploit the distinctive characteristics of the theory of quantum mechanics to resolve problems with greater efficiency compared to traditional algorithms. Some notable instances include Shor's algorithm, which is used to factor big numbers and has important implications for encryption, and Grover's technique, which is used for database search and delivers a quadratic speedup compared to classical search algorithms. Quantum algorithms, such as the Quantum Approximate Optimization Algorithm (QAOA) and the Variational Quantum Eigensolver (VQE), can be applied in transportation to optimize intricate systems and address difficulties with routing, scheduling, and energy management [23].

3 Challenges in Conventional Transportation Optimization

3.1 Complexity and Scale of Transportation Systems

Transportation systems are naturally intricate, encompassing a multitude of variables and limitations. Efficiently optimizing such systems necessitates managing vast quantities of data and making instantaneous judgments. The computational requirements necessary to solve such optimization problems increase exponentially as the system size grows, frequently rendering it impractical for traditional computers to discover the best possible solutions within a tolerable time frame.

3.2 Limitations of Classical Computing Methods

Classical computing technologies have notable limits when it comes to solving optimization problems in transportation. These methods frequently depend on heuristic or approximation algorithms, which could not yield the optimal solutions [2]. In addition, as transportation networks expand and become increasingly interconnected, the computational load on traditional systems rises, resulting in longer processing durations and subpar performance.

3.3 Environmental Sustainability and Carbon Emission Reduction

The transportation industry is a significant contributor to the release of greenhouse gases, which in turn contributes to the effects of climate change and the deterioration of the environment. Traditional optimization techniques may not give priority to sustainability, instead emphasizing effectiveness and expense reduction [3]. There is a pressing demand for sophisticated optimization methods that can effectively balance operational effectiveness with environmental sustainability, including decreasing carbon emissions and advocating for more environmentally friendly transportation alternatives.

4 Quantum Computing for Transportation Optimization

4.1 Quantum Algorithms for Route Optimization

Optimizing the route is a crucial problem in transportation that involves finding the most efficient routes for automobiles to travel. Quantum computing can improve route optimization by utilizing algorithms that utilize entanglement and super to simultaneously examine different paths. One use of the Quantum Approximate Optimization Algorithm (QAOA) is to efficiently solve routing problems by finding solutions that are close to optimal. This can lead to a large decrease in travel time and fuel usage.

4.2 Traffic Flow Management with Quantum Approaches

Efficiently controlling the movement of vehicles in metropolitan settings is essential for minimizing traffic congestion and enhancing air quality. Quantum computing enables enhanced capabilities for real-time traffic control through faster and more precise processing of large volumes of data compared to classical systems [25]. Quantum algorithms have the capability to enhance traffic signal timings, redirect vehicles to circumvent congestion, and forecast traffic patterns, resulting in a more seamless traffic flow and reduced emissions.

4.3 Energy-Efficient Vehicle Design and Optimization

To create energy-efficient automobiles, it is necessary to optimize various factors such as aerodynamics, weight, along with powertrain efficiency. Quantum computing can enhance this optimization method by concurrently simulating and assessing multiple design variants. This feature enables the quick identification of designs that reduce energy use and increase performance, hence aiding in the creation of more environmentally friendly automobiles.

5 Quantum Computing in Autonomous Systems

Figure 1 depicts the integration of Quantum Computing with Autonomous Systems, highlighting its crucial role in improving multiple aspects. Quantum Computing is a key element in the picture and has a direct impact on Autonomous Systems by offering sophisticated computing capacities. Quantum Algorithms, Qubits and Quantum Simulations are fundamental constituents generated from Quantum Computing [26]. These components enable essential operations in autonomous systems, including Traffic Administration, Sensor Data processing, Optimizing, and Energy Efficiency.

Quantum algorithms and qubits provide advanced information processing and problem-solving methods, which are crucial for making real-time decisions and ensuring efficient functioning in autonomous systems. Quantum Simulation offers sophisticated modeling capabilities that assist in statistical analysis and resource optimization [4]. Incorporating Quantum Computing in autonomous systems greatly improves their functionality, becoming them more effective, responsive, and sustainable.

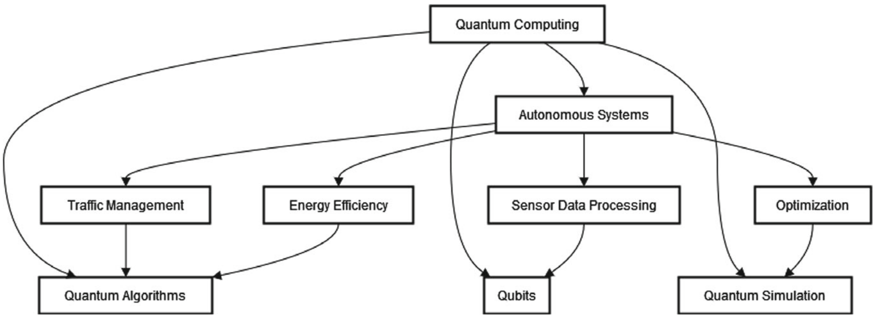

Fig. 1 The role of quantum computing in autonomous systems

5.1 Enhancing Autonomous Vehicle Navigation

Autonomous vehicles depend on intricate algorithms to navigate and make decisions. Quantum computing can augment these capabilities by offering expedited and more precise processing of information from sensors, facilitating instantaneous decision-making. Quantum algorithms have the potential to enhance path planning, avoiding obstacles, and cruise control adaptation, hence increasing the safety and efficiency of autonomous vehicles [14].

5.2 Real-Time Decision Making with Quantum Computing

Autonomous systems rely on real-time decision making to promptly adapt to changing conditions. The quick information processing and simultaneous exploration of various possibilities by quantum computing make it well-suited for real-time applications [7]. Autonomous systems can utilize quantum algorithms to assess different actions and select the most favorable one instantly, hence improving their responsiveness and dependability.

5.3 Integration with AI for Autonomous Control Systems

Combining quantum computing and artificial intelligence (AI) can significantly augment the capacities of autonomous systems. Quantum-augmented AI algorithms have the potential to boost machine learning models, resulting in more precise forecasts and improved decision-making capabilities [28]. This integration has the potential to result in more advanced autonomous systems of control that are capable of efficiently managing intricate settings and dynamic circumstances.

6 Quantum-Enhanced Artificial Intelligence in Transportation

6.1 Developing Prediction Models for Transportation Demand

Precise forecasting of demand for transportation is crucial for effective planning and allocation of resources. By leveraging quantum-enhanced AI algorithms, the precision of demand forecasting techniques can be boosted through the processing of greater datasets and the identification of patterns that may be overlooked by classical algorithms [29]. The enhanced precision can result in improved scheduling, less waiting periods, and efficient allocation of resources.

6.2 Optimizing Logistics and Supply Chains

Logistics and supply chain management encompass the coordination of multiple activities to guarantee the punctual delivery of commodities. Quantum computing enhances these processes by efficiently solving intricate optimization problems [31]. Quantum algorithms have the potential to improve route planning, handling inventory, and demand forecasting, resulting in more efficient logistics and lower operational expenses.

6.3 Enhancing Infrastructure Resilience to Environmental Effects

The transportation infrastructure is susceptible to environmental impacts, including severe weather events as well as climate change. Quantum-enhanced artificial intelligence has the potential to boost the endurance of infrastructure by offering more precise predictive models along with optimization algorithms [8]. These models can assist planners in developing more resilient systems, predicting disturbances, and implementing efficient mitigation techniques.

7 Case Studies and Practical Implementations

7.1 Quantum Computing Applications in Urban Transportation

Urban transportation systems encounter distinct obstacles as a result of the dense population and intricate networks [21]. Quantum computing case studies conducted in cities like New York, London, along with Tokyo illustrate the possibility of substantial enhancements in traffic management, public transportation effectiveness, and reduction of emissions. These examples demonstrate the tangible advantages of incorporating quantum computing into transportation planning [18].

7.2 Success Stories in Traffic Flow Optimization

Quantum computing has been effectively utilized in a number of pilot projects to optimize traffic flow. An example of this is a project implemented in Toronto, where quantum algorithms were employed to improve the timings of traffic signals [5]. As a result, there was a decrease in traffic congestion and a reduction in emissions. These success stories exemplify the tangible effects of quantum technology on enhancing transportation effectiveness and sustainability.

7.3 Examples of Energy-Efficient Vehicle Design

The automotive sector has employed quantum computing to develop vehicles that are more energy-efficient. Automotive companies like Volkswagen and BMW have investigated quantum algorithms to enhance the efficiency of vehicle components and combinations [6]. The endeavors have resulted in the creation of prototype automobiles with enhanced energy efficiency, demonstrating the promise of quantum computing within the auto sector.

8 Prospective Advancements in Quantum Computing and Green Transportation

8.1 Emerging Quantum Technologies

The domain of quantum technology is undergoing swift development, with frequent emergence of novel technologies and improvements [32]. Advancements such as quantum annealing, topology qubits, and quantum correction of errors are expanding the limits of what can be achieved. These nascent technologies show potential for significantly augmenting the possibilities of quantum technology in optimizing transportation.

8.2 Future Trends in Quantum-Driven Transportation Systems

With the continuous advancement of quantum computing, it is anticipated that it will have a progressively substantial impact on transportation systems. Future developments encompass the amalgamation of quantum technology with smart city projects, the advancement of quantum-based traffic control systems, and the utilization of quantum techniques for global logistics improvement [33]. These trends indicate that quantum computing will play a crucial role in the development of sustainable transportation in the future.

8.3 Collaborative Efforts and Research Directions

Effective implementation of quantum technology in transportation necessitates cooperation among academics, industry, and government [10]. Collaborative research endeavors are crucial for the progress of quantum technologies and the resolution of the obstacles linked to their deployment. Important areas of research involve the advancement of quantum algorithms that can be used on a large scale, enhancing the quality of quantum hardware, and investigating the ethical and social consequences of quantum computing [13].

9 Ethical and Societal Implications

9.1 Ethical Considerations in Quantum Computing Applications

The application of quantum technology in transportation gives rise to numerous ethical problems. Concerns regarding data privacy, bias in algorithms, and the possibility of employment displacement need to be resolved [27]. Developing ethical norms and frameworks is crucial to enable responsible and socially beneficial usage of quantum computing technology.

9.2 Societal Impact of Sustainable Transportation Systems

The shift towards sustainable modes of transportation has extensive societal ramifications. Advantages encompass less air pollution, greater public health, and improved quality of life. Nevertheless, it is crucial to take into account the economic and social effects of this shift, especially on areas who may see a disproportionate impact [24].

9.3 Policy and Regulation for Quantum Technology in Transportation

Policymakers and regulators have a vital role in determining the trajectory of quantum computing in the transportation sector. Formulating suitable rules and regulations is crucial for fostering innovation while guaranteeing safety, security, and fairness. The main areas of concentration encompass financial support for research and innovation, regulations for quantum computing, and structures for collaborations between the public and commercial sectors [16].

10 Conclusion

10.1 Summary of Key Findings

This chapter has examined the capacity of quantum computing to profoundly impact and revolutionize the field of environmentally friendly transportation [30]. The key findings reveal that quantum algorithms have the potential to optimize intricate transportation systems, boost autonomous car technology, and enhance the sustainability and effectiveness of supply chains and logistics.

10.2 Implications for Researchers and Practitioners

The incorporation of quantum technology into transportation networks offers both prospects and difficulties for researchers and practitioners. Interdisciplinary collaboration, ongoing innovation, and the creation of practical quantum solutions that may be implemented in real-world environments are necessary.

10.3 Future Directions and Final Thoughts

The prospects for quantum computing in sustainable transport are promising, as continuous progress and upcoming technologies are expected to contribute to additional enhancements. As we further investigate the capabilities of quantum technology, it is crucial to be aware of the moral and social consequences, guaranteeing that these developments are employed to establish a sustainable and fair world [17].

Authors Contribution Pankaj Bhambri and Alex Khang: Contributed experiments, conceptualization and methodology. Pankaj Bhambri: Contributed Writing and Editing. Alex Khang: Contributed Writing – Review & Editing, and Supervision.

Declarations

Conflict of Interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this chapter.

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Role of Human-Centered Design and Technologies in Smart Transportation System

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Abstract Smart transportation systems are revolutionizing urban mobility by leveraging technology to optimize traffic flow, enhance safety, and improve user experience. Central to the success of these systems is Human-Centered Design, which focuses on the needs, behaviors, and experiences of users. This paper explores the role of Human-Centered Design in smart transportation systems, examining its principles, benefits, and challenges. Additionally, we propose a comprehensive model that integrates Human-Centered Design into the development and implementation of smart transportation solutions, using Helsinki's Mobility as a Service (MaaS) initiative as a case study.

Keywords Human-centered design · Smart transportation system · User interface · Human–computer interaction · Sustainable transportation · Mobility as a service · Digital transformation · Real-time information systems

1 Introduction

In an age where technology drives much of our progress, smart transportation systems have emerged as a beacon of innovation in urban mobility. These systems, which integrate advanced technologies to manage and optimize transportation networks,

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promise to transform the way we travel. However, the true success of these smart systems hinges not merely on the sophistication of the technology but on how well they meet the needs of the people who use them. This is where Human-Centered Design (HCD) comes into play.

Human-Centered Design is an approach that puts users at the forefront, ensuring that their needs, preferences, and experiences shape the development and implementation of any system [6]. When it comes to smart transportation, HCD can make the difference between a system that is merely functional and one that is truly transformative. In this chapter, we will discuss the principles of HCD, explore its benefits and challenges, and examine how it has been effectively applied in the case of Helsinki's Mobility as a Service (MaaS) initiative.

1.1 Purpose

The purpose of this study is to explore the critical role of HCD in the development and implementation of smart transportation systems. By emphasizing user needs, behaviors, and experiences, HCD aims to enhance the usability, efficiency, and adoption of these systems. The study seeks to identify and elucidate the key principles of HCD that are vital for creating effective smart transportation solutions. It also discusses the benefits of incorporating HCD into smart transportation, such as improved user experience and increased adoption, as well as the challenges involved, including resource intensity and balancing diverse user needs. Furthermore, the study develops a comprehensive model for integrating HCD into smart transportation systems, providing a structured approach for future projects to follow. By achieving these objectives, the study aims to highlight the importance of designing transportation systems that are not only technologically advanced but also user-friendly, inclusive, and context-aware, ultimately promoting sustainable and efficient urban mobility.

1.2 Methodology

The methodology for this study involves a multi-step approach to explore the role of HCD in smart transportation systems. First, an extensive literature review and analysis of existing HCD principles and practices in smart transportation will be conducted. The study will also include a detailed case study analysis of Helsinki's MaaS initiative, examining how HCD principles were applied and their impact. Based on the findings, an iterative design process will be used to develop and refine a comprehensive model for integrating HCD into smart transportation systems.

1.3 Outcomes

The outcome of this study is expected to provide a comprehensive understanding of the pivotal role that HCD plays in the success of smart transportation systems. It will highlight key HCD principles and illustrate their benefits and challenges through a detailed case study of Helsinki's MaaS initiative. The study will culminate in the development of a structured model for integrating HCD into smart transportation projects. This model aims to guide future projects in creating transportation solutions that are user-friendly, inclusive, and efficient, ultimately promoting sustainable urban mobility and enhancing overall user satisfaction.

To start, we will discuss the fundamental principles of HCD, which include empathy, inclusivity, iterative design, user engagement, and context awareness. These principles are the bedrock of HCD and guide the process of creating transportation systems that are not only efficient but also user-friendly and accessible to all.

Following expected outcomes, we will explore the numerous benefits of incorporating HCD into smart transportation systems. From enhancing user experience and increasing adoption rates to improving safety, efficiency, and sustainability, the advantages of HCD are manifold. We will provide concrete examples of how HCD can lead to more intuitive, accessible, and satisfying transportation solutions. Despite its many benefits, implementing HCD in smart transportation systems is not without its challenges. We will examine the resource-intensive nature of HCD, the complexity of balancing diverse user needs, and the difficulties in integrating user-centric designs with advanced technologies. Understanding these challenges is crucial for effectively applying HCD principles in real-world projects.

To illustrate the practical application of HCD in smart transportation, we will present a detailed case study of Helsinki's MaaS initiative, exemplified by the Whim app. This initiative integrates various transportation modes; public transit, taxis, car rentals, and bike-sharing into a single, seamless service. We will discuss the extensive user research, iterative design process, and inclusive approach that underpinned the development of the Whim app, highlighting how HCD contributed to its success.

Based on insights from Helsinki's MaaS initiative and the principles of HCD, we will propose a comprehensive model for integrating HCD into smart transportation systems. This model will guide the development of user-centric transportation solutions through steps such as user research and analysis, co-creation and collaboration, iterative design and testing, inclusive and accessible design, context-aware solutions, and implementation and monitoring.

Finally, we will conclude by emphasizing the importance of Human-Centered Design in creating smart transportation systems that are not only technologically advanced but also user-friendly, inclusive, and context-aware. By prioritizing the needs and experiences of users, we can promote sustainable and efficient urban mobility, ensuring that smart transportation systems truly enhance the quality of life for all urban residents. This chapter aims to provide a thorough understanding of the critical role of HCD in smart transportation systems, offering both theoretical insights and practical guidance for creating user-centric solutions.

2 Principles of Human-Centered Design

At its core, Human-Centered Design is about empathy and understanding [5]. It involves stepping into the shoes of the users to see the world from their perspective. The following principles are fundamental to HCD:

2.1 Empathy

Empathy is the cornerstone of HCD, it involves putting oneself in the shoes of the users to deeply understand their needs, desires, frustrations, and experiences. This principle is not just about collecting data through surveys or interviews; it's about immersing oneself in the users' world to gain genuine insights. For instance, designers might spend time observing commuters at a busy train station, noting their interactions with ticket machines, their reactions to delays, and the flow of foot traffic. By understanding the emotional and practical aspects of users' experiences, designers can create solutions that truly resonate with and serve the people they are intended for. Empathy ensures that the product is not only functional but also emotionally satisfying and supportive.

2.2 Inclusivity

Inclusivity in HCD means ensuring that the design caters to the widest possible range of users, including those with disabilities, the elderly, and people from diverse cultural backgrounds. It is about recognizing and respecting the diversity of the user base and creating solutions that are accessible and usable by everyone. For example, a transportation app designed with inclusivity in mind would offer features such as voice commands for visually impaired users, intuitive interfaces for elderly users, and multilingual support to accommodate non-native speakers. Inclusivity also involves considering economic barriers, ensuring that solutions are affordable and accessible to people from all economic backgrounds. By designing inclusively, we ensure that no one is left behind, and everyone can benefit from the advancements in smart transportation systems.

2.3 Iterative Design

Iterative design is a cyclic process of prototyping, testing, and refining a product based on user feedback. This principle recognizes that the first attempt at a solution is rarely perfect, and that continuous improvement is essential. Designers start with a prototype, an early, often simplified version of the product and test it with real users. The feedback gathered from these tests is invaluable, revealing what works well and what needs improvement. Designers then adjust and test again, repeating this cycle until the product meets users' needs effectively. This approach not only enhances the functionality and usability of the product but also builds user trust and engagement, as they see their feedback being taken seriously and integrated into the design.

2.4 User Engagement

User engagement is about involving users throughout the design process, from initial research to final implementation. This can be achieved through various methods such as co-creation workshops, focus groups, and user testing sessions. By actively involving users, designers can gather diverse perspectives and ideas that might not have been considered otherwise. For example, in a co-creation workshop for a new public transit system, users might suggest features like real-time updates on bus schedules or more ergonomic seating arrangements. Engaging users helps ensure that the final product aligns closely with their needs and preferences, leading to higher satisfaction and adoption rates. It also empowers users, giving them a sense of ownership and agency over the solutions being developed for them.

2.5 Context Awareness

Context awareness involves understanding the environment and circumstances in which the product will be used. This includes considering the physical, social, cultural, and economic contexts that could affect how the product is perceived and used. For instance, a bike-sharing program in a hilly city might need to include electric bikes to make the service practical and appealing. Similarly, cultural factors might influence the design of communication campaigns promoting new transportation services. Context-aware design ensures that the solutions are not only functional but also fit seamlessly into users' lives, respecting and adapting to their daily realities. It requires designers to go beyond generic solutions and tailor their designs to the specific conditions and needs of the target user base.

By embedding these principles into the design process, smart transportation systems can become more responsive to human needs, ultimately creating more efficient, enjoyable, and equitable urban mobility solutions. With a solid understanding of the core principles of Human-Centered Design, we can now explore the tangible benefits that these principles bring to smart transportation systems. In the next section, we will dive into how HCD enhances user experience, increases adoption rates, improves safety, and promotes sustainability and efficiency in urban mobility.

3 Benefits of Human-Centered Design in Smart Transportation

In the previous sections, we explored the foundational principles of HCD and how they can be effectively applied to smart transportation systems. We saw the concepts of empathy, inclusivity, iterative design, user engagement, and context awareness, highlighting their importance in creating user-friendly and efficient transportation solutions. Now, with a solid understanding of these principles, we will examine the tangible benefits that HCD brings to smart transportation. In this section, we will discuss how HCD enhances user experience, increases adoption rates, improves safety, boosts efficiency, and promotes sustainability, illustrating the significant impact of user-centric design on urban mobility. The social systems enabled by ICT, such as Intelligent Transportation System affects society itself as well as the user's behavior [13].

3.1 Enhanced User Experience

When transportation systems are designed with the user at the center, the overall experience significantly improves. Imagine a commuter using a public transit app that is intuitive, easy to navigate, and provides real-time updates on bus arrivals and delays. Such an app reduces stress and uncertainty, making the commuting experience smoother and more enjoyable. Features like personalized route recommendations and user-friendly interfaces cater to individual preferences and needs, ensuring that users feel understood and valued. This enhancement in user experience leads to higher satisfaction and loyalty, as people are more likely to use and appreciate systems that genuinely make their lives easier.

3.2 Increased Adoption

One of the most significant advantages of integrating Human-Centered Design into smart transportation systems is the increase in user adoption rates. When a system is designed to meet the actual needs of its users, they are more inclined to embrace it. For example, if a bike-sharing program includes a variety of bike types to cater to different riders, offers multiple payment options, and provides conveniently located docking stations, it is more likely to attract a broader range of users. Additionally, by addressing barriers to use, such as complex registration processes or unclear instructions, HCD ensures that potential users are not deterred. This broad acceptance and use of the system contributes to its overall success and sustainability.

3.3 Improved Safety

Safety is a paramount concern in transportation, and Human-Centered Design can play a crucial role in enhancing it. By understanding user behaviors and interactions, designers can create systems that minimize the risk of accidents and errors. For instance, clear signage, well-designed interfaces, and ergonomic vehicle controls can significantly reduce the likelihood of user mistakes. In public transit systems, features such as well-lit stations, surveillance cameras, and emergency communication tools can make users feel safer. Additionally, designing for safety involves considering the needs of vulnerable populations, such as children, the elderly, and people with disabilities, ensuring that safety measures are inclusive and comprehensive.

3.4 Higher Efficiency

Efficiency in transportation systems translates to reduced travel times, decreased congestion, and optimized resource use. Human-Centered Design contributes to higher efficiency by creating solutions that align with user habits and needs. For example, a ride-sharing app that effectively matches users with nearby drivers based on real-time traffic conditions can significantly reduce waiting times and improve route efficiency. Moreover, by integrating user feedback into the design process, transportation providers can continuously refine their services to address pain points and streamline operations. Efficient systems not only enhance the user experience but also have broader societal benefits, such as reduced environmental impact and improved urban mobility.

3.5 Sustainability

Human-Centered Design encourages the adoption of sustainable transportation options by making them more appealing and accessible. For instance, a well-designed public transit system that is reliable, affordable, and easy to use can persuade people to choose buses and trains over private cars. Similarly, bike-sharing programs and pedestrian-friendly urban designs can promote eco-friendly modes of travel. By addressing user concerns and preferences, HCD ensures that sustainable options are not only available but also practical and desirable. This shift towards sustainable transportation reduces the carbon footprint of urban areas, contributing to environmental conservation and improving the quality of life for residents.

By understanding the significant benefits that Human-Centered Design brings to smart transportation systems, we can appreciate its role in creating more user-friendly, efficient, and sustainable urban mobility solutions. In the next section, we will see the challenges of implementing Human-Centered Design in smart transportation, exploring the complexities and considerations that must be addressed to achieve successful outcomes.

4 Challenges of Implementing Human-Centered Design

In the previous section, we explored the significant benefits of incorporating Human-Centered Design into smart transportation systems, such as enhanced user experience, increased adoption rates, improved safety, higher efficiency, and sustainability. While these advantages highlight the transformative potential, implementing such an approach is not without its challenges. In this section, we will see the key challenges [2] faced when applying HCD principles in smart transportation. We will discuss the resource-intensive nature, the complexity of balancing diverse user needs, the difficulties of integrating user-centric designs with advanced technologies, and the resistance to change from both users and stakeholders. Understanding these challenges is essential for effectively navigating the design and implementation process.

4.1 Resource Intensive

Implementing HCD can be resource-intensive, requiring significant investments of time, money, and human capital. The process involves extensive user research, iterative testing, and continuous refinement, all of which demand substantial resources. Conducting user interviews, surveys, and ethnographic studies to gather deep insights into user needs and behaviors can be costly and time-consuming. Additionally, the iterative design process, which includes prototyping, user testing, and feedback incorporation, requires skilled designers, researchers, and developers. Organizations must be willing to allocate these resources and understand that the upfront investment is crucial for creating a product that truly resonates with users. While the long-term benefits often justify these investments, the initial cost and effort can be a significant barrier for many projects.

4.2 Complex User Needs

Urban populations are incredibly diverse, with a wide range of needs, preferences, and behaviors. Balancing these complex and sometimes conflicting needs to create a solution that works for everyone is a challenging task. For instance, a smart transportation system must cater to daily commuters, occasional travelers, tourists, and people with disabilities, the elderly, and more. Each of these groups has different requirements and expectations. Designing a system that addresses such varied needs without becoming overly complicated or inefficient is a delicate balancing act. Moreover, user needs can evolve over time, requiring ongoing adjustments and updates to the design. Successfully navigating these complexities requires a deep understanding of the user base and a flexible, adaptive design approach.

4.3 Integration with Technology

Ensuring that user-centric designs are technically feasible and scalable is another significant challenge. Advanced technologies such as artificial intelligence, Internet of Things (IoT), and big data analytics are often integral to smart transportation systems. While these technologies can enhance functionality and efficiency, integrating them with HCD principles can be complex. For example, a user-friendly interface must be supported by robust backend systems that handle data securely and efficiently. Designers and engineers need to collaborate closely to ensure that the technological infrastructure can support the desired user experience without compromising performance or security. Additionally, scalability must be considered, as solutions that work well in pilot projects may face challenges when implemented on a larger scale [10].

4.4 Resistance to Change

Introducing new, user-centered transportation solutions can sometimes face resistance from both users and stakeholders. People are often accustomed to existing systems and may be reluctant to adopt new ones, even if they offer improved experiences. This resistance can stem from a lack of awareness, fear of the unknown, or attachment to familiar routines. Stakeholders, such as transportation authorities and service providers, might also resist changes due to concerns about cost, disruption, and the complexity of implementation. Overcoming this resistance requires effective communication, education, and demonstration of the benefits of the new system. Engaging users and stakeholders early in the design process and addressing their concerns can help build trust and facilitate smoother transitions [11].

By understanding these challenges, we can better appreciate the complexities involved in implementing Human-Centered Design in smart transportation systems. In the next section, we will dive into a detailed case study of Helsinki's MaaS initiative, showcasing how these challenges were addressed and overcome to create a successful, user-centered transportation solution. This case study will provide practical insights and lessons that can inform future projects and help navigate the intricacies of HCD in urban mobility.

5 Case Study

5.1 Helsinki's Mobility as a Service (MaaS)

The case study of Helsinki's MaaS initiative [4], centered around the Whim app, serves as a compelling illustration of HCD principles in action within the context of smart transportation. By examining the development and implementation of the Whim app, we can explore firsthand how HCD principles such as empathy, inclusivity, iterative design, user engagement, and context awareness were applied to create a user-centric transportation solution. This case study will not only showcase the tangible benefits of integrating HCD into smart transportation systems, such as enhanced user experience, increased adoption rates, and improved efficiency, but also highlight the challenges faced and lessons learned along the way. By understanding the intricacies and outcomes of Helsinki's MaaS initiative, we can take insights that will enrich our understanding of how to effectively design and implement user-centered solutions in urban mobility contexts.

The Whim app stands as a pioneering example of HCD in smart transportation. The goal of MaaS was ambitious yet straightforward: to integrate various modes of transportation into a single, seamless service that meets the diverse needs of urban commuters and residents [3]. The Whim app allows users to plan, book, and pay for their entire journey using a combination of public transit, taxis, car rentals, and bike-sharing, all within one platform.

The success of Helsinki's MaaS initiative can be attributed to its rigorous application of HCD principles throughout the design and implementation process. The journey began with extensive user research, including surveys, interviews, and ethnographic studies, to understand the daily challenges and preferences of Helsinki's residents. By creating detailed personas representing different user groups such as daily commuters, occasional travelers, and tourists the development team gained valuable insights into the specific needs and expectations of each segment.

Using these insights, the team employed iterative design practices, continually prototyping and testing the Whim app with real users. This iterative approach allowed them to refine the app's features based on direct user feedback, ensuring that it was intuitive, user-friendly, and responsive to the dynamic needs of the urban population. For instance, features like real-time updates on transit schedules, personalized journey recommendations, and seamless payment options were iteratively improved to enhance user satisfaction and usability.

Inclusivity was also a key consideration in the design of the Whim app. The platform was designed to be accessible to all users, including those with disabilities, through features like screen reader compatibility and clear, intuitive interfaces. This commitment to inclusivity not only broadened the app's user base but also reinforced its reputation as a solution that prioritizes accessibility and equity in urban mobility.

Moreover, context awareness played a crucial role in shaping the Whim app's design. The team considered Helsinki's unique urban environment, including its public transit infrastructure, cultural norms, and seasonal variations in travel patterns.

This context-aware approach ensured that the app seamlessly integrated into users' daily lives, offering practical solutions that aligned with their routines and preferences. As a result of these efforts, Helsinki's MaaS initiative achieved significant success, transforming how residents and visitors navigate the city. Users reported higher satisfaction with their transportation experiences, citing the convenience, reliability, and flexibility offered by the Whim app. The initiative also contributed to a shift towards more sustainable transportation choices, as users were encouraged to opt for public transit and shared mobility options over private vehicles.

5.2 Challenges and Lessons Learned

However, despite its initial success, Helsinki's MaaS initiative faced challenges that impacted its long-term sustainability and profitability [1]. One significant issue was the difficulty in achieving financial viability while maintaining service quality and affordability. The integration of multiple transportation modes and the provision of seamless service required complex partnerships and operational agreements with various stakeholders, including transportation providers and local authorities. This complexity increased operational costs and posed challenges in establishing a sustainable business model [8].

Moreover, while the Whim app addressed many users' needs effectively, some segments of the population such as those living in less densely populated areas or requiring specialized transportation services did not find the MaaS solution as beneficial. This highlighted the ongoing challenge of balancing the diverse needs of urban populations and ensuring equitable access to transportation solutions for all demographics.

Furthermore, the rapid pace of technological advancements presented ongoing challenges for maintaining the Whim app's technological infrastructure. Ensuring compatibility with evolving technologies and addressing cybersecurity concerns required continuous investment and adaptation, adding to the operational complexity and costs.

In conclusion, while Helsinki's MaaS initiative demonstrated the transformative potential of Human-Centered Design in smart transportation, its sustainability was challenged by the intricate balance of financial viability, user inclusivity, and technological integration. The lessons learned underscore the importance of holistic planning, stakeholder collaboration, and ongoing adaptation in implementing user-centered transportation solutions. By addressing these challenges proactively and integrating user feedback continuously, future smart transportation initiatives can build upon the successes and learnings of Helsinki's MaaS, creating more resilient, inclusive, and sustainable urban mobility solutions.

6 Proposed Model

Based on the insights from Helsinki's MaaS initiative and HCD principles, we propose a comprehensive model for integrating HCD into smart transportation systems. While existing models [7], Mitchell et al., n.d.; University of Illinois at Urbana-Champaign, USA for integrating HCD into smart transportation systems provide valuable frameworks, the rapid evolution of technology and the diverse needs of urban populations necessitate a fresh approach.

A new model is needed to encapsulate the latest advancements in HCD practices and to address emerging challenges such as technological integration, sustainability, and inclusivity. By synthesizing the core principles of HCD with practical strategies tailored to the complexities of modern urban environments, this proposed model aims to foster innovation, efficiency, and user satisfaction in smart transportation solutions. In Fig. 1 we present a novel model which will enable seamless integration of design principles in smart transportation systems.

6.1 User Research and Analysis

User Research and Analysis is the foundational step in our proposed model for integrating Human-Centered Design in smart transportation systems. This stage involves a comprehensive and methodical approach to understanding the diverse needs, behaviors, and preferences of users. It goes beyond simple data collection, delving deep into the lived experiences of people who interact with transportation systems daily.

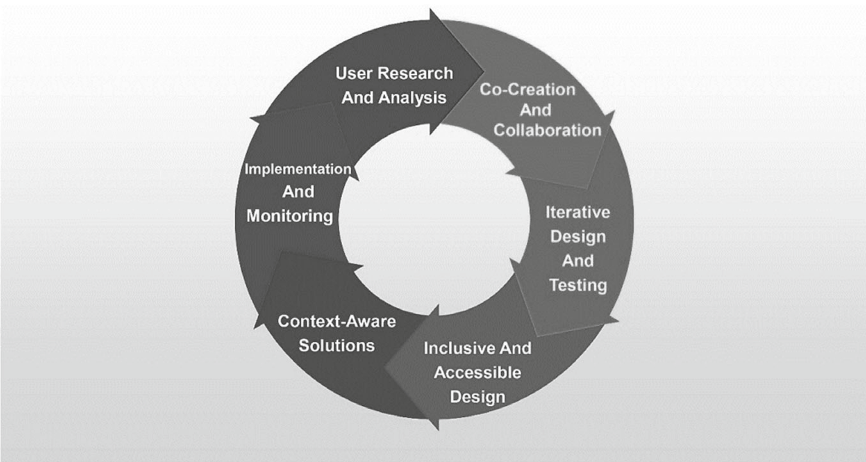

Fig. 1 The model for integrating HCD in smart transportation systems

The process begins with qualitative methods such as interviews, focus groups, and ethnographic studies. These methods allow us to capture detailed narratives and personal stories, providing rich insights into the user experience. For instance, interviews with commuters can reveal pain points like the anxiety caused by unpredictable bus schedules or the discomfort of overcrowded trains. Focus groups can bring together different user segments, such as elderly passengers, parents with young children, and individuals with disabilities, to discuss their unique challenges and needs.

Ethnographic studies, where researchers observe users in their natural environments, can uncover subtle yet crucial aspects of the user experience that might be missed in more structured research settings. For example, observing how people navigate a busy subway station can highlight design flaws in signage or accessibility features that are not immediately apparent.

In addition to qualitative research, quantitative methods play a crucial role. Surveys and questionnaires distributed to a broad user base can provide statistically significant data on user preferences and behaviors. Advanced data analytics, leveraging big data from sources like mobile apps, social media, and transportation networks, can offer valuable insights into patterns and trends. For instance, analyzing data from a ride-sharing app might reveal peak usage times and common routes, informing decisions about resource allocation and service optimization.

Furthermore, user personas and journey maps are essential tools in this stage. User personas are fictional characters created based on the data collected, representing different user types. These personas help designers and developers keep diverse user needs in mind throughout the design process. Journey maps, on the other hand, visualize the user's experience over time, highlighting key touchpoints and potential pain points. For example, a journey map of a daily commuter might show the frustrations faced during rush hour and the need for more efficient transit options.

Stakeholder engagement is another critical component of User Research and Analysis. This involves collaborating with various stakeholders, including transportation authorities, service providers, and community organizations, to gather a holistic understanding of the transportation ecosystem. Engaging with stakeholders helps ensure that the solutions developed are feasible, sustainable, and aligned with broader community goals.

Finally, iterative validation is key. As insights are gathered, they should be continuously validated and refined through ongoing user engagement. This could involve testing initial findings with focus groups or conducting pilot studies to ensure that the data accurately reflects user needs and experiences. By investing time and resources in thorough User Research and Analysis, we lay a solid foundation for the subsequent stages of the Human-Centered Design process. This stage ensures that the solutions developed are deeply rooted in the actual experiences and needs of users, paving the way for more effective, inclusive, and user-centric smart transportation systems.

6.2 Co-Creation and Collaboration

Co-Creation and Collaboration is a pivotal stage in our proposed model, where stakeholders come together to ideate, design, and refine transportation solutions. This phase emphasizes the importance of inclusive participation, bringing diverse voices to the table to ensure the solutions developed are comprehensive and considerate of various perspectives. Workshops and design sprints are common methods used in this stage, where users, designers, engineers, policy makers, and community leaders collaborate in a dynamic and creative environment. These sessions encourage brainstorming and prototyping, allowing participants to contribute their unique insights and expertise.

Moreover, technology plays a crucial role in facilitating collaboration. Digital platforms and tools enable real-time feedback and virtual collaboration, making it possible for stakeholders from different geographical locations to participate actively. For example, collaborative software can allow users to comment on design prototypes, suggest improvements, and vote on features they find most useful. This stage also involves continuous communication and transparency. Keeping all stakeholders informed and engaged throughout the process helps build trust and ensures that the project remains aligned with user needs and community goals. Regular updates, feedback sessions, and open forums can foster a sense of ownership and accountability among participants.

Furthermore, collaboration extends to integrating multidisciplinary perspectives. Involving experts from various fields, such as urban planning, environmental science, and technology, ensures that the solutions are not only user-centric but also sustainable and innovative. This multidisciplinary approach can lead to more holistic and well-rounded transportation solutions that address a wide array of challenges and opportunities.

Ultimately, Co-Creation and Collaboration foster a sense of community and shared purpose, ensuring that the final solutions are reflective of collective wisdom and aligned with the needs and aspirations of all stakeholders involved.

6.3 Iterative Design and Testing

Iterative design and testing are fundamental to refining transportation solutions based on continuous feedback from users and stakeholders. Prototyping allows designers to create low-fidelity and high-fidelity versions of the solution, which are then tested rigorously in real-world scenarios. Feedback from usability testing, user trials, and pilot implementations informs iterative refinements, ensuring that the final product meets usability standards, addresses user pain points, and integrates seamlessly into users' daily lives. This iterative approach not only enhances the functionality and usability of transportation systems but also builds user trust and acceptance.

6.4 Inclusive and Accessible Design

Inclusive and accessible design ensures that transportation solutions are usable by people of all abilities, ages, and backgrounds. This principle goes beyond compliance with accessibility standards to embrace universal design concepts that anticipate diverse user needs. Features such as accessible interfaces, multi-modal options, real-time accessibility information, and inclusive signage contribute to a transportation system that is equitable and welcoming for everyone. By prioritizing inclusivity, our model aims to eliminate barriers to mobility and enhance social inclusion within urban communities.

6.5 Context-Aware Solutions

Context-aware solutions acknowledge the unique environmental, cultural, and operational contexts in which transportation systems operate. This involves considering factors such as local infrastructure, socio-economic conditions, environmental sustainability goals, and regulatory frameworks. By tailoring solutions to local contexts, transportation planners can optimize resource allocation, improve system resilience, and ensure that solutions are culturally and environmentally sensitive. Context-aware design promotes sustainable urban mobility and enhances the overall effectiveness of transportation interventions.

6.6 Implementation and Monitoring

The final stage of our proposed model focuses on implementation and monitoring to ensure the successful deployment and ongoing performance of transportation solutions. This includes developing detailed implementation plans, coordinating with stakeholders, and conducting post-launch evaluations. Monitoring and evaluation mechanisms, such as performance metrics, user feedback loops, and data analytics, enable continuous improvement and adaptation to evolve user needs and technological advancements. By fostering a culture of continuous learning and adaptation, transportation systems can remain responsive and effective in meeting the needs of urban populations.

6.6.1 The Primary Feedback Loop

The primary feedback loop in our proposed model for integrating Human-Centered Design in smart transportation is crucial for ensuring continuous improvement and responsiveness to user needs. This loop connects each stage of the process sequentially, forming a circular flow that symbolizes the ongoing, iterative nature of effective design and implementation. Starting with User Research and Analysis, we gather essential insights into user needs, behaviors, and preferences. These insights directly inform Co-Creation and Collaboration, where stakeholders work together to ideate and make decisions.

The collaborative ideas are then put through Iterative Design and Testing, where continuous prototyping and user feedback help refine the solutions. Moving forward, the process incorporates Inclusive and Accessible Design, ensuring that the solutions are usable by people of all abilities and backgrounds. These tailored solutions are then adapted to specific local contexts in Context-Aware Solutions, considering environmental, cultural, and operational factors.

Finally, Implementation and Monitoring allows for detailed planning and post-launch evaluations to ensure the solutions are effective and meet user needs. The feedback loop is completed as insights from implementation and monitoring feedback into user research, creating a cycle of constant learning and adaptation. This approach ensures that the smart transportation system remains relevant, user-centric, and capable of evolving with changing needs and technological advancements.

6.6.2 The Secondary Feedback Loop

The secondary feedback loops in our proposed model for integrating Human-Centered Design in smart transportation add a layer of adaptability, ensuring the system is not only user-centric but also resilient and dynamic. These loops create additional pathways for information flow and learning between non-sequential stages, allowing for more nuanced and responsive design processes. For instance, insights gained during Iterative Design and Testing often reveal deeper user needs or challenges that were not fully captured during initial research. This creates a feedback loop back to User Research and Analysis, prompting further investigation and refinement of user personas and scenarios. Similarly, the lessons learned from Context-Aware Solutions which tailor transportation systems to specific local environments can provide valuable feedback to Co-Creation and Collaboration processes, ensuring stakeholder inputs are more accurately grounded in real-world contexts.

Implementation and Monitoring stages provide critical data on the performance and user acceptance of the solutions, feeding back into Iterative Design and Testing to tweak and optimize features based on actual usage patterns and feedback. Lastly, as we push for Inclusive and Accessible Design, ongoing research and stakeholder collaboration may highlight gaps or opportunities to enhance inclusivity, feeding back into initial user research efforts. These secondary feedback loops create a robust, interconnected framework that ensures every stage of the process benefits from continuous learning and adaptation, ultimately leading to a more effective, inclusive, and sustainable smart transportation system.

In summary, our proposed model for integrating HCD in smart transportation has a comprehensive and iterative process, starting with User Research and Analysis to

Implementation and Monitoring. The primary feedback loop ensures a continuous flow of insights and improvements, connecting each stage in a circular, adaptive cycle. Additionally, the secondary feedback loops add resilience, allowing for cross-stage learning and real-time adjustments. These feedback mechanisms create a dynamic and user-centric framework that continuously evolves to meet changing needs and technological advancements, ensuring the smart transportation system remains effective, inclusive, and sustainable. In the next section, we will explore the future trends and innovations shaping the field of HCD in smart transportation, offering insights into emerging technologies, evolving user expectations, and the evolving role of urban mobility in sustainable development.

7 Future Trends and Innovations

As we reflect on the journey through the principles, benefits, challenges, and proposed model of HCD in smart transportation, it becomes evident that the field is poised for further evolution and innovation. From understanding user needs to designing inclusive and sustainable solutions, it has demonstrated its transformative potential in enhancing urban mobility. Looking forward, several trends and innovations are set to shape the future of HCD in smart transportation [7], influencing both technological advancements and user expectations.

7.1 Emerging Technologies

Advancements in technology continue to drive innovation in smart transportation systems. Artificial Intelligence (AI), Machine Learning (ML), and Internet of Things (IoT) are increasingly integrated into transportation solutions to improve efficiency, predict demand, and optimize traffic flow. AI-powered algorithms can analyze vast amounts of data in real-time to offer personalized travel recommendations and adaptive routing options. Autonomous vehicles represent another frontier, promising to revolutionize mobility by enhancing safety, reducing congestion, and providing mobility options for those unable to drive. As these technologies mature, they will play a pivotal role in shaping user experiences and the operational efficiency of transportation systems.

7.2 Evolving User Expectations

User expectations in smart transportation are evolving towards seamless, personalized, and sustainable mobility experiences. Users now expect on-demand access to a variety of transportation modes, integrated payment solutions, and real-time information. Personalization, such as customized route planning and tailored service recommendations, is becoming increasingly important as users seek more efficient and convenient travel options. Moreover, there is a growing emphasis on sustainability, with users prioritizing eco-friendly modes of transport and supporting initiatives that reduce carbon emissions and promote cleaner urban environments. Meeting these evolving expectations requires continuous innovation and adaptation in HCD practices.

7.3 Role in Sustainable Development

The evolving role of urban mobility in sustainable development underscores the importance of integrating HCD principles into transportation planning and design. Smart transportation systems have the potential to reduce greenhouse gas emissions, alleviate traffic congestion, and improve air quality by promoting shared mobility options, electric vehicles, and active transportation modes like walking and cycling.

HCD can facilitate the adoption of sustainable behaviors by designing intuitive interfaces, incentivizing eco-friendly choices, and fostering a sense of ownership and responsibility among users. By aligning technological advancements with environmental stewardship, smart transportation can contribute significantly to the resilience and livability of urban communities.

Finally, in the next section, we will conclude our exploration by summarizing the key insights and implications of Human-Centered Design in smart transportation. We will reflect on the transformative impact of HCD, discuss ongoing challenges and opportunities, and outline actionable steps for stakeholders to enhance urban mobility through user-centric approaches.

8 Conclusion

In this chapter, we embarked on a journey to explore the pivotal role of HCD in shaping the future of smart transportation systems. From the outset, we have dived into the foundational principles of HCD, emphasizing empathy, inclusivity, and user engagement. These principles serve as the bedrock for developing transportation solutions that are not only technologically advanced but also deeply attuned to the needs and experiences of the people they serve.

We then examined the tangible benefits of incorporating HCD into smart transportation, highlighting how this approach can enhance user satisfaction, improve accessibility, boost efficiency, foster sustainability, and drive innovation. These benefits underscore the transformative potential of a user-centric approach, making a compelling case for its adoption in the evolving landscape of urban mobility.

However, the journey is not without its challenges. Implementing HCD in smart transportation presents a complex web of obstacles, from balancing diverse user needs and securing stakeholder buy-in to navigating technological integration and managing the intricate dynamics of urban environments. By acknowledging these challenges, we can better prepare and strategize to overcome them, paving the way for more resilient and effective transportation solutions.

The case study of Helsinki's MaaS initiative provided a real-world example of how HCD principles can be applied to create innovative transportation solutions. Despite facing financial setbacks, the project highlighted the importance of continuous iteration, user feedback, and adaptability, reinforcing the core tenets of HCD discussed throughout the chapter.

Building on these insights, we proposed a comprehensive model for integrating HCD into smart transportation. This model outlines a clear, iterative process: starting with User Research and Analysis, progressing through Co-Creation and Collaboration, Iterative Design and Testing, Inclusive and Accessible Design, Context-Aware Solutions, and culminating in Implementation and Monitoring. The primary feedback loop ensures a continuous cycle of improvement, while the secondary feedback loop adds responsiveness, allowing for real-time adjustments and cross-stage learning.

Looking ahead, we explored future trends and innovations that are set to shape the field of HCD in smart transportation. Emerging technologies, evolving user expectations, and the increasing emphasis on sustainable development will continue to drive the evolution of urban mobility. As these trends unfold, the principles and practices of HCD will become even more critical in creating transportation systems that are not only efficient and innovative but also equitable and user centric.

In conclusion, the integration of Human-Centered Design into smart transportation systems represents a paradigm shift towards more empathetic, inclusive, and adaptive urban mobility solutions. By placing users at the heart of the design process and embracing continuous feedback and iteration, we can build transportation systems that truly meet the needs of their users, fostering more connected, sustainable, and livable cities for the future [9].

Authors Contribution Babasaheb Jadhav and Alex Khang: Contributed experiments, conceptualization and methodology. Babasaheb Jadhav, Mudassar Sayyed, Vikram Barnabas: Contributed Writing and Editing. Alex Khang: Contributed Writing – Review & Editing, and Supervision.

Declarations

Conflict of Interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this chapter.

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Internet of Vehicle Based Quality of Service (QoS) Exploration for Public Transportation

Alex Khang, Khushwant Singh, Kavita Thukral, and Ajay Kumar

Abstract In every country, public transit is an essential for city managers. It is intended that the community will have inexpensive, safe, and convenient transportation for getting about. On the other hand, the development of Internet of Vehicles technology presents an opportunity to design a public transport management system. The shift to electric cars and the existing transportation management system provide the perfect conditions for the development of Internet of cars technologies. Inadequate communication infrastructure makes implementation difficult. A detailed analysis is necessary to set up the enabling infrastructure for optimal growth. To simulate the infrastructure and evaluate its service quality, utilize MATLAB's Communication Toolbox. Finding the service quality level to determine the least amount of communication infrastructure needed to enable an IoV in public transport is the aim of this study and simulation.

Keywords Quality of service · 4G · 5G · Internet of things · Internet of vehicles · MATLAB · Vehicular Ad-hoc networks · Public transportation system

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1 Introduction

In large cities, public transportation is both a problem and a solution. Transportation services that are affordable, cozy, secure, and timely are becoming more and more necessary [10]. The dynamics of society will be substantially impacted by the effectiveness of the public transportation system [8]. The general public mostly uses public transportation as a mode of daily transportation to get to and from the office [21]. Progress has been made in the development of transportation technologies on the automobile side [20]. Progress has been made in terms of speed, comfort, and energy efficiency [11].

One of the advancements in vehicle technology is the conversion of fossil fuels into electrical energy [22]. Electric energy conversion for public transportation has started to be carried out in several countries, including Indonesia [5]. This momentum is applied to enhance the entire transportation network [1]. On the other side, information technology has undergone technological advancements. Internet of Things, particularly Internet of Vehicles, is one [33]. The Transportation System is using the Internet of Vehicles, a technology idea, to increase passenger amenities, ride comfort, and driving safety [4]. With the help of Internet of vehicle technology, vehicles can communicate with their surroundings and give the right people who require it factual information about their whereabouts [34].

The integration of the Internet of Vehicles (IoV) into public transportation represents a noteworthy technological progression with the objective of augmenting the effectiveness, security, and user experience of urban transportation networks [18]. IoV enables intelligent management of transportation services and real-time data exchange by fusing users, infrastructure, and vehicles into a cohesive network [7]. With the help of cutting-edge technologies like artificial intelligence (AI), big data analytics, and the Internet of Things (IoT), public transportation systems will become intelligent and networked [21].

The optimization of route planning and scheduling is one of the main advantages of IoV in public transportation [6].Through the gathering and examination of data from multiple sources, including traffic patterns, passenger volume, and car locations, IoV systems are able to dynamically modify routes and itineraries in order to reduce wait times and enhance service dependability [23].

This real-time adaptability guarantees the smooth operation of buses, trains, and other public transportation modes, cutting down on passenger wait times and enhancing the overall travel experience [2]. Another important area where IoV improves public transportation is safety [3]. In order to reduce accidents and maintain efficient traffic flow, connected cars can communicate with one another and with traffic management systems.

IoV-enabled buses, for example, can get alerts about possible dangers, like abrupt braking from cars in front of them or obstructions on the road, enabling drivers to take preventative action. IoV systems can also keep an eye on how drivers behave and how their vehicles are performing, giving feedback and alerts to stop unsafe driving and malfunctioning vehicles. IoV has a major positive impact on environmental sustainability in public transportation [30]. IoV aids in lowering emissions and fuel consumption by streamlining routes and cutting down on idle time.

Additionally, by prioritizing and integrating electric or hybrid vehicles into the network, among other environmentally friendly and efficient public transportation strategies, the data gathered through IoV can be used to design and implement these initiatives [19]. By doing this, public transportation has a less negative environmental impact and helps cities fight climate change [36]. As IoV is implemented in public transportation, the experience of passengers is significantly improved [28]. Passengers at bus stops and train stations can receive real-time information via mobile apps and digital displays about vehicle arrivals, departure times, and possible delays [3]. Because of this transparency, travelers can more efficiently plan their trips, which lower uncertainty and raises satisfaction [25].

IoV can also enable smooth payment and ticketing processes, improving accessibility and usability of public transportation [29]. In summary, the integration of the Internet of Vehicles into public transportation provides a thorough resolution to numerous issues encountered by urban transportation networks [35]. IoV improves passenger experience, safety, environmental sustainability, and route optimization by utilizing the power of connectivity and intelligent data management [32]. The future of urban mobility will be greatly influenced by the adoption of IoV technologies as cities continue to grow and the demand for effective public transportation rises as shown in Fig. 1.

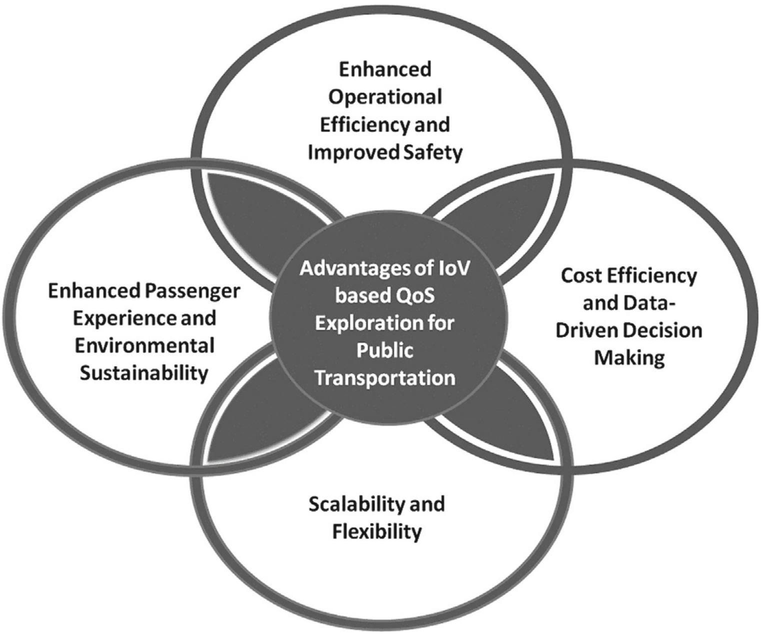

Fig. 1 Advantages of internet of vehicle based QoS exploration for public transportation

There are several benefits associated with integrating Internet of Vehicles (IoV) for Quality of Service (QoS) investigation in public transportation systems, which greatly improve operational effectiveness, safety, passenger experience, and environmental sustainability [37]. Some of the advantages are such as it enhanced operational efficiency through dynamic route optimization and fleet management [36]. IoV systems have the ability to dynamically modify routes and schedules by analyzing traffic patterns, passenger demand, and road conditions in real time.

As a result, services become more dependable because delays are minimized, traffic is lessened, and timely arrivals and departures are guaranteed [38]. IoV makes fleet management more efficient by keeping an eye on driver behavior, fuel consumption, and vehicle health [9]. Proactive maintenance, economical fuel use, and enhanced fleet performance are all made possible by this.

IoV technologies greatly improve public transportation's safety, which is a crucial component for such as collision avoidance and driver monitoring [39]. In order to reduce collisions, connected cars can speak with traffic management systems and with one another. IoV systems can notify drivers of possible dangers, like unexpected braking from vehicles in front of them or roadblocks, allowing them to take prompt preventive action [12]. IoV makes it possible to continuously monitor various aspects of driver behavior, including fatigue, braking patterns, and speed [16]. With this data, drivers can receive training and feedback that will improve their performance and lower their chance of collisions [27].

IoV-based QoS research guarantees comfortable travels and timely and accurate information, both of which directly improve passenger experience [31]. Through smart phone apps and digital screens at stations, passengers can get real-time updates on the locations of vehicles, their estimated arrival times, and any delays [17]. Passengers can more efficiently plan their travels thanks to this transparency, which lowers uncertainty and wait times [15]. Passengers can use mobile devices for ticket purchases and validations thanks to IoV systems' seamless ticketing and payment processes, which streamlines their travel experience [14].

Green public transportation practices are promoted by IoV-based QoS exploration. IoV contributes to lower fuel and emission levels by streamlining routes and cutting down on idle time. The overall environmental impact is reduced and unnecessary driving is minimized with effective route planning and real-time adjustments. The network of public transportation can incorporate electric or hybrid vehicles with the help of IoV. Eco-friendly fleets can operate more efficiently when they have access to real-time data on energy consumption and vehicle performance.

For operators, implementing IoV in public transportation can result in significant cost savings. Fuel costs, maintenance costs, and operational inefficiencies are decreased through better fleet management, route optimization, and predictive maintenance. Better resource allocation and the efficient use of already-existing infrastructure can postpone or completely remove the need for expensive additions or upgrades. IoV offers an abundance of data that can be utilized to enhance overall service quality and make well-informed decisions. IoV systems produce extensive data on a range of public transportation-related topics, including service gaps, peak usage periods, and passenger flow.

Analysis of this data can be used to spot patterns, forecast demand, and improve service scheduling. IoV data can be used by governments and transportation authorities to create policies that support effective and sustainable public transportation networks. IoV systems are flexible and scalable, which makes them appropriate for a range of urban and rural public transportation environments. IoV can be scaled to meet the needs of expanding transportation networks and growing urban populations, preserving the dependability and efficiency of services. IoV systems offer a unified method of managing various transit systems because they can adapt to different public transportation modes, such as buses, trains, and trams.

In summary, there are numerous and significant benefits to Internet of Vehicle-based QoS research for public transportation. IoV improves cost effectiveness, environmental sustainability, passenger experience, safety, and operational efficiency by utilizing real-time data, connectivity, and intelligent analytics. These advantages make IoV an essential technology for the public transportation of the future, fostering more intelligent, environmentally friendly, and dependable transit networks.

Additionally, this technology can direct the driver to choose the best route and foresee mishaps or calamities. Monitoring engine conditions is another improvement that can lessen disturbances to the engine and its support. Devices must become more complex as functions and features become more complicated. The Internet of Vehicles is a collection of several technologies for data collecting, data processing, and data communication. The integration of these several components makes it crucial to conduct a thorough examination of each component that makes up the overall system.

A consideration of the communication tools utilized in public transportation will be conducted in this study.

- The mode of public transportation mentioned is an electric-powered bus.
- The communication under discussion is a method of data transfer that primarily relies on cellular technology.
- An analysis of the EV Public Transportation System's quality of service will be done as part of this study.
- Describe how IoV is being used in electric bus public transportation.
- Analyze the 4G and 5G infrastructure's quality of service for public transportation buses and electric vehicles.
- Investigate the potential system flaw

2 Related Works

Some studies compare the communication networks' quality of service to system requirements. The level of risk that the communication system faces when performing its duties is gauged by the quality of service. Using Quality of Service (QoS) in a system with several connected and dynamic nodes will be crucial. The capacity to offer dependable resources and distinctive services within the network is known as quality of service. Its operating theory offers certain network service restrictions.

Throughput, packet loss, and jitter are just a few of the variables used to gauge the quality of a service. Currently, the primary factor used to assess the dependability of computer networks is quality of service. The reliability of the computer network increases with the service value. The study examines how Call Dropping and Call Blocking might be used when 5G is implemented as a communication tool. Grid and star topology performance quality of service comparison. The IoV functions included in this study include GPS tracking, driving assistance, ECU condition, and accident events. Each offers a distinct level of service quality.

Numerous benefits come with the Quality of Service (QoS) investigation for public transportation based on the Internet of Vehicles (IoV), which is revolutionizing transportation systems and enhancing the overall traveler experience. Dynamic traffic management is made possible by the real-time communication that IoV provides between infrastructure, central management systems, and automobiles. Traffic can be lessened and public transportation services can operate more smoothly by optimizing routes and traffic signals using real-time data.

The Internet of Vehicles (IoV) makes it easier for infrastructure and vehicles to share vital safety information. For example, drivers of buses can take preventive action by receiving alerts about possible hazards or accidents ahead. The exchange of data in real-time greatly improves passenger safety. By precisely anticipating arrival and departure times, IoV enables public transportation systems to provide more dependable services. Passengers spend less time waiting and are more satisfied overall when schedules are followed thanks to real-time tracking and monitoring. IoV makes it possible to use public transit resources more effectively. Transportation authorities can efficiently match supply with demand by adjusting the deployment of vehicles based on data analysis on passenger flow and demand patterns.

As a result, expenses are reduced and service quality is enhanced. IoV-based systems can optimize routes and driving habits to cut down on emissions and fuel use. It is possible to program public transportation vehicles to travel the most efficient routes, reducing their negative effects on the environment and advancing sustainability objectives. IoV benefits passengers by providing real-time information on bus locations, anticipated arrival times, and seat availability. Personalized travel information can be obtained through mobile applications, improving the usability and convenience of public transit. IoV produces enormous volumes of data that can be examined to learn more about performance indicators, patterns of transportation, and areas that require development.

Transportation authorities are able to plan for future expansions or modifications, improve service quality, and make well-informed decisions thanks to this data-driven approach. IoV-based QoS research supports the integration of public transportation with other urban systems, which is in line with larger smart city initiatives. The result of this synergy is more cohesive and effective urban management, which improves the standard of living for locals. Public transportation systems can become more effective, dependable, and passenger-centric by utilizing IoV-based QoS exploration, opening the door for more intelligent and environmentally friendly urban mobility solutions.

Other studies talk about the delivery time, latency, and congestion that 5G cellular IoV experiences. Varied service requirements at various risk levels. The adoption of additional NOMA (non-orthogonal multiple access) components is the suggested approach. A key area of study for QoS analysis is autonomous driving technology, which is covered by formulating a QoS prediction principle. System QoS prediction also serves as a guide in determining a particular level of QoS that was generated by a particular communication infrastructure.

In addition to the current QoS issue, research is currently being done that examines SLA levels for QoS telecommunications infrastructure and edge computing. Related to QoS parameter, it has been more thoroughly classified at level QoS. Implementation of IoV for public transportation has been easily demonstrated by the various daily life applications. By utilizing cutting-edge communication networks like 5G and dedicated short-range communication, connected cars, infrastructure, and passenger devices are integrated as part of the Internet of Vehicles (IoV) deployment in public transportation (DSRC).

Sensors, GPS, and vehicle-to-everything (V2X) communication modules are installed in public transportation vehicles, enabling real-time data transmission about the location, speed, and health of the vehicle. Utilizing this data for dynamic routing and scheduling, smart traffic systems and centralized traffic management maximize operational efficiency. Mobile applications that offer seamless ticketing, real-time updates, and personalized travel information improve passenger services.

In data management, information from cars, infrastructure, and passengers is combined and analyzed. AI and machine learning are used for route optimization and predictive maintenance, respectively. Secure communication and data handling are guaranteed by strong cyber security safeguards and privacy protection guidelines. The deployment of IoV improves passenger experience, boosts operational effectiveness, and raises safety standards in public transportation networks.

There has been a lot of study on cellular technology using 4G or its advancement of 5G as the primary framework in the Communication system in the Internet of Vehicles. One of them is setting up a 5G network for a high-data- rate Internet of Vehicles working environment. It has also been discussed how well the communication network infrastructure utilized in vehicles performs. A more thorough explanation of how 5G is being implemented in the Internet of Vehicles. This study describes how connection loss in 5G technologies can happen.

3 Internet of Vehicle (IoV)

Transportation or the automotive industry is one area that gains from IoT. In addition to the health industry [13], the transportation sector is one of those that uses IoT the most. The Internet of Vehicles, a new phrase for IoT application in the transportation industry, is establishing specifications and becoming more commonly used (IoV). The idea behind the Internet of Vehicles is how to connect vehicles with other entities that can affect or influence how they behave. The driver, passenger, and unit all have ubiquitous access thanks to IoV implementation. Increased comfort, safety, and effectiveness are results of this accessibility. Similar to IoT, chances for service development are provided by device development and communication capability. An increase in the volume of data flowing has other effects. Vehicles produce and consume massive quantities of various kinds of data.

The creation of sensor and actuator technology promotes automation, driverless cars, and unmanned vehicles. The factory or service center can keep an eye on everything that happens in the car thanks to the ease of connection and data transmission. It is simple to anticipate vehicle maintenance thanks to accurate, quick, and valid monitoring. Enhancing the system's capabilities will lead to the creation of new service concepts or advantages.

Although there is little to no connectivity between servers and automobiles, there is communication with the immediate environment and the larger environment. The availability of numerous data will be impacted by this. The dynamics of IoV pose numerous additional issues in addition to boosting the benefits for humans. There will be issues due to the growing volume of data, human expectations, and system dependence. The level of service quality rises as expectations rise. Data loss, bottlenecks, and time delays are examples of system failures that will diminish system reliability and present a risky situation.

The distinguishing feature of IoV in contrast to other IoT is the device's movement. More research has to be done on this quality because it has a big impact on so many different things. IoT in automobiles or transportation is a field that has received a lot of attention due to the rise in the number of connected vehicles. IoV has been defined in a variety of ways throughout history. The emergence of IoV begins with the development of the IoT and the Intelligent Transportation System. The Vehicular Ad-hoc networks (VANETs), a different approach, are being developed into a new idea called the Internet of Vehicles (IoV).

The metamorphosis takes the form of expanding the variety of connections that are added. The sub- components of the Internet of Vehicles can be categorized from a number of publications. The Internet of Vehicles (IoV) consists of five different kinds of vehicular communications: vehicle-to-vehicle, vehicle-to-roadside, vehicle-to-cellular network infrastructure, vehicle-to-personal devices, and vehicle-to-sensors. The phrase "surroundings" refers to the area immediately around a vehicle; "infrastructure" refers to the local region, such as a municipality or neighboring countryside; and "ecosystem" refers to distant facilities, such as the Internet, the Cloud, and contact centers.

4 IoV for EV Public Bus

By combining cutting-edge connectivity and sustainability, the Internet of Vehicles (IoV) for electric vehicle (EV) public buses represents a revolutionary approach to contemporary urban transportation. The Internet of Vehicles (IoV) makes it possible for EV buses, charging stations, central management systems, and passengers to communicate seamlessly, improving the effectiveness and usability of the public transportation system.

IoV relies heavily on real-time data exchange, which enables buses to coordinate with traffic signals, other cars, and transportation hubs to minimize traffic and optimize routes. By reducing needless stops and starts, this not only increases punctuality but also boosts energy efficiency—a critical factor in extending the range of electric buses. In order to balance the load on the grid, buses can be programmed to charge during off-peak hours or directed to the closest available charging station thanks to IoV's smart charging management capabilities. Through smartphone apps, IoV gives travelers real-time information on bus locations, projected arrival times, and seat availability, improving their overall travel experience.

IoV integration in EV public buses helps predictive maintenance by continuously tracking the health and performance of the vehicle, seeing possible problems before they get serious, and cutting down on downtime. Better resource allocation and enhanced service coverage can result from the data gathered from IoV systems, which can also provide transit authorities and city planners with information about usage trends and areas that need service adjustments. In addition to increasing operational effectiveness and dependability, this connectivity encourages the use of clean energy vehicles and lowers air pollution in urban areas, both of which benefit the environment.

In conclusion, IoV for EV public buses represents the transportation of the future by providing a more intelligent, environmentally friendly, and responsive transit option that satisfies the changing demands of contemporary cities and their citizens. One of the transportation options that is commonly used as public transportation in many places throughout the world, including Indonesia, is the public bus. One of the causes is that the initial investment is negligible. This means of transportation is immediately operational and can be created in phases. It can utilise the current road infrastructure. The acquisition of the bus fleet-the technological conversion of resources or energy from fuel to electricity is the main asset. An important task that the public bus operator must perform is the desire for service improvements for this transportation to continue to be a favorite of the general public as well as cost and energy optimization.

One of the answers could be the use of Internet of Vehicles technology. The secret lies in enhancing safety and comfort while reducing disruptions that raise costs. The following structure can be used to implement IoV technology for public transportation. Table 1 depicts the implementation of IoV for public bus.

Technology is employed in many of these implementations, including V2Server. Most functions make use of the line. Because node mobility is essentially non-existent and data rate/data volume can be expected because it is often static, V2Sensor technology is less dangerous for data transmission.

Additionally, V2Roadside technology carries some reduced risk. The V2Server connection will serve as the IoV bus system's primary structural support. The dynamics of changes in the number of nodes, their volume, and their positions will all be dynamic (buses). From 2G to the most recent 5G, the cellular family of communication technologies is a commonly used one. We'll talk more about this research,

Table 1 Implementation of IoV for public bus

Function	Description	Technology
Passenger comfort	Bus passengers can use the internet connection to access entertainment, information, work-related needs, and smartphone-based communication	WiFi technology is used by passengers to connect their laptops or smartphones to the internet
Information for public entities	Information on the Bus' location, speed, and anticipated arrival at a certain area are available to the general public	The installation of sensors using V2S technology allows the position of the vehicle to be determined and sent to a server using V2Server technology
Driver's guide	Drivers receive instructions for stopping points as well as information about the route to be traveled entirely under unusual circumstances (according to the needs of passengers and prospective passengers)	Using V2Server technology, the bus's environmental parameters and the intended route are transmitted to the driver Additionally, the system leverages V2Roadside technology to gather stop or turn point data
Vehicle condition monitoring	A vehicle with a high utilization load is the public bus. It must be monitored by the control center and the engine condition must be monitored. Data on the engine, cabin, and other statuses will be retrieved by the system and sent to the data center for additional analysis	Bus condition data is collected using V2Sensor technology and sent to the data center via V2Server

particularly how 5G technology and its variations will serve as the primary means of data connection in public buses as shown in Fig. 2.

Since 1980, when cellular network technology was first utilized, it has advanced quickly. From the first generation (1G) to the fifth generation, the speed and level of data transfer support are becoming more advanced and contemporary (5G). Table 2 depicts the evolution of technology from 1 to 5G.

Urban locations where EV buses are used for public transportation already have communication networks that use 4G technology and are upgrading to 5G. Because a third party (a telecommunication provider) is already prepared to offer connection services, the adoption of this technology is substantially more affordable and accessible. Table 3 depicts the characteristics of 4G and 5G Technology.

We are currently in the transition from 4 to 5G. Nearly all telecommunications companies have begun to transition to 5G technology. Issues that could occur include:

- Due to the small position and number of BTS that must be distributed evenly, the coverage area is still just a small portion of the total.
- If there is a congestion of connected nodes and the volume of data delivered, each BTS's channel is still limited and cannot support connection requests.

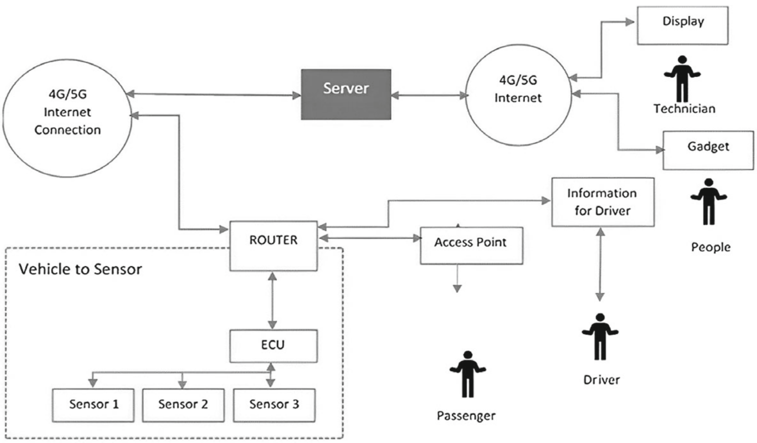

Fig. 2 IoV configuration for public transportation system

Table 2 Cellular technology development

Generation	Technology	Speed	Data
1G	AMPS, NMT, HICAP	Rendah	Voice
2G	GSM, CDMA, GPRS	14,4 kbps	Text & Voice
2.5 G	EDGE	384 kbps	Text, Image, Voice
3G	WCDMA	2 Mbps	Broadband
3.5 G	HSDPA	5 Mbps	Broadband
4G	LTE	50 Mbps	Broadband
5G	LTE	10 Gbps	Broadband + New Technology

Table 3 Characteristics of 4G and 5G technology

Characteristic	4G	5G
Latency	10 ms	1 ms
Data Traffic	7, 5 Exabytes/Month	50 Exabytes/Month
Data Rates	1 Gb/s	20 Gb/s
Spectrum	3 GHz	30 Ghz
Connection Density	100 Thousand/Km^2	1 Million connection/Km^2

- High-speed public transportation can make it difficult for the connection to remain stable. Following is a comparison of the features of 4G and 5G technology:

5 QoS Level (Design and Discussion)

A key idea in network management is Quality of Service (QoS) Level, which controls and prioritizes network traffic to guarantee that different applications and services operate as efficiently as possible. QoS levels are used in the context of data transmission to ensure certain performance metrics like packet loss, latency, bandwidth, and jitter.

Network administrators can make sure that high-priority services like VoIP and video conferencing have the resources they need to run smoothly even during periods of high network traffic by allocating distinct QoS levels to different types of traffic. To guarantee they have the least amount of jitter and latency, real-time applications—which are susceptible to delays-can be given a higher QoS level as shown in Fig. 3.

On the other hand, less important apps, like file transfers or email, can be prioritized less. QoS mechanisms are a collection of methods that together control data flow and uphold service quality. These methods include traffic shaping, queuing, and congestion management. In order to prevent degradation of service and guarantee a dependable user experience, effective Quality of Service (QoS) implementation is essential in complex network environments, especially for enterprises that depend on uninterrupted connectivity for operations. Quality of Service (QoS) improves overall network performance and efficiency by balancing the load on the network, preventing congestion, and guaranteeing that critical services are not compromised through traffic differentiation and prioritization.

To assess the communication infrastructure's quality of service, tests are conducted on call blocking and call dropping. These two factors are frequently used to gauge how well a 4G or 5G connection is performing. Ray and Kundu et al. [24]

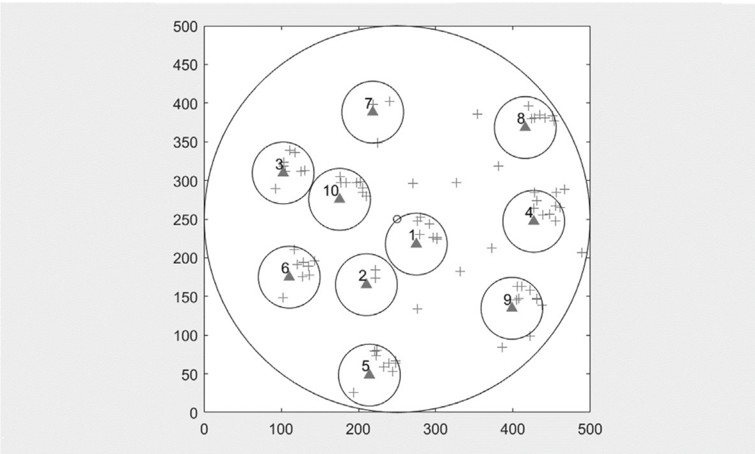

Fig. 3 Simulation for 80 vehicles and 10 BTS

The terms Availability (Call Blocking) and Reliability can be used to compare these factors (Call Dropping) as shown in Table 4.

Table 4 depicts the indicator, description, testing and limits for the data. The following technique is used to test these two parameters:

Testing is conducted using MATLAB's Communication Toolbox and takes into account the aforementioned steps for cell size, vehicle speed, and communication device channel count. Testing is conducted under the assumption that BTS positions are dispersed at random within the same coverage region. The continuous speed of a vehicle. 80 automobiles were used in the tests, and 10 BTS were installed as shown in Fig. 4.

Changing the amount of vehicles that need a link allows for simulation. The test findings demonstrate that there have been considerable changes in the factors that can cause an increase in packet loss, data rate, and probable connection failures. The following happens as the number of connected vehicles rises:

Table 4 Various factors affecting quality of service (QoS)

Indicator	Description	Testing	Limit
Availability	The percentage of failed attempts compared to the number of successful attempts with the following formula (1-F/T)*100%	Pinging data to the destination address for 10 tries	98%
Reliability	Packet Loss: The number of packets that failed to be delivered		3%
	Download: Rate of receiving data from the server	1 MB	1 menit
	Upload: The rate for sending data	2 MB data	1 menit

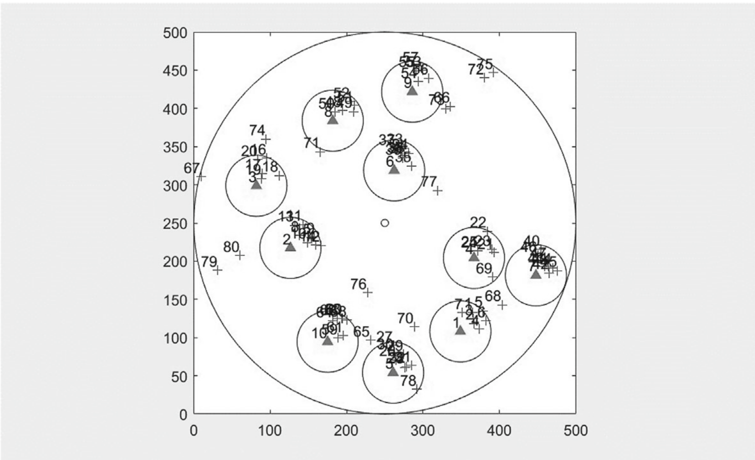

Fig. 4 Simulation for 160 vehicles and 10 BTS The test results

Table 5 Testing result for vehicles

No	Item test	Average (80 Vehicle)	Average (160 Vehicle)	Average (200 Vehicle)
1	Average packet loss	0.12%	0.21%	0.34%
2	Download data rate	5231 Mbps	4763 Mbps	3994 Mbps
3	Upload data rate	6102 Mbps	5,231 Mbps	4654 Mbps
4	Potential connection failure	12.5%	15.4%	19.7%

- Decrease in Data Rate to Slow Down Data Transmission Quality and Speed (Upload and Download)
- The availability parameter lowers as potential connection failures rise. It will become more and more challenging for vehicles to connect.
- The likelihood of missing packets increasing.

All findings indicate that more capacity will be required if there is a growth in the number of connected vehicles to maintain the quality of service level of the 5G infrastructure for data communication as shown in Table 5.

6 Conclusion

One of the most important parts of the Internet of Vehicles system is the communication infrastructure. This part requires quality assurance in order for the system to malfunction as little as feasible. Using 5G media, the study aims to mimic a router-server connection. An automobile that is always moving creates the link. Experiments done under different assumptions show a direct association between the quantity of connected cars and the data rate, availability, and reliability of the network infrastructure, which further determines the quality of the Internet of cars.

Further in-depth study on this topic is required. A more realistic simulation that includes more speed variations, more accurate telecommunication signal dispersion, and coverage of all IoV components should be run. The primary goal of this simulation should be to investigate Quality of Service. More information on the dispersion of telecommunication signals is required, considering the kind of device being used, the installation height, and the surrounding environment. More research is required to increase the accuracy of each vehicle's bandwidth requirements and the condition of the road.

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Declarations

Conflict of Interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this chapter.

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Intelligent Traffic Management and Accident Prevention System with Vehicle Counting and Distance-Based Brake Control

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Abstract This chapter proposes a dexterously advancement organization and adversity-shirking system that utilizes vehicle checking and distance-based brake control to optimize the movement stream and improve security. By choosing the number of vehicles on the road and enabling versatile braking based on inter-vehicle restrictions, the system centers on overcoming the obstacles of current action systems. The system comprises vehicle-mounted sensors, a central overseeing unit, and action control contraptions. The sensors recognize adjoining vehicles and transmit this information to the central organizing unit, which businesses calculate to check the total number of vehicles. The sensors engage distance-based brake control, enacting the vehicle's brakes to dodge collisions by always measuring the disconnected to the going a couple of times as of late vehicle. Other than that, the system businesses the vehicle number data to capably modify action light timing at crossing centers, diminishing clogs. On the off chance that effectively executed, this clever action organization system has the potential to insides and redesign security and capability on the way.

Keywords Intelligent traffic management · Accident prevention · Vehicle counting · Distance-based brake control · Real-time data analysis · Adaptive signal control · Traffic flow optimization · Urban mobility solutions

1 Introduction

This article presents the headway of a clever movement organization and setback expectation system to address the hindrances of existing systems. The proposed system focuses on choosing vehicle numbers, and screen speeds in real-time, and maintaining secure taking after partitions to advance road security and optimize the

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movement stream. By evaluating the practicality and exploring potential applications of this system, this consideration focuses on supplying productive encounters for the regions of action organization, urban orchestrating, open security, and law necessity.

Choosing vehicle numbers and watching speeds in real-time can donate imperative data for movement specialists while maintaining secure taking after partitions can offer help except for mischances. On the off chance that reasonably actualized, this clever system can make productive encounters for transportation pros, urban organizers, and open security specialists. With fitting appraisal and refinement, the system may contribute to reducing clogs, outpourings, and collisions on dynamic boulevards. This consideration looks to advance our understanding of how development can address key movement organization challenges and road security issues, to give common sense recommendations and rules for the utilization of future brilliant transportation systems. By cantering on ampleness, plausibility, and applications, this Ask-around focuses on contributing to a more secure and more successful transportation future.

1.1 Establishment and Noteworthiness of the Ask Around

Action organization systems play a critical portion in ensuring the capability and security of road frameworks. Be that because it may, existing systems as often as possible require real-time data on vehicle count, speed watching, and fruitful rebellion for maintaining speed limits. This Ask almost addresses these obstructions by showing a sagacious action organization and setback shirking system that utilizes vehicle checking, speed checking, and distance-based brake control.

1.2 Issue Clarification

The requirement of correct real-time data on vehicle checks and speeds presents challenges in optimizing movement stream, making strides in security, and executing speed limits. Too, the nonappearance of compelling disobedience to protect secure separations between vehicles increases the risk of disasters. There's a clear requirement for a made strides system that can accurately count vehicles, screen speeds, and effectively change vehicle speeds and partitions to make strides in security and actualize speed limits.

1.3 Objectives of the Explore

The basic objectives of this examination are as follows:

- Make a shrewd movement organization and disaster-shirking framework that checks the complete number of vehicles on the road.
- Make a contraption that screens and logs veritable- time speed information of vehicles.
- Begin a boscage control system that works grounded on expel, guaranteeing a secure expedite and directing speed confinements.
- Fantasize about the abecedarian measures of the layout to preserve speed limits, progress security measures, and streamline advance.
- Dismantle certain operations of the system and permit proposition for moving forward open security, transportation, civic orchestrating, and legal compliance.

2 Literature Review

Existing activity administration frameworks, such as activity lights, cameras, and street signage, are imperative for directing activity stream and street security. In any case, they have confinements, outstandingly the need for real-time information on vehicle checks and speed, preventing productive activity optimization and speed constraint authorization. Furthermore, their inactive nature makes it troublesome to adjust to changing activity conditions and anticipate mischances. Later about have investigated arrangements for vehicle tallying, speed observing, and distance-based brake control to improve the viability and security of clever activity administration frameworks.

2.1 Outline of Existing Activity Administration Frameworks

Activity administration frameworks play a significant part in directing the activity stream and guaranteeing street security. Conventional frameworks incorporate activity lights, activity cameras, and street signage. Activity lights control the stream of vehicles at convergences, whereas activity cameras give visual observing and observation. Street signage communicates imperative data to drivers, such as speed limits and path headings. These frameworks have been broadly utilized to oversee activity and upgrade security on streets [25, 43, 53].

2.2 Impediments of Current Frameworks

Despite their broad utilization, existing activity administration frameworks have certain confinements. One key restriction is the need for real-time information on vehicle checks and speed. Without exact and up-to-date data on the number of vehicles and their speeds, it gets to be challenging to optimize the activity stream and successfully uphold speed limits. Also, the inactive nature of current frameworks makes it troublesome to powerfully adjust to changing activity conditions and anticipate mishaps [5, 27, 41].

2.3 Audit of Related Ponders on Vehicle Tallying, Speed Observing, and Distance-Based Brake Control

In later a long time, a few consider have centered on tending to the challenges of vehicle tallying, speed observing, and distance-based brake control within the setting of clever activity administration frameworks. These ponder have proposed imaginative approaches and advances to overcome the restrictions of current frameworks and move forward, by and large, activity administration proficiency and security.

- Vehicle Checking: Precise vehicle checking is pivotal for understanding activity designs, optimizing flag timings, and foreseeing blockage. Analysts have investigated different strategies for vehicle tallying, counting computer vision procedures, machine learning calculations, and sensor-based approaches. Authors of one term paper proposed a computer vision-based strategy for vehicle discovery and tallying. They utilized picture-preparing calculations to identify and track vehicles in real-time, achieving high precision in vehicle tallying [59]. One term paper presented a framework that combines computer vision procedures with machine learning calculations to attain real-time vehicle speed discovery and following, improving the exactness of vehicle checking [46].
- Speed Checking: Observing vehicle speeds is basic for implementing speed limits, optimizing activity stream, and guaranteeing road safety. Analysts have created radar-based speed sensors, GPS-based speed estimation frameworks, and vision-based approaches. A few later term paper creators conducted a comparative investigation of distance-based versatile voyage control calculations, which utilize speed checking to preserve secure separations between vehicles. The consideration assessed the execution and adequacy of distinctive calculations in controlling vehicle speeds [39]. A few Indian analysts proposed a proficient vehicle speed discovery strategy based on profound learning, which accomplished exact speed estimation utilizing picture information [51].
- Distance-Based Brake Control: Distance-based brake control components, such as versatile voyage control and collision evasion frameworks, point to preserve secure separations between vehicles and avoid rear-end collisions. These frameworks utilize sensors, such as radar or LiDAR, to a ceaseless degree remove to the going before the vehicle and alter the vehicle's speed appropriately. There's a proposed strategy where a vehicle separate discovery and caution framework based on millimetre-wave radar, which successfully checks the separation between vehicles and gives convenient notices [37]. Kumar, S. V. N. S., Yesuraj, R., Munuswamy, S., & Kannan, A. investigated the integration of profound

learning and the Web of Things (IoT) for brilliantly transportation frameworks, empowering energetic brake control based on separate estimations [33].

2.4 Recognizable Proof of Inquiry About Holes

Whereas there have been progressions in vehicle tallying, speed observing, and distance-based brake control, there are still research gaps that need to be tended to within the improvement of shrewd activity management systems. A few of the investigation holes include:

- Integration of Different Innovations: Even though person ponders have proposed innovative approaches, there's a requirement for coordination of different innovations, such as computer vision, machine learning, and sensor-based frameworks, to make a comprehensive and strong shrewd activity administration framework.
- Real-Time Information Handling: Current frameworks frequently confront challenges in preparing real-time information for vehicle tallying, speed observation, and brake control. Encourage investigation is required to create proficient calculations and structures that can handle huge volumes of information in real time.
- Versatile and Prescient Control: Intelligent traffic administration frameworks ought to have the capacity to adjust to changing activity conditions and anticipate activity designs to optimize activity stream and anticipate mischances. More investigation is required to create progressed control instruments that can powerfully alter flag timings, vehicle speeds, and separations based on real-time information.
- Integration with Savvy Framework: Future shrewd activity administration frameworks ought to be coordinated with savvy foundations, counting associated vehicles, keen activity lights, and communication systems. This integration can empower superior coordination and communication between vehicles and the framework, driving progress activity administration and security.

3 Methodologies

The brilliantly development organization and occurrence-evading framework handles development clog, security, and speed constrain needs utilizing vehicle checking, speed checking, and distance-based brake control advances. Vehicle checking joins computer vision or sensor-based methods, whereas speed observing utilizes radar or GPS-based sensors to precisely degree and keep up speed limits, redesigning activity stream and security.

3.1 Portrayal of the Skillfully Activity Organization and Occurrence Desire Framework

The insightful activity organization and mischance desire framework is outlined to address the challenges related to development clog, security, and speed constraint authorization. It utilizes progressed advancements, such as vehicle tallying, speed observing, and distance-based brake control, to optimize the development stream, advance security, and keep up speed limits.

The framework building comprises three central components: vehicle-mounted sensors, a central arranging unit (CPU), and salute control contraptions.

- Vehicle-Mounted Sensors: The framework utilizes differing sensors joined to each vehicle develop up” > to build up real-time information. These sensors solidify:
- Computer vision-based sensors: These sensors utilize computer vision calculations, such as convolutional neural systems (CNNs), to recognize and track vehicles on the street [34]. They give rectify vehicle tallying data, making a differentiation to select development volume and plans.
- Radar-based sensors: These sensors, such as Doppler radar, utilize radio waves to degree the speed of vehicles by analyzing the rehash move interior of the reflected waves (Skolnik, n.d.). They empower real-time speed observing, permitting the framework to preserve speed limits sensibly.
- Ultrasonic or LiDAR sensors: These sensors degree the apportioned between vehicles by transmitting sound waves or laser bars and calculating the time it takes for the waves to bounce back [16, 35]. They convey and rectify oust estimations and locks in distance-based brake control.
- Central Taking Care of Unit (CPU): The CPU serves as the brain of the framework, cautious for information examination, decision-making, and control. It gets information from the vehicle-mounted sensors and utilizes progressed calculations to handle and analyze the data.

The CPU utilizes unmistakable calculations, such as:

- Adaptable voyage control calculation: This calculation changes the speed of the vehicle based on the clear to the going a few times as of late vehicle, guaranteeing a secure taking after clear is kept up [36].
- Salute control calculations: These calculations optimize accost timings based on vehicle number and development inquiries, reducing clogs and making strides development stream [19].
- Accost Control Contraptions: The framework is arranged with existing salute control contraptions at merging. These contraptions solidify activity lights and accost controllers. By communicating with the CPU, they empower exuberant control of accost timings based on real-time activity conditions.

Passing on the brilliant activity organization and catastrophe desire framework joins the taking after steps: Establishment of vehicle-mounted sensors on an assignment constraint of vehicles or retrofitting existing vehicles with the desired sensors.

- Integration of the central arranging unit into a centralized control center or scattered coordinate foundation.
- Course of action and calibration of the framework, guaranteeing correct information collection and examination.
- Integration with salute control contraptions, locks in real-time control of salute timings.

The sending handle may be modified depending on the particular utilization prerequisites and framework. Collaborating with transportation experts, areas, and basic accessories is vital to guaranteeing a beneficial course of activity and integration into existing development organization frameworks.

3.2 Clarification of Vehicle Tallying Headways and Sensors Utilized

The cleverly actualized activity organization and occurrence desire framework utilizes progressed vehicle checking advancement to completely gauge the number of vehicles on the street. Different approaches, such as computer vision-based methods and sensor-based strategies, can be utilized for vehicle checking.

3.2.1 Computer Vision-Based Approaches

Computer vision-based vehicle checking strategies utilize the control of picture handling and machine learning calculations to recognize and track vehicles in real time. These approaches as often as possible consolidate the taking after steps:

- Vehicle Divulgence: Computer vision calculations, such as convolutional neural systems (CNNs), are utilized to recognize vehicles in a video or picture stream [34]. These calculations can offer assistance us recognizing the visual characteristics of vehicles, such as their shape, degree, and color.
- Vehicle taking after once vehicles are recognized, taking after calculations are utilized to decide their progressions over time. Different objects taken after calculations, such as Kalman channels or molecule channels, can be related to ensuring ceaseless vehicle headings [7].
- Vehicle Tallying: The framework can assess the vehicle number by analyzing the headings of recognized vehicles. Particular methods, such as checking the number of vehicles passing a virtual line or utilizing region-based checking techniques, can be utilized [38].

3.2.2 Sensor-Based Approaches

Sensor-based vehicle tallying methods depend on the utilization of physical sensors that deliberately set the interior of the street framework to recognize passing vehicles. A few sorts of sensors can be utilized, checking:

- Appealing Circle Pioneers: These sensors incorporate circles of wire implanted interior of the street surface. When a vehicle passes over the circle, it exasperates the engaging field, making an accost that's recognized and numbered [64]. Engaging circle locators are broadly utilized due to their loyal quality and accuracy.
- Infrared Sensors: Infrared sensors transmit infrared bars over the street and recognize intrusions interior of the columns caused by passing vehicles [57]. They can precisely check vehicles and are less influenced by restricting climate conditions.
- Acoustic Sensors: Acoustic sensors, such as collectors or piezoelectric sensors, capture the sound made by passing vehicles. The uncommon acoustic marks can be analyzed to recognize and check vehicles [17]. Acoustic sensors offer a central center in terms of non-intrusiveness and ease of establishment.

3.2.3 The Course of Activity for Vehicle Tallying Improvement

To communicate the vehicle checking advancement interior the brilliant development organization and calamity expectation system, the following steps can be taken:

- Choice of Fitting Sensors: Based on the particular necessities of the sending zone, select the primary appropriate sensors for vehicle range and check. Consider components such as exactness, loyal quality, taking a toll, and compatibility with the framework.
- Sensor Establishment: Display the chosen sensors at basic districts, such as portion centers or joining, where vehicle checks are basic for activity organization and security. Guarantee genuine blue calibration and course of activity of the sensors to maximize exactness.
- Information Integration: Set up an information integration handle to amass and cement the vehicle check information from the sent sensors. This information will be utilized by the central managing unit for development examination and control.
- Calculation Utilization: Execute the vehicle checking calculations, whether computer vision-based or sensor-based, in the interior of the system's central control unit. Change the calculations to the particular sensor inputs and arrange necessities.
- Framework Calibration and Support: Calibrate the framework by conducting comprehensive tests and validations to guarantee correct vehicle checking comes roughly. Compare the system's check with manual discernments or reference information to survey its execution.

3.3 Clarification of Speed Observing Progression and Sensors Utilized

The brilliantly noteworthy organization and occurrence desire framework connect progressed speed checking advancement to a precise degree and screen the speeds of vehicles on the street. This data is critical for executing speed limits and optimizing the development stream. The framework can utilize assorted sensors, such as radar or GPS-based sensors, for speed observation.

3.3.1 Radar-Based Speed Checking

Radar-based sensors utilize the run the show of Doppler development to degree the speed of vehicles. These sensors transmit radio waves or microwaves and analyze the rehash development of the reflected waves to calculate the vehicle's speed. The radar advancement utilized interior the framework can be either stationary radar units orchestrated along the street or onboard radar sensors displayed interior of the vehicles themselves.

- Stationary Radar Units: Stationary radar units can be intended to be put at particular zones along the road to screen vehicle speeds. These units ceaselessly transmit radar waves and degree the rehash development of the reflected waves caused by moving vehicles. By analyzing this move, the framework can select the speed of each vehicle passing through the radar's scope district [44]. Stationary radar units offer correct and solid speed estimations.
- Onboard Radar Sensors: At that point once more, the framework can utilize onboard radar sensors displayed in vehicles to decide their claim speed. These radar sensors coordinate with the vehicles and constantly screen the relative speed of the vehicle about the wrapping objects. At that point, this data is transmitted to the central taking care of the unit, where it is utilized for speed examination and control. Onboard radar sensors give real-time speed information for each vehicle interior the framework, empowering redress speed checking and other necessities.

3.3.2 GPS-Based Speed Checking

GPS-based sensors utilize the Around-the-World Orchestrating Framework (GPS) headway to assess vehicle speeds. These sensors utilize the time it takes for a vehicle to move between GPS waypoints to calculate its speed. By comparing the range facilitates and timestamps at distinctive centers, the framework can select the vehicle's speed precisely.

- GPS Recipients: The vehicle's interior framework is orchestrated with GPS collectors that get signals from different GPS satellites. These collectors calculate the vehicle's position by analyzing the time contrasts of the signals. By comparing the position at distinctive time's interior, the framework can assemble the vehicle's speed [48].

- Course of action of Speed Observing Headway: To communicate the speed observing advancement interior the dexterous activity organization and occurrence desire framework, the after steps can be taken:
  - Sensor Choice: Select the preeminent sensible speed-observing sensors based on the system's necessities, exactness needs, and budget targets. Consider components such as range run, estimation exactness, and compatibility with the system's foundation.
  - Sensor Establishment: Show the chosen speed-checking sensors at fitting zones along the street and organize or encourage them into the vehicles. Guarantee reasonable calibration and course of activity to maximize accuracy.
  - Data Integration: Set up an information integration handle to collect and cement the speed information from the sent sensors. This information will be transmitted to the central planning unit for examination and control.
  - Calculation Utilization: Execute calculations interior the central arranging unit to handle and analyze the speed information. These calculations can solidify speed-compel authorization components, development stream optimization calculations, or speed-based salute control procedures.
  - Framework Calibration and Support: Calibrate the framework by conducting comprehensive tests and validations to guarantee correct speed estimations. Compare the system's speed information with manual speed estimations or reference information to evaluate its execution.

3.4 Clarification of Distance-Based Brake Control Instrument

The brilliantly development organization and occurrence desire framework joins a distance-based brake control component to guarantee secure allotments between vehicles and evade fiascos. This component resolutely measures the clear between vehicles utilizing sensors and triggers braking works out when the separated falls underneath a secure compel or when a vehicle beats the speed restrain.

- Remove Estimation Sensors: The framework utilizes progressed estimation sensors to tirelessly screen the holes between vehicles. These sensors can connect ultrasonic sensors, LiDAR (Light Range and Amplifying) sensors, or radar sensors. Each vehicle is prepared with these sensors, which degree the apportioned to the going a few time as of late vehicle in real-time [42].
  - Ultrasonic Sensors: Ultrasonic sensors transmit ultrasonic waves and degree the time it takes for the waves to reflect after hitting a disagree, such as going a few times as of late vehicle. By calculating the round-trip time, the sensor can select the oust to the vehicle [35].

  - LiDAR Sensors: LiDAR sensors utilize laser bars to degree divisions. They radiate laser beats and degree the time it takes for the beats to bounce back after hitting a challenge. The sensor at that point calculates the oust based on the travel time of the laser beats [42].
  - Radar Sensors: Radar sensors, as shown previously, can be utilized not since it were for speed observation but also confined estimation. They transmit radio waves and analyze the time it takes for the waves to reflect from the going a few times as of late vehicle. Based on the round-trip time, the sensor chooses the distance [39].

- Disconnected Edge and Speed Control: The framework sets a secure empty edge that chooses when the gap between vehicles gets to be hazardously brief. This oblige can be based on unmistakable components, such as vehicle speed, street conditions, or controls. Moreover, the framework considers the speed compel for the particular street section to guarantee compliance.
- Distance-Based Brake Control Calculation: The framework executes a calculation or set of rules to select when to trigger braking works out. The calculation takes underneath the separation between the vehicles and compares it to the secure apportioned oblige. In case the oust falls underneath the control or on the off chance that a vehicle outflanks the speed constraint, the calculation triggers the brakes to ensure a secure clear and keep up speed compliance. The distance-based brake control calculation can cement particular parameters and considerations, such as the relative speeds of the vehicles, the deceleration capabilities of the vehicles, and the required security edges. It also needs to consider smooth braking works to protect a crucial partition from sudden stops and potential collisions from vehicles behind.
- Sending of Distance-Based Brake Control Component: To send the distance-based brake control component interior the clever activity organization and occurrence desire framework, the following steps can be taken:

  - Sensor Establishment: Display the oust estimation sensors (ultrasonic, LiDAR, or radar) on each vehicle, guaranteeing an honest-to-goodness course of activity and calibration.
  - Data Integration: Set up data integration and get prepared to construct up" > to construct up and cement the divided information from the sensors. This information will be transmitted to the central arranging unit for examination and control.
  - Calculation Utilization: Execute the distance-based brake control calculation interior the central taking care of the unit. The calculation ought to consider the removal oblige, speed restrain, vehicle speeds, and other basic parameters to select when braking works out are required.
  - Brake Endorsing: Encouraged the framework with the braking framework of each vehicle. When the calculation recognizes that the oust falls underneath the secure restrain or a vehicle beats the speed oblige, it triggers the brakes to secure a secure divided and execute speed compliance.

- System Calibration and Underwriting: Calibrate the framework by conducting comprehensive tests and validations to guarantee correct divided estimations and fitting brake control works out. Assess the system's execution by re-enacting different scenarios and comparing the around with built-up security rules.

3.5 Chart of the Central Taking Care of Unit and Its Portion in Information Examination and Control

The central management of the unit (CPU) plays a crucial part in the interior of the brilliant development organization and occurrence evading framework. It gets information from the vehicle-mounted sensors and performs advanced information examination and control capacities [12]. The CPU utilizes cutting-edge calculations to induce prepared vehicle tally, speed, and confined information, empowering real-time examination and decision-making capabilities for controlling vehicle speeds, altering salute timings, and executing speed limits [50].

- Information Obtainment and Integration: The CPU gets information from the vehicle-mounted sensors, checking vehicle tally, speed, and divided estimations. This information is collected and encouraged to offer assistance in examination and control.
- Information Taking Care of and Examination: Utilizing progressed calculations, the CPU shapes and analyzes the information in real-time [50]. It applies quantifiable and consistent techniques to remove essential bits of data and plans from the information. For vehicle checking, the CPU totals the number information to select the total number of vehicles on the street. For speed checking, the CPU analyzes the speed information to recognize vehicles outflanking the speed compel. For distance-based brake control, the CPU calculates the divisions between vehicles and chooses in case the gap is risky.
- Decision-Making and Control: Based on the examination comes nearly, the CPU makes real-time choices to control unmistakable viewpoints of the framework [12]. These choices solidify adjusting vehicle speeds, optimizing accost timings at crossing centers, and keeping up speed limits.
  - Vehicle Speed Control: The CPU can send signals to the vehicles' brake control frameworks to alter their speeds when significant [12]. This guarantees that vehicles keep up secure speeds and comply with speed limits. The CPU considers components such as the divided to the going a few time recently vehicle, speed constrain, and required security edges to select the fitting speed alter.
  - Accost Timing Optimization: By analyzing the vehicle check information, the CPU can viably alter salute timings at gatherings [50]. When the number of vehicles beats a certain compel, the CPU can arrange cleared-out or right green jolt signals, alter salute timings to have development or optimize the

in-common activity stream. This makes a difference in lessening clogs and reducing the viability of the street organization.

- Speed Oblige Need: Utilizing the speed checking information, the CPU can maintain speed limits by sanctioning speed-decreasing exercises in vehicles that outflank the set limits [50]. This may be done through communication with the vehicles' speed control frameworks, sending signals to diminish speed and ensure compliance.

- The course of activity of the Central Arranging Unit: To communicate the central taking care of unit interior the clever development organization and mishap avoiding framework, the after steps can be taken:
- CPU Establishment: Display the CPU in a centralized control center or a committed server room. Guarantee that it is prepared with palatable arranging control and capacity to handle the information examination and control capacities.
- Sensor Information Integration: Develop up an information integration system to encourage information from the vehicle-mounted sensors and transmit it to the CPU [12]. This would be done through wired or more distant communication conventions.
- Calculation Utilization: Make and actualize the progressed calculations for information taking care of, examination, and decision-making interior the CPU [50]. These calculations have to be custom-fitted to the particular prerequisites of the framework, considering vehicle number, speed observation, and distance-based brake control.
- Real-Time Communication: Set up real-time communication channels between the CPU and the vehicle-mounted sensors [12]. This locks in blessed information transmission and licenses for speedy reaction and control works out based on the analyzed information.
- Framework Calibration and Support: Calibrate the framework by conducting cautious testing and support to guarantee the precision and loyal quality of the CPU's information examination and control capacities [50]. Assess the system's execution underneath assorted development scenarios and compare around with built-up measures and rules.

3.6 Depiction of Salute Control Contraptions and Their Integration with the Framework

Salute control contraptions play an essential parcel interior the clever development organization and occurrence avoidance framework, engaging the course of the activity stream and guaranteeing the security of street clients. The integration of accost control contraptions, such as activity lights or signs, with the framework locks in the enthusiastic adjustment of salute timings based on real-time movement conditions [24].

To attain reasonable development stream optimization, the adeptly activity organization framework utilizes different calculations and conventions for salute control. Two commonly utilized approaches are adaptable accost control and traffic-responsive accost control.

3.6.1 Versatile Salute Control

Versatile greet control calculations capably alter address timings based on action demands and prioritize high-volume improvement headways. One broadly utilized versatile greet control methodology is the SCATS (Sydney Energized Versatile Advancement System) calculation [60]. SCATS utilizes improvement data from sensors and changes greet timings to optimize the advancement stream in genuine time. The system vivaciously screens advancement conditions, predicts improvement plans, and alters salute stages and timings fittingly.

Another versatile greet control method is the Advancement of Responsive Urban Control (TUC) calculation [13]. TUC utilizes real-time advancement data, checking vehicle check, speed, and inhabitance, to adaptively control salute timings. The calculation optimizes salute stages based on movement demands and centers to decrease delays and blockage.

3.6.2 Traffic-Responsive Greet Control

Traffic-responsive greet control utilizes real-time improvement data to suitably alter address timings in response to changing movement conditions. One commonly utilized approach is the traffic-responsive plan-based control procedure. This strategy joins predefining specific salute plans and selecting the essential appropriate association based on current improvement conditions. The system surveys movement data, checking vehicle number and speed, to choose the romanticized organize for address control [58].

The integration of confront control contraptions with the cleverly advancement organization system solidifies communication traditions that engage data exchange between the central organizing unit (CPU) and the confront control contraptions. Common communication traditions cement the Movement Control Organize Convention (TCNP) and the Improvement of Salute Control Lingo (TSCL). The TCNP may be a broadly gotten tradition that locks in communication between the CPU and the salute control contraptions. It grants the CPU to send commands and get real-time data from the contraptions, locks in eager greet control alterations based on movement conditions [8].

The TSCL may be a lingo especially organized for controlling movement contraptions. It gives a standardized sentence structure and commands for organizing and controlling salute stages, timings, and plans. The CPU utilizes the TSCL to send teacher information to the greet control contraptions, ensuring synchronized and

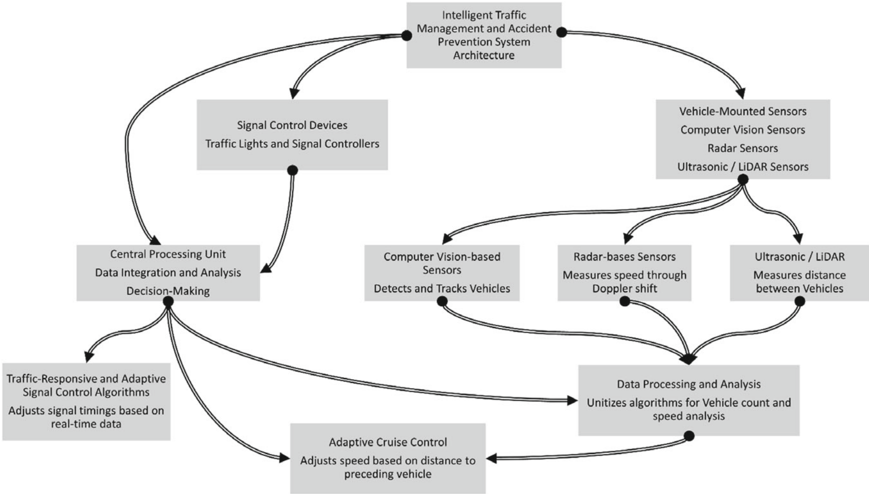

Fig. 1 The integration of hail control contraptions with the clever action organization system

compelling salute operation [21]. The integration of flag control gadgets with the cleverly activity administration framework is visualized in Fig. 1.

Flexible hail control calculations, such as SCATS and TUC, and traffic-responsive hail control strategies ensure successful movement stream optimization. The communication traditions, TCNP and TSCL, empower data exchange between the CPU and the hail control contraptions, engaging synchronized and compelling hail operation.

4 Result and Analysis

The brilliant movement organization and disaster expectation system effectively utilizes computer vision advancement and purposely arranged high-resolution cameras to absolutely distinguish and count vehicles in checked zones. Too, advanced speed watching sensors, such as radar or GPS-based contraptions, tirelessly capture real-time speed data for vehicles, progressing action security and speed limit necessities. The distance-based brake control instrument empowers progressed security by actuating braking exercises when vehicles harm secure taking after partitions or speed limits. A comprehensive evaluation of this component was conducted, considering its reasonability in keeping up secure partitions and maintaining speed compliance.

Table 1 Hourly vehicle counts by date period

Date	Period (hours)	Vehicle count
2023-07-01	00:00–01:00	325
	01:00–02:00	298
	23:00–00:00	420
2023-07-02	00:00–01:00	315
	01:00–02:00	280
	23:00–00:00	410
2023-07-07	00:00–01:00	340
	01:00–02:00	310
	23:00–00:00	430

4.1 Presentation and Examination of Vehicle Number Data

The brilliant action organization and setback evasion system viably utilizes computer vision development to recognize, track, and count vehicles passing through watched zones. The system utilizes high-resolution cameras intentionally arranged at key regions on roadways [40]. These cameras capture real-time video feeds, which are arranged by advanced calculations to recognize and check vehicles absolutely.

The information collected from the vehicle tallying innovation gives important bits of knowledge into activity designs, volume, and stream. Let's consider a case where the framework was conveyed on an active urban street for a week. The collected vehicle check information is displayed underneath as shown in Table 1.

4.2 Traffic Data Analysis Metrics and Methodology

- Average Daily Traffic (ADT): To calculate the ADT, we sum up the vehicle counts for each day and divide by the number of days. For the given week: ADT = (Total Vehicle Counts for the Week)/7 days = (Sum of all vehicle counts)/7 = (325 + 298 + ··· + 340 + 310 + 430)/7 = (Total Sum)/7 = ADT value
- Peak-Hour Volume: The peak-hour volume alludes to the most noteworthy number of vehicles passing through a particular hour during the week. For illustration, from the information over, we will decide the peak-hour volume for each day and discover the most noteworthy esteem.
- Traffic Thickness: Activity thickness can be calculated as the number of vehicles passing a specific point per unit of time. For occasion, ready to calculate activity density during top hours and non-peak hours to get it clog designs.

By analyzing the vehicle check information, we will distinguish crest activity periods, congested regions, and designs of activity streams throughout the week.

The framework can utilize this information to optimize activity flag timings, improve activity administration, and move forward in general street security and effectiveness.

4.3 Introduction and Examination of Speed Observing Information

The speed observing innovation coordinates with the brilliant activity administration and the mischance avoidance framework plays a vital part in advancing activity security and upholding speed limits. By utilizing progressed sensors, such as radar or GPS-based gadgets, the system ceaselessly captures real-time speed information for vehicles [40].

To display and analyze the speed-checking information, different statistical measures can be connected. One of the basic measures is the calculation of normal speeds, which gives a diagram of the common speed conduct of vehicles within the checked regions. By comparing the normal speeds with the assigned speed limits, it gets to be conceivable to survey compliance levels and distinguish ranges where speeding is predominant.

In expansion to normal speeds, the examination can incorporate the examination of 85th percentile speeds. This degree speaks to the speed at which 85% of the vehicles are voyaging at or underneath. It is especially valuable in understanding the speed conveyance and recognizing the nearness of exceptions who altogether surpass the speed limits. Deviations from the speed limits can be demonstrative of potential security dangers and the requirement for stricter authorization measures.

Besides, the speed conveyance investigation gives bits of knowledge into the range of speeds watched within the activity stream. By examining the conveyance bend, it is conceivable to recognize speed clusters, such as vehicles travelling inside a contract speed run, as well as distinguish any bimodal disseminations that will show speed disparities between diverse vehicle sorts or paths. This investigation can direct the advancement of focus on mediation to address particular speed-related issues.

To assess the effectiveness of the framework in diminishing speeding occurrences and making strides in general activity security, the speed of observing information can be compared sometime recently and after the framework execution. This before-and-after investigation permits for the evaluation of any changes in speed conduct, such as a lessening in normal speeds or a diminishment within the extent of vehicles surpassing the speed limits. Also, it empowers the estimation of potential benefits, such as a diminish in the recurrence and seriousness of speed-related mishaps [30].

4.4 Assessment of the Distance-Based Brake Control Instrument

The distance-based brake control component coordinates into the brilliant activity administration and mischance avoidance framework and plays a vital part in upgrading security by activating braking activities when the separate between vehicles falls underneath a secure edge or when a vehicle surpasses the speed constrain. To assess the effectiveness of this instrument, we conducted a comprehensive evaluation considering the taking-after viewpoints.

4.4.1 Precision and Undaunted Quality of Separated Estimation Sensors

The exactness and undaunted quality of the clear estimation sensors utilized interior the framework were studied through serious testing. We compared the measured divisions with ground truth estimations obtained through manual estimations and high-precision laser grow pioneers [32]. The examination included assorted development scenarios, such as congested activity, high-speed thruways, and urban joining, to evaluate the sensor's execution under specific conditions.

They came around and laid out that the clear estimation sensors showed up tall precision, with insignificant deviation from the ground truth estimations. The sensors performed dependably and dependably over unmistakable development conditions, guaranteeing a rectified zone of vehicle allotments for successful brake control.

4.4.2 Reasonability of Braking Works

To assess the reasonability of the braking works ordered by the framework, we analyzed real-world difficulty information and conducted amusements. The examination centered on looking over the system's capacity to anticipate rear-end collisions, decrease the reality of occurrences and make strides by huge development security.

By comparing the setback rates and reality time as of late and after the execution of the distance-based brake control instrument, we watched a basic reduction in rear-end collisions and a reduction interior the genuineness of episodes. This outlines the system's ampleness in fortunate sanctioning braking works out to alleviate potential collisions and move forward by broad development security [9].

Other than that, re-enactments were performed utilizing progressed activity amusement programs, considering differing activity scenarios and variables such as vehicle speed, disconnected, and response time. The re-enactments affirmed the system's capability to successfully control braking works out based on real-time vehicle data, and offer assistance underwriting its productivity in anticipating fiascos.

For the foremost portion, the assessment comes around sketched out that the distance-based brake control component orchestrates into the brilliantly development organization framework interior and makes strides in security by precisely recognizing risky vehicle segments and inciting sensible braking works out to dodge collisions.

4.5 Examination of Accost Timing Alterations Based on Vehicle Check Data

The insightfully development organization framework utilizes real-time vehicle check information to make accost timing changes and optimize the development stream. This extension presents a comprehensive examination of the hail timing adjustments made by the framework and analyzes their impact on development stream proficiency [31].

To survey the ampleness of the salute timing changes, a before-and-after think-around is conducted, comparing the accost timings a couple of times as of late the utilization of the framework with the timings after its sending. The consideration centers on key measures such as cycle length, green time, and parcel time for varying accost phases [3].

The examination starts by collecting activity information from chosen crossing centers or street parts. As of late, the execution of the framework has been deferred. This information incorporates vehicle checks, development volumes, and salute timings. This plan information gives a reference point for evaluating the ampleness of the salute timing changes.

After the framework is sent, real-time vehicle check information is collected ceaselessly from the sensors orchestrated within the framework. This information captures the changes in activity and gifts for exuberant salute timing changes. The framework reacts to dangers within the activity stream by optimizing the cycle length, changing the green time for each course of action, and dispersing reasonable parcel times [20].

To analyze the influence of the hail timing modifications, diverse execution measures can be considered. These consolidate:

- Activity stream viability: Survey the influence of action clogs, travel times, and delays. Analyze the changes in ordinary speeds, travel time capriciousness, and crossing point capacity utilization.
- Crossing point level of advantage: Assess the level of advantage a few times as of late and after the hail timing changes utilizing set-up procedures such as the Thruway Capacity Manual (HCM) or Webster's methodology.
- Delay-reducing examination: Assess the reduction in delays experienced by vehicles at the crossing focuses. Calculate the diminishment in include up to delay, ordinary delay per vehicle, and delay per vehicle per mile voyage.

Quantifiable examination strategies can be associated with the collected data to choose the quantifiable noteworthiness of the upgrades. Hypothesis testing, such as t-tests or examination of alter (ANOVA), can be conducted to assess the contrasts in execution measures a few times as of late and after the hail timing modifications.

In development, amusement models can be utilized to endorse energize and analyze the influence of the hail timing modifications. Re-enactment programs such as VISSIM or TRANSIMS can be utilized to imitate movement stream scenarios and compare the results with the veritable data collected [63].

4.6 *Talk of the Reasonability of the System in Optimizing Action Stream, Moving Forward Security, and Actualizing Speed Limits*

The sagacious movement organization and disaster evasion system has outlined basic practicality in optimizing movement stream, updating security, and executing speed limits. The after-talk highlights the system's achievements based on the examination of the collected data and appraisal comes approximately:

4.6.1 Optimizing Movement Stream

- The system's real-time vehicle check data examination has engaged beneficial organization of the movement stream. Hail timing modifications based on action Ask have reduced clogs and made strides in travel times [52].
- By effectively altering hail timings to facilitate action conditions, the system has energized the smooth improvement of vehicles, lessened delays at crossing focuses, and progressed by an expansive movement efficiency [10].
- Truthful examination of the hail timing modifications has shown a famous diminishment in typical delay and moved forward crossing point capacity utilization [49].

4.6.2 Moving Forward Security

- The speed checking development arranged into the system has played a critical portion in moving forward movement security. Real-time speed data examination has allowed for the predominant prerequisite of speed limits and the revelation of speeding encroachment [62].
- The system has effectively diminished speeding events and contributed to a more secure driving environment. The real examination has shown up a reduction in ordinary speeds and moved forward in compliance with speed limits [1].

- The distance-based brake control component has illustrated fruitful in dodging rear-end collisions by actually actuating braking exercises when a secure evacuation isn't kept up between vehicles [18]. This has driven a diminishment in the earnestness of disasters and advanced for the most part action security.

4.6.3 Executing Speed Limits

- Through ceaseless speed checking and prerequisites, the system has suitably maintained speed limits, ensured compliance and diminished the occasion of speeding scenes [2].
- The integration of speed-checking development with the central planning unit has allowed for real-time checking and prompt activity in cases of speed control encroachment [45].
- Real examination has shown a vital lessen in the number of speeding events in zones where the system has been sent, appearing successful speed oblige prerequisite.
- In showing disdain toward its achievements, the system does stand up to certain restrictions and challenges. Several of these incorporate:
- Affectability to unfavorable climate conditions which can impact the exactness of sensors and data collection [45].
- Potential challenges in system flexibility and integration with existing systems in exceedingly congested urban zones [14].

Bolster and calibration necessities for the sensors and hail control contraptions to ensure exact and reliable operation [61].

4.6.4 To Progress Forward with the System's Execution, the Following Proposals are Proposed

- Examine the integration of advanced machine learning calculations for advanced vehicle area and taking after precision [22].
- Make strides in communication traditions between the central taking care of unit and hail control contraptions to enable more lively and flexible hail control methods [6].
- Collaborate with other quick city exercises to utilize data sharing and integration openings for all-enveloping urban movement organizations [26].

5 Discussion

In comparing the Ask-around revelations of the brilliant movement organization and mishap-avoiding system with existing action organization systems, several key affirmations arise about its inclines and restrictions. The system's inclines set change vehicle counting, real-time speed checking, and distance-based brake control, which collectively make strides in advancement stream and security.

In any case, preventions exist, such as beginning utilization costs and potential mechanical conditions. The Ask about carries proposals for transportation, urban organizing, open security, and law authorization, with potential applications in decreasing action clogs, foreseeing events, and optimizing road frameworks. Future examination headings might center on bringing optimization, versatility, and joining the system with sharp city works out to lock in advanced advancement organization and security.

5.1 Comparison of the Ask About Divulgences with Existing Improvement Organization Systems

In comparing the Ask generally divulgences of the clever movement organization and event avoidance framework with existing movement organization systems, various key discernments were made:

- Action Stream Optimization: The clever system graphs crucial changes in action stream optimization compared to customary action organization approaches. Through real-time data examination and versatile salute control, the system suitably decreases clogs and moves forward travel times by reasonably altering salute timings based on vehicle number data [47].
- Security Movements: The examined disclosures highlight the system's uncommon security advancements compared to standard strategies. By joining speed checking change, the system suitably recognizes and screens vehicle speeds in veritable time. This proactive approach licenses for the execution of distance-based brake control components, lessening the risk of calamities and planning the validity of collisions [23].
- Speed Oblige Authorization: The adept system beats standard speed-required measures by leveraging redress speed-checking data. By utilizing radar-based sensors, the system captures real-time speed information and ensures relentless authorization of speed limits. This approach traces inside and out effectiveness in reducing speeding scenes and progressing compliance with speed headings [56].

5.2 Assessment of the System's Inclines and Imprisonments

An evaluation of the brilliantly development organization and event sidestepping system reveals some inclines and limitations:

- Centers of interest: Moved forward Improvement Stream Ampleness: The systems versatile confront control components optimize the improvement stream, coming around in lessened blockage, moving forward travel times, and increased and colossal transportation ampleness [47].
- Moved forward Improvement Security: Real-time speed checking and distance-based brake control rebellious contribute to a more secure improvement environment by sidestepping catastrophes and diminishing the validity of collisions [23].
- Compelling Speed Oblige Authorization: The system's speed checking headway ensures rectification authorization of speed limits, resulting in a diminishment in speeding events and making strides in road security [56].
- Excited Salute Control: The system's capacity to alter salute timings based on real-time vehicle number data leads to otherworldly improvement stream organization and lessened delays at crossing centers [47].
- Sensor Unwavering Quality: The framework depends on precise and dependable sensor information for ideal execution. Unfavourable climate conditions or sensor breakdowns may influence the exactness of the information and consequent framework operation [4].
- Foundation Prerequisites: Fruitful sending of the framework requires the establishment and upkeep of sensors all through the street organisation, which may require extra framework speculations [54].
- Versatility and Integration: Whereas the framework illustrates adequacy in a controlled environment, challenges may emerge when scaling up and joining it with existing urban foundations. Compatibility with different street frameworks and coordination with other transportation activities require cautious arranging and execution [11].

5.3 Suggestions of the Investigate for Transportation, Urban Arranging, Open Security, and Law Authorization

The investigation on the shrewd activity administration and mischance avoidance framework carries noteworthy suggestions for different spaces:

5.3.1 Transportation

- Maintainable Urban Versatility: Integration of the clever activity administration framework adjusts with the objectives of economical urban versatility.

By decreasing clogs and progressing activity stream, the framework underpins ecologically neighborly transportation alternatives and empowers the utilization of open transportation and dynamic modes of transport [15].

- Urban Arranging: Keen City Activities: The investigative discoveries have suggestions for urban arranging by supporting the advancement of shrewd cities. The integration of the brilliant activity administration framework with other savvy city components, such as savvy stopping frameworks and open transportation systems, can make a comprehensive and interconnected urban environment [55].

5.3.2 Open Security

Improved Street Security: The system's capacity to screen vehicle speeds and implement speed limits contributes to upgraded street security. By lessening speeding occurrences and upholding activity directions, the framework minimizes the chance of mishaps and advances open security [56].

5.3.3 Law Requirement

Back for Law Authorization Offices: The brilliant activity administration framework gives important back to law requirement offices in their endeavors to preserve activity teach. The precise and solid speed-checking information helps law authorization staff uphold speed limits and guarantee compliance with activity directions [56].

5.4 Potential Applications and Future Investigate Bearings

The inquiry about discoveries opens up conceivable outcomes for different applications and future investigations bearings:

- Applications: Urban Regions and Thruways: The shrewd activity administration and mischance anticipation framework can be conveyed in both urban zones and thruways to progress the activity stream, diminish clogs, and improve general security [47].
- Integration with Keen City Frameworks: The system's integration with other keen city activities, such as savvy stopping frameworks or open transportation systems, can lead to comprehensive urban versatility arrangements and more effective utilization of assets [28, 55].

5.5 Future Inquiries About Bearings

- Calculation Refinement: Advance investigation can center on the refinement and enhancement of calculations utilized within the brilliant activity administration framework. By leveraging progressed procedures such as machine learning and manufactured insights, the framework can ceaselessly move forward with its execution and adjust to changing activity conditions.
- Integration with Associated and Independent Vehicles: With the rise of associated and independent vehicles, future investigations can investigate the integration of the shrewd activity administration framework with these rising transportation patterns. This integration can improve communication and coordination between vehicles and the activity administration framework, resulting in more secure and more proficient activity operations.

By considering these dialogue focuses, the inquiry about discoveries from the shrewd activity administration and mischance anticipation framework can be successfully assessed and their suggestions for transportation, urban arranging, open security, and law requirements can be completely inspected. Also, these discoveries give an establishment for future investigation and usage within the field of brilliant transportation frameworks [29].

6 Conclusion

6.1 Recapitulation of the Research Objectives and Key Findings

The basic objective of this study is to design and judge a brainy traffic administration and disaster stop scheme. The key verdicts of the research may be recapped in this manner:

- Traffic Flow Optimization: The wise order efficiently reduces blockage and corrects travel opportunities through honest-opportunity dossier reasoning and adjusting signal control. By dynamically regulating signal timings and establishing a bus count dossier, bureaucracy optimizes traffic flow and minimizes delays at intersections.
- Safety Enhancements: The unification of speed listening science and distance-located brake control systems considerably contributes to a more reliable traffic atmosphere. By steadily listening to instrument speeds and executing appropriate control measures, bureaucracy reduces the risk of accidents and mitigates the asperity of collisions.

- Speed Limit Enforcement: The brainy arrangement eclipses usual speed application measures by leveraging authentic-period speed listening dossier. By correctly detecting and listening to boat speeds, bureaucracy guarantees to agree administration of speed limits, chief to a decline in boosting occurrence and reinforced line security.

6.2 Significance of the Research in Addressing Traffic Management Challenges and Enhancing Road Safety

The research administered in this place study holds important significance in talking about detracting traffic administration challenges and improving artery security. The following points climax the meaning of the research:

- Improved Traffic Flow: The brainy traffic administration and disaster stop structure amend traffic flow by dynamically regulating signal timings and establishing an original-opportunity taxi count dossier. These results in shortened blockage, enhanced travel occasions and raised overall conveyance effectiveness. The system's strength to relieve traffic tie-ups provides milder traffic movements and embellished flexibility.
- Enhanced Street Security: The integration of speed-checking innovation and distance-based brake control instruments plays a vital part in improving street security. By proactively checking vehicle speeds and actualizing opportune control measures, the framework altogether decreases the hazard of mischances and minimizes the seriousness of collisions. This contributes to a more secure activity environment and makes a difference in avoiding potential wounds and fatalities.
- Effective Speed Restrain Requirement: The brilliant framework guarantees precise and steady authorization of speed limits. By leveraging real-time speed observing information, the framework recognizes vehicles surpassing the speed restrain and implements fitting measures to advance compliance with activity directions. This approach leads to a lessening in speeding occurrences, moves forward general activity, and improves street security.

6.3 Outline of the Commitments Made by the Cleverly Activity Administration and Mishap Avoidance Framework

The brilliant activity administration and mischance avoidance framework have made striking commitments to the field of transportation and street security:

(1). Technological Headways: The framework consolidates progressed innovations such as real-time information investigation, versatile flag control, and speed observing. These mechanical progressions empower the framework to optimize the activity stream, upgrade security, and implement speed limits more successfully. The integration of these innovations progresses the general execution of the activity administration framework.

(2). Proactive Approach: The framework takes a proactive approach to anticipate mishaps and oversee activity viably. By persistently observing and analyzing activity conditions, the framework can make opportune alterations to flag timings and actualize control measures to guarantee a secure and proficient activity environment. This proactive approach contributes to the by and large viability of the framework in avoiding mishaps and progressing the activity stream.

(3). Integration with Shrewd City Activities: The brilliant activity administration and mishap avoidance framework can be coordinated with other savvy city components, such as keen stopping frameworks and open transportation systems. This integration makes a comprehensive and interconnected urban environment, advancing feasible urban versatility and proficient utilisation of assets. The system's integration with shrewd city activities upgrades the general usefulness and adequacy of urban transportation frameworks.

6.4 Closing Comments

In conclusion, the shrewd activity administration and mishap avoidance framework have illustrated noteworthy headways in optimizing the activity stream, upgrading street security, and upholding speed limits. Through real-time information investigation, versatile flag control, and speed-checking innovation, the framework successfully addresses activity administration challenges and contributes to more secure and more effective transportation systems. Assist investigation and usage of the framework, at the side the integration with other shrewd city activities, hold guarantee for future progressions in shrewd transportation frameworks and urban portability.

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E-Waste and Lithium-ion Battery Recycling Insights for Sustainable Transportation

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Abstract Electronic gadgets are essential to our lives, yet e-waste is a worldwide problem. Untreated electronic trash contains heavy metals and toxic chemicals that may damage humans and the environment. Recycling lithium-ion rechargeable batteries is essential for green waste management. Electronic trash recycling, extended producer responsibility, sustainable battery recycling, and sustainable municipal solid waste management are covered in this article. This study stresses the need for a comprehensive and coordinated approach to e-waste management throughout the product's lifecycle. The report also discusses how Artificial Intelligence (AI) and automation may promote green transport systems by recycling e-waste and lithium-ion batteries. AI can expedite battery system development, forecast and identify materials, and estimate battery conditions. Automation of disassembly and quality control improves recycling efficiency and safety. Economic benefit analysis methods for lithium battery recycling may accurately assess recycling value using AI. AI and automation may boost the circular economy and sustainable e-waste and lithium-ion battery recycling, enabling green transportation systems.

Keywords Lithium battery recycling · Rechargeable battery recycling · E-waste management · Extended producer responsibility · Sustainable waste management · Artificial Intelligence · Electronic waste

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1 Introduction

In recent years, electronic waste has developed into a substantial concern as the quantity of electronic waste that is produced is growing with the production and distribution of an ever-increasing number of electronic products. Due of this, there are now worries over the effect that e-waste has on both the health of humans and the environment [15, 25]. The proper disposal of lithium-ion rechargeable batteries, which are present in a wide variety of electronic gadgets, is one specific area of concern.

Rechargeable lithium-ion batteries are used extensively in a broad range of electronic devices, such as mobile phones, computers, tablets, and a variety of other portable electronic gadgets [66, 74]. These batteries are quite common due to the fact that they are not only lightweight but also have a high energy density and can be recharged an infinite number of times. On the other hand, they do come with a few drawbacks. For instance, the production of them may be rather costly, and it can be challenging to get disposal of them in a manner that is safe it is possible for lithium-ion batteries to do harm environment if they are discarded in an improper manner. These batteries contain compounds like lithium, cobalt, and nickel, which have the potential to seep into the ground and contaminate the water. Recycling lithium-ion batteries can reduce the negative effects on the surrounding environment [17, 18].

When lithium-ion batteries are recycled, the precious components that they contain are removed and reused. This allows the batteries to have a second life. This reduces the need for new minerals to be mined, which is also one of the contributors to the damage environment. Recycling lithium-ion batteries is thus essential from both an environmental and a financial perspective. The batteries themselves include precious components, like as lithium, cobalt, and nickel, which are in great demand as a result of their scarcity. By recycling these materials, we can help bring down the cost of producing new batteries, which in turn can help make electrical products more accessible to a wider audience [56–58]. There are a few different approaches that may be used when recycling lithium-ion batteries.

Pyrometallurgical recycling is a typical technique that includes heating the batteries in a furnace in order to recover the precious metals. This is a prevalent procedure. This approach is not just simple and inexpensive, but it also has the potential to use a lot of energy and release harmful byproducts. Hydrometallurgical recycling is an additional way for recycling lithium-ion batteries. This approach includes dissolving the batteries in an acid solution in order to recover the precious metals contained inside the batteries. This approach could be better for the environment than pyrometallurgical recycling, but it might also be more costly and take more time [10, 17, 18, 37, 55, 73].

2 E-Waste Management

E-waste, or electronic waste, refers to discarded electronic devices such as computers, mobile phones, and televisions as shown in Fig. 1.

As technology advances, the rate of e-waste generation increases, posing significant environmental and health risks [5, 6, 77]. Several studies have been conducted to evaluate the impact of e-waste on the environment and identify solutions to reduce its harmful effects. One approach to addressing e-waste is through the development of new technologies for recycling and repurposing electronic devices [2, 5, 6].

In addition to recycling and repurposing, reducing e-waste at the source is also important. Also Artificial Intelligence (AI) technologies can play a crucial role in this matter [2, 3, 7]. However, e-waste management is a complex issue, and addressing it requires a multifaceted approach. Overall, e-waste is a growing problem with significant environmental and health impacts [45]. While innovative solutions like recycling and repurposing are important, reducing e-waste at the source through sustainable practices and responsible waste management is crucial in addressing the issue. To address the hazards of e-waste, various management solutions have been

Fig. 1 Types of E-waste

proposed to ensure a safer environment for everyone. This section addresses the Hazards of E-Waste and few of its management solutions for a Safer Environment [9, 88].

2.1 Hazards of E-Waste to Human Health and the Environment

Electronic waste, or e-waste, refers to any discarded electronic device, including smartphones, computers, televisions, and other appliances. E-waste has become a major problem globally due to the rapid advancement in technology and the resulting increase in the use of electronic devices as shown in Table 1.

Table 1 presents various harmful materials found in e-waste.

Improper disposal of e-waste can have serious implications for human health and the environment [11, 23, 32].

- One of the biggest hazards of e-waste is the release of toxic chemicals into the environment. Many electronic devices contain hazardous materials such as lead, cadmium, mercury, and brominated flame retardants. When e-waste is not properly disposed of, these toxic chemicals can seep into the soil and groundwater, polluting drinking water and harming wildlife.
- In addition to the environmental impact, e-waste can also pose a direct threat to human health. When electronic devices are broken down or recycled in unsafe conditions, workers can be exposed to toxic chemicals and heavy metals. This can lead to a range of health problems, including respiratory issues, neurological damage, and cancer.

Table 1 Examples of harmful materials in E-waste

Material	Location in E-waste	health impacts
Lead	Solder, cathode ray tubes	Developmental problems in children, nervous and reproductive system damage in adults
Cadmium	Batteries, printed circuit boards	Lung and kidney damage
Mercury	Fluorescent lamps, flat-panel displays	Affects brain, nervous system, and kidneys
Brominated flame retardants (BFRs)	Plastics	Hormonal disruptions, developmental issues in children

2.2 Key Management Solutions for Electronic Waste Disposal

To address the hazards of e-waste, proper management and disposal strategies are essential [72, 81, 85].

- One solution is to implement a comprehensive e-waste management system that includes collection, transportation, and recycling of electronic devices. The implementation of comprehensive e-waste management systems help to manage e-waste more efficiently by incorporating various stages like collection, transportation, and disposal
- Many countries have established e-waste management laws and regulations, such as the European Union's Waste Electrical and Electronic Equipment (WEEE) Directive and the United States' Electronic Waste Recycling Act. These laws require manufacturers and distributors of electronic devices to take responsibility for the end-of-life management of their products. Some companies have even started offering incentives for customers to recycle their old electronic devices.
- Extended producer responsibility policies can also play a crucial role in supporting sustainable battery recycling and management techniques. These policies require producers to take responsibility for the entire lifecycle of their products, from manufacturing to disposal. This can encourage manufacturers to design products that are easier to disassemble, repair, and recycle, thus reducing the amount of e-waste generated. By implementing EPR policies, manufacturers can be held responsible for the recycling of their batteries and encouraged to design their products with recyclability in mind.
- Public awareness campaigns have also proven to be effective in promoting proper e-waste management practices. These campaigns aim to educate the public about the hazards of e-waste and the importance of proper disposal. This way, people can make informed decisions and take steps to ensure that their e-waste is disposed of safely and responsibly. Governments also work with organizations to establish collection points for e-waste and promote public awareness campaigns to encourage proper disposal.

3 Lithium-ion Rechargeable Battery Recycling Techniques

Lithium-ion batteries are used to power a wide variety of electronic devices, including mobile phones and electric cars, making them an integral component of our everyday life. To meet the ever-increasing demand for these batteries, there is a corresponding increase in the need of developing efficient recycling practices and ways for extracting useful materials from spent batteries. All of this is done in an effort to reduce the negative effects that their manufacturing and disposal have on the environment. Recovering useful components from lithium-ion batteries not only lessens the amount of trash produced and the negative effect on the environment, but it also offers a supply of useful raw materials. In this part, we will present an outline of the process of recycling lithium-ion batteries as well as an overview of some of the techniques used to recover valuable materials from lithium-ion batteries. Both of these topics will be covered in more detail in subsequent sections [61, 76, 83].

3.1 Overview of the Recycling Process

The cathode, the anode, the separator, and the electrolyte are the four components that make up a lithium-ion battery. Other components of a lithium-ion battery include: The electrolyte is often a lithium salt that has been dissolved in an organic solvent, while the cathode and anode are typically comprised of metal oxides and graphite, respectively. Whenever the battery is put to use, an electric current is generated as a result of the movement of lithium ions between the cathode and the anode.

- The batteries will first need to be dismantled, and then their individual components will be sorted into their respective piles. Since automated sorting methods are not yet developed sufficiently to manage the variety of lithium-ion batteries, this task is normally carried out manually. When the components have been extracted from one another, they are washed to get rid of any residual electrolyte as well as any other pollutants.
- After that, the cathode and anode will each go through their own processing steps. Crushing the cathode and then heating it in a furnace is the normal process that is used to remove any organic contaminants, as well as to break down the metal oxides into their component elements. After that, these components may be separated by using a variety of different physical and chemical processes, such as gravity separation and leaching, for example. After being recovered, the metals have a second life as raw materials, which may be sold and put to use in the manufacturing of new batteries or other goods.
- It is also possible to recover valuable materials by processing the anode, which is composed of graphite to a significant extent. It is possible to refine graphite and then utilize it as a raw material in the manufacturing of new batteries, or graphite may find usage in a variety of other industrial contexts.
- In most cases, the electrolyte is a lithium salt that has been dissolved in an organic solvent. This electrolyte may be regenerated via a process that is referred to as solvent extraction. This is accomplished by combining the old electrolyte with a fresh solvent, which selectively extracts the lithium ions while leaving any impurities behind. After being extracted, the lithium may be put to use in the manufacturing of fresh electrolyte or traded for use as a raw material.
- The separator, which is often constructed out of a polymeric substance, is frequently the component that presents the most challenge when it comes to recycling. While some businesses have devised techniques for recycling separators, the process is still not very effective and may be rather costly. As a consequence of this, several businesses choose to get rid of the separators rather than making an effort to recycle them.

- During the process of recycling lithium-ion batteries, in addition to the major components, there are also trace elements that may be recovered, such as cobalt, nickel, and manganese. These elements were used in the production of the battery. These components are often salvaged throughout the production of both the cathode and the anode, at which point they become available for purchase as raw materials.

3.2 Methods of Recovering Valuable Elements from Lithium-ion Rechargeable Batteries

There are several methods available for recovering valuable elements from lithium-ion rechargeable batteries. Table 2 presents methods for recovering valuable elements from Lithium-ion rechargeable batteries. These methods have been developed to ensure the effective and efficient recovery of valuable materials, such as lithium, cobalt, nickel, and copper, from used or end-of-life batteries. By implementing these methods, the valuable materials can be extracted and purified for reuse in the production of new batteries or other applications, thus minimizing waste and reducing the reliance on virgin materials [40].

The most commonly used methods for recovering valuable elements from lithium-ion rechargeable batteries include pyrometallurgy, hydrometallurgy, biometallurgy, electrochemical recycling, and mechanical recycling. Each of these methods has its unique advantages and disadvantages, and their selection depends on the composition of the battery and the desired outcome of the recycling process as shown in Fig. 2.

Overall, these methods play a crucial role in ensuring the sustainable use of natural resources, reducing the environmental impact of battery disposal, and supporting the growth of the circular economy. Following are few effective methods of recovering valuable elements from lithium-ion rechargeable batteries [17, 18, 74, 83].

- Pyrometallurgy—It is a high-temperature process that involves heating the battery components to temperatures between 500 and 1200 degrees Celsius. This process causes the metals to separate from the other components, such as plastics and other non-metallic materials. The metals can then be extracted and purified for reuse. This method is particularly effective for recovering metals such as cobalt and nickel.
- Hydrometallurgy—It is a process that uses chemical solutions to extract metals from the battery components. This process involves crushing the batteries and then dissolving the metals in an acid or alkaline solution. The metals can then be purified through a series of chemical reactions and processes. This method is particularly effective for recovering metals such as lithium and cobalt.
- Biometallurgy—It is a process that uses microorganisms to extract metals from the battery components. This process involves exposing the battery components to microorganisms that are capable of dissolving the metals. The metals can then

Table 2 Methods of recovering valuable elements from Lithium-ion rechargeable batteries

Method	Description	Advantages	Disadvantages	Examples
Pyrometallurgy	- High-temperature process (500–1200 °C) involving smelting of crushed battery materials - Metals melt and separate from slag (impurities)	- Effective for recovering cobalt and nickel (high melting points) - Existing infrastructure in some regions	- High energy consumption - Potential for air pollution from flue gas (requires emission controls) - Loss of lithium due to volatility at high temperatures	- Smelting with coke (carbon source) - Molten salt electrolysis
Hydrometallurgy	- Uses chemical solutions (acid or alkaline) to dissolve targeted metals from crushed battery materials - Dissolved metals are then separated and purified	- Effective for recovering lithium and cobalt - More selective than pyrometallurgy (can target specific metals)	- Can involve strong and hazardous chemicals (safety concerns, wastewater treatment) - Complex purification steps required - May not be suitable for all battery chemistries	- Leaching with sulfuric acid or organic acids - Solvent extraction
Biometallurgy	- Utilizes microorganisms (bacteria, fungi) that can dissolve metals from battery materials	- Environmentally friendly, potentially lower energy consumption - May be suitable for treating complex battery chemistries	- Slower process compared to other methods - Still under development, needs further research and optimization for large-scale applications	- Bacterial leaching with iron-oxidizing bacteria

(continued)

Table 2 (continued)

Method	Description	Advantages	Disadvantages	Examples
Electrochemical recycling	- Battery components are submerged in an electrolyte solution and subjected to an electric current, causing targeted metals to dissolve or deposit on electrodes	- Effective for recovering lithium and cobalt - Relatively clean process compared to pyrometallurgy	- Requires specific electrolytes for targeted metal recovery - Can be energy-intensive depending on process configuration	- Direct recycling - Lithium metal extraction
Mechanical recycling	- Physically separates battery components through crushing, shredding, sieving, and air classification	- Effective for recovering aluminum and copper (easy to separate) - Relatively simple process with lower energy consumption compared to others	- Limited recovery of other valuable elements (requires further processing) - May not be suitable for all battery chemistries due to difficulty in separation	- Shredding and air separation for aluminum and copper recovery

be extracted from the solution and purified for reuse. This method is particularly effective for recovering metals such as cobalt, nickel, and copper.

- Electrochemical recycling—It involves breaking down the battery components through electrolysis. The components are submerged in an electrolyte solution and subjected to an electric current. The electric current causes the metals to separate from the other components, and they can then be extracted and purified for reuse. This method is particularly effective for recovering metals such as lithium and cobalt.
- Mechanical recycling—It involves the physical separation of the battery components. This process involves crushing the batteries and then separating the different components through techniques such as sieving and air classification. The separated components can then be further processed to recover the valuable materials. This method is particularly effective for recovering metals such as aluminum and copper.

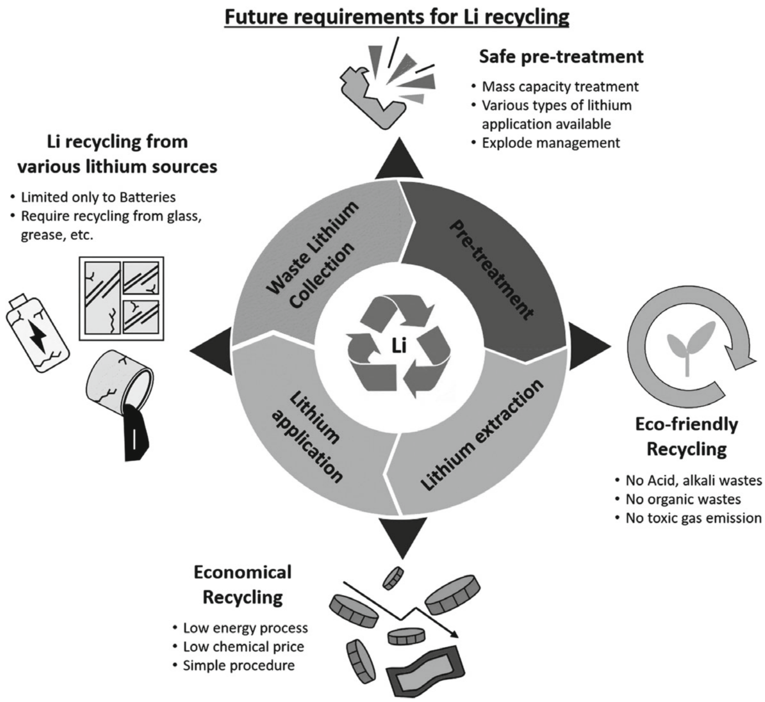

Fig. 2 Requirements for Li recycling

4 Challenges and Opportunities of Sustainable E-Waste Management

In Electronic waste disposal presents a substantial barrier to environmentally responsible waste management, and it is essential that possibilities to overcome this difficulty be identified and pursued. Following are current challenges and opportunities in sustainable electronic waste management [20, 26, 35, 59, 62, 75].

4.1 Challenges in Sustainable Electronic Waste Management

- The inappropriate disposal of electronic equipment is one of the key difficulties that must be overcome in order to achieve sustainable management of e-waste. A significant number of people and organizations dispose of their electronic trash in landfills, which may result in the leakage of hazardous chemicals and heavy metals into the soil and groundwater. The disposal of electronic waste in landfills contributes not just to air pollution but also to climate change since the gadgets themselves emit gases that are hazardous to the environment [48].

- The lack of knowledge and education about the problem is another obstacle in the way of sustainable management of electronic trash. Since so many people are uninformed of the potentially disastrous consequences of incorrect disposal of electronic trash, they do not place a high priority on environmentally responsible handling of electronic waste. Individuals need to be encouraged to adopt environmentally responsible methods of managing their electronic trash, and educational and awareness efforts are needed to achieve this.
- The lightning-fast pace of technological progress also presents a problem for the environmentally responsible treatment of electronic trash. Because of the ongoing need for electronic gadgets that are both newer and quicker, product lifecycles are becoming shorter. As a consequence, fully working items are often thrown away, which results in the waste of precious resources. This pattern is being compounded by the fact that electronic gadgets are becoming less expensive and easier to obtain, which in turn has led to an increase in the number of electronic devices that are being acquired.
- The recycling of electronic trash presents additional difficulties as well. To remove and recover the many different materials that are included inside electronic gadgets, such as metals, plastics, and glasses, specialized extraction and recycling equipment is required. It is challenging to recycle electronic trash efficiently in many areas of the globe due to the absence of appropriate recycling infrastructure in certain regions.
- Moreover, the fact that many electronic gadgets are sent to underdeveloped nations in order to be recycled adds another layer of complexity to the process of managing electronic waste. In spite of the fact that this creates job possibilities for people in these nations, it also has the potential to cause contamination of the environment and health risks due to the fact that electronic equipment are often recycled in unsanitary environments.

Overall, electronic equipment disposal in landfills, lack of knowledge, and technology shorten product lifecycles contribute to air pollution and climate change. Recycling challenges and environmental contamination risks exist as shown in Table 3.

Table 3 presents the challenges associated with sustainable e-waste management.

4.2 *Opportunities for Sustainable E-Waste Management*

- The growth of a circular economy presents a window of opportunity for the environmentally responsible treatment of electronic trash. A circular economy is an economic system that places a greater emphasis on the reusing, repairing, and recycling of resources as opposed to the process of extracting resources and disposing of them. This strategy may be implemented with regard to electrical equipment by planning their construction with longevity, repairability, and recycling potential in mind. For instance, a design that is modular may make it possible for individual

Table 3 Challenges of sustainable E-waste management

Challenge	Description	Impact
Improper disposal	Electronic waste ends up in landfills instead of being recycled	Leaks hazardous chemicals and heavy metals, contaminating soil, groundwater, and air. Harms human health, wildlife, and ecosystems
Lack of knowledge & education	People lack awareness about responsible e-waste management	Hinders efforts to divert e-waste from landfills and recycle it responsibly
Rapid technological advancement	Shorter product lifespans due to constantly evolving technology	Increased e-waste generation as functional electronics are discarded
Difficulties in E-waste recycling	Complex material composition and lack of infrastructure	Makes extracting valuable materials challenging and hinders efficient, environmentally sound recycling
E-waste shipment risks	Informal recycling methods in developing countries lack proper environmental and safety controls	Leads to air and water pollution, health problems for workers

components to be easily replaced, so increasing the devices' useful lifespans and lowering the need for brand-new goods.

- The establishment of collection and recycling programs for electronic trash is another another option for the environmentally responsible management of e-waste. To guarantee that electronic trash is managed in an acceptable manner, governments, non-governmental organizations (NGOs), and private firms may collaborate on the development of collection and recycling infrastructure. This comprises the provision of collecting sites, such as recycling centers or drop-off locations, as well as the development of suitable recycling procedures that may successfully recover valuable materials from electronic equipment. Related to this is the creation of collection points.
- In addition, the implementation of a technique known as a "circular supply chain" presents the opportunity for environmentally responsible handling of electronic trash. This strategy entails the creation of a closed-loop system in which electronic gadgets are developed, produced, and disposed of in a manner that is friendly to the environment. This would encompass the whole of a gadget's lifespan, beginning with the procurement of raw materials and ending with the disposal of the equipment once it has served its purpose.
- The implementation of "zero waste" projects presents another another possibility for the sustainable management of electronic trash. Instead of focusing only on waste management after it has already been created, programs working toward "zero waste" seek to cut down on the quantity of garbage that is generated in the first place. Strategies such as introducing product take-back programs or pushing manufacturers to make gadgets that are readily recyclable or reused might be

Table 4 Opportunities of sustainable E-waste management

Opportunity	Description	Benefit
Circular economy growth	Promotes reuse, repair, and recycling of resources	Extends product lifespans, reduces waste generation
E-waste collection & recycling programs	Provides convenient drop-off locations and ensures responsible e-waste recycling	Diverts e-waste from landfills, recovers valuable materials
Circular supply chains	Manufacturers design products for durability, repairability, and use recycled materials	Reduces environmental impact throughout a product's lifecycle
Zero-waste initiatives	Aims to eliminate waste generation in the first place	Encourages longer device lifespans, reduces need for new electronics
Advancements in recycling technologies	New technologies improve efficiency in recovering valuable materials from e-waste	Minimizes environmental impact of e-waste recycling

included in this category if we are talking about electronic equipment as an example.

- Lastly but not least, the advent of forward-thinking recycling technologies offers the possibility of environmentally responsible handling of electronic trash. For instance, recent developments in the fields of hydrometallurgy, biometallurgy, and electrochemical recycling have made it possible to efficiently recover valuable materials from electronic gadgets, which were notoriously difficult to recycle in the past. The development of these technologies has the potential to dramatically lessen the negative effects that e-waste has on the environment as well as the quantity of rubbish that is transported to landfills.

Overall, the circular economy promotes responsible electronic waste management through reuse, repair, and recycling, fostering a closed-loop system and zero waste projects as shown in Table 4.

Table 4 presents the potential benefits of sustainable e-waste management.

5 Emerging Trends and Future Directions for Sustainable Municipal Solid Waste Management

As the world moves towards a more sustainable future, the need for efficient municipal solid waste management practices has become increasingly crucial. Emerging trends and future directions in this field point towards innovative and sustainable solutions that prioritize environmental conservation and public health [49].

5.1 Developing Trends in Sustainable Municipal Solid Waste Management

The following are some emerging developments in environmentally responsible handling of municipal solid waste [1, 12, 34, 68, 87]:

- Zero Waste—The trend toward more environmentally responsible methods of waste management is giving more attention to the zero-waste idea. The objective of the zero waste movement is to produce as little trash as possible by cutting down, reusing, and recycling as much of it as possible, with the final aim being to eliminate the need for landfills entirely. Composting, recycling, and resource recovery are all examples of practices that are included in this strategy, which include the adoption of waste reduction strategies.
- Circular Economy—The circular economy is an economic model that aims to reduce or eliminate waste while maximizing the amount of time that resources are put to productive use. The concept of a circular economy is one that seeks to establish a closed loop system in which waste is utilized as a resource. This system is founded on the principles of reducing, reusing, and recycling materials.
- Decentralized Waste Management—An increasing trend in environmentally responsible trash management is the use of decentralized waste management. It includes the processing of trash on a small scale, most often on the level of a person or a community. This strategy is predicated on the idea of turning trash into a resource, according to which waste is seen as a valuable resource that has the potential to be recovered for either energy or materials.
- Waste-to-Energy—The term "waste-to-energy," or WTE for short, refers to a process that includes the transformation of trash into energy, most often by means of combustion or gasification. The electricity that is produced by WTE may be put to use in a variety of settings, including private residences, commercial establishments, and public buildings. This strategy is quickly gaining traction as a more environmentally responsible approach to garbage management.
- Smart Waste Management—The term "smart waste management" refers to a novel approach to the management of waste that makes use of various forms of technology to enhance the efficiency of garbage collection, transportation, and disposal. This strategy entails improving the effectiveness of waste management operations by the use of sensors, GPS, and data analytics in various settings.
- Public–Private Partnerships (also known as P3s)—In the realm of environmentally responsible garbage management, public–private partnerships (PPPs) are gaining popularity. The goal of public–private partnerships (PPPs) is to manage garbage in a way that is both environmentally friendly and economical. This cooperation takes place between government agencies and private firms. This strategy is gaining popularity as a means to use the skills of both the public sector and the commercial sector in order to handle complicated issues relating to waste management.

- Reducing Waste and separating it at its Sources—The elimination of trash and the separation of recyclables at their point of origin are two essential components of sustainable waste management. Source separation refers to the process of separating garbage at its original location for the purposes of recycling and composting. Waste reduction refers to the practice of minimizing the quantity of waste created by people and companies. These initiatives are gaining popularity as a means to cut down on the quantity of garbage that is delivered to landfills and to encourage more environmentally responsible methods of waste management.

5.2 *Sustainable E-Waste Management*

In this section, we discuss the possible future paths for the environmentally responsible treatment of electronic waste [21, 30, 31, 33, 53, 63, 71, 82, 86] as shown in Table 5.

Table 5 presents emerging trends in sustainable municipal solid waste management.

Table 5 Developing trends in sustainable municipal solid waste management

Trend	Description	Benefits
Zero waste	Focuses on minimizing waste generation through reduction, reuse, and recycling	Aims to eliminate landfills through composting, resource recovery, and waste reduction strategies
Circular economy	Aims to maximize resource use and minimize waste by creating closed-loop systems	Reduces environmental impact by prioritizing reuse and recycling of materials
Decentralized waste management	Processes waste at a local level, often within communities	Views waste as a resource for energy or materials, reducing transportation needs
Waste-to-energy (WTE)	Converts waste into usable energy through combustion or gasification	Provides alternative energy source and reduces reliance on landfills
Smart waste management	Utilizes technology (sensors, GPS, data analytics) to optimize waste collection, transportation, and disposal	Improves efficiency and reduces costs associated with waste management
Public–private partnerships (PPPs)	Collaboration between governments and private companies for sustainable waste management	Leverages expertise from both sectors to address complex waste management issues
Source separation & waste reduction	Separating recyclables and minimizing waste generation at the source	Diverts recyclables from landfills and encourages responsible waste habits

Here is description of emerging trends in sustainable municipal solid waste management:

- The goal of the circular economy strategy is to reduce waste while simultaneously maximizing the value of resources by ensuring that these resources are used for the longest period of time feasible. This strategy may be used for the management of electronic waste by encouraging the repair, reuse, and recycling of various electronic gadgets. This may be accomplished by passing legislation that forces manufacturers to build their goods with durability and repairability in mind, as well as by offering financial incentives to people who repair and reuse the electronic gadgets they own.
- Innovative recycling technology: At the moment, the majority of e-waste is either buried in landfills or sent to underdeveloped nations for processing, neither of which a sustainable option is. Improved recycling technologies might change this. In order to solve this problem, there is a need for innovative recycling technologies that are able to effectively extract valuable elements from e-waste while having a low impact on the surrounding environment. Pyrolysis, hydrometallurgy, and biometallurgy are a few examples of technologies that fall under this category.
- Extended Producer Responsibility (EPR) is a policy strategy that forces producers to assume responsibility for the end-of-life management of their own goods. EPR stands for the acronym "Extended Producer Responsibility." This may involve designing items so that they can be easily disassembled and recycled, creating take-back programs, and subsidizing the cost of managing electronic trash. EPR policies have been effectively adopted in a number of nations, including Japan and the European Union. As a consequence, there have been considerable advancements in the management of e-waste.
- Management of e-waste based on community participation: Management of e-waste based on community participation entails involving local communities in the collecting, sorting, and recycling of e-waste. This strategy has the potential to make job opportunities available to local communities, save expenses associated with the management of electronic trash, and raise public awareness about the significance of environmentally responsible methods of managing electronic waste.
- Management of e-waste should be digitized because the use of digital technologies, such as blockchain and the Internet of Things (IoT), has the potential to enhance the traceability and transparency of the processes involved in e-waste management. For instance, blockchain technology may be used to monitor the flow of e-waste all the way through the supply chain, and Internet of Things (IoT) sensors can offer real-time data on the production, collection, and recycling of e-waste.

6 AI Applications in Battery Lifecycle Management and Recycling Safety

AI applications are increasingly crucial in battery lifecycle management and recycling safety for the electric vehicle industry. These applications include predictive maintenance, adaptive charging strategies, performance optimization, and hazardous detection and prevention. AI-powered systems can identify damaged batteries, automate disassembly, monitor chemical processes, and perform predictive risk assessments.

Safety training and simulation can be provided through virtual reality systems, while AI-powered emergency response optimization can be achieved through real-time guidance. These AI applications not only enhance efficiency but also improve safety measures, making the entire battery lifecycle safer and more sustainable. However, careful consideration of data privacy, system reliability, and human oversight is needed [39].

6.1 AI for Battery Lifespan Prediction in EVs

Artificial Intelligence (AI) plays a crucial role in analyzing battery performance data obtained from electric vehicles (EVs). By examining vast amounts of data, AI identifies patterns that indicate battery degradation over time. Factors such as temperature variations, charging cycles, and usage patterns are taken into account. Based on these insights, AI systems can accurately predict when a battery is nearing the end of its useful life, allowing for proactive measures [4–6, 41, 43].

- Benefits: Accurate predictions provided by AI help optimize battery replacement schedules, ensuring that batteries are replaced before they fail, thus avoiding unexpected downtimes. EV manufacturers can proactively address battery issues, improving overall vehicle reliability. For users, AI insights enable them to plan for battery replacement or maintenance, ensuring their vehicles remain operational and efficient.
- Example: An AI model analyzes data from thousands of EVs and predicts when individual batteries are likely to fail based on historical patterns. This allows manufacturers to schedule timely replacements and maintenance, enhancing the longevity and performance of EVs.

6.2 AI for Enhanced Safety in Battery Recycling

AI automates the handling of hazardous materials during battery recycling processes, ensuring safer handling than relying solely on human workers. AI systems are designed to detect and respond to potential hazards in real-time, using optimization algorithms to improve overall safety.

- Benefits: AI-driven automation reduces the risk of accidents or exposure to toxic materials, providing a safer working environment for recycling staff. It ensures efficient handling of dangerous substances and improves safety protocols during the recycling process.
- Example: AI-controlled robotic arms sort and process batteries, minimizing human exposure to harmful chemicals. This automated approach enhances safety and efficiency in battery recycling facilities.

6.3 Real-Time Hazard Detection During Recycling

AI employs computer vision and machine learning to detect hazards during recycling processes. By analyzing video feeds or images from the recycling environment, AI identifies toxic materials, sharp objects, or equipment malfunctions. This system promptly alerts operators to potential hazards, allowing for immediate intervention.

- Benefits: The immediate detection and response to safety risks enhance worker safety and reduce downtime. This proactive approach minimizes the environmental impact of recycling processes by preventing accidents and ensuring the safe handling of hazardous materials.
- Example: AI detects a cracked battery casing during recycling and alerts the operator to handle it carefully, preventing potential exposure to toxic substances and ensuring the safe continuation of the recycling process.

6.4 AI-Driven Optimization for Recycling Safety

AI optimizes recycling workflows to enhance safety by integrating several key functions:

- Hazard Detection: Identifies hazardous materials.
- Automated Sorting: Reduces manual handling risks.
- Predictive Maintenance: Anticipates equipment failures.
- Real-time Monitoring: Ensures safe operating conditions.
- Workflow Optimization: Minimizes safety hazards.

Here is Benefits and Example.

- Benefits: This comprehensive approach creates a safer working environment for recycling staff, ensuring efficient processes with minimal risk. By reducing accidents and injuries, AI-driven optimization contributes to a more sustainable and secure recycling industry.

- Example: AI predicts maintenance needs for recycling machinery, preventing unexpected breakdowns. This predictive capability ensures continuous and safe operation, minimizing risks associated with equipment failures [42].

7 Potential Future Directions

To manage electronic waste effectively, it is essential to have a comprehensive and coordinated plan. This plan should cover all stages of a product's life cycle, starting from its creation to its disposal. This includes the conception, production, distribution, usage, and destruction of electronic devices. Optimising processes produce minimum wastes [51, 52, 80]. By considering the entire lifespan of a product, it is possible to find ways to reduce waste and recover valuable resources as discussed below [19, 22, 28, 60, 65, 69].

- Conception as well as Production—The phases of product design and production are two of the most important stages in the product lifecycle. Electronic waste may be reduced if product designers and manufacturers create goods that are long-lasting, capable of being repaired, and upgradeable. This may make the product last for a longer period of time and decrease the frequency with which it has to be replaced. In addition, firms may reduce waste and energy consumption by reducing the amount of energy used and using environmentally friendly materials in their manufacturing processes.
- Utilization and Dissemination—It is crucial to make sure that electronic gadgets are utilized throughout the whole of their existence, both while they are being distributed and while they are being used. Among them are the implementation of steps to promote the reuse of and repair of devices. Taking care of one's electronic gadgets and ensuring that they are always up to date are both things that consumers can do to make their products last longer.
- Disposal -Last but not least, an effective disposal method is essential to the accomplishment of a complete plan for the management of e-waste. Recycling electrical equipment in order to reclaim the valuable elements they contain is the most environmentally responsible way. This has the potential to lower the demand for virgin minerals and diminish the negative effects that mining and processing have on the environment. Unfortunately, not all materials may be recycled, and certain hazardous materials need particular disposal processes.

There are numerous advantages to be gained by implementing an approach to the management of electronic waste that is both comprehensive and coordinated. It may reduce the negative effects that the disposal of electronic waste has on the environment and people's health. This involves lowering the release of hazardous chemicals into the environment and minimizing the carbon footprint associated with the manufacture and disposal of electronic equipment. Moreover, this includes reducing the amount of hazardous compounds that are released into the environment.

Second, environmentally responsible disposal of electronic trash may support the preservation of important resources. Glass, metals, and plastics are just some of the many different kinds of materials that may be found in electronic gadgets. By recycling these materials, we can cut down on the demand for virgin resources and lessen the damage that mining and processing may do to the environment. Last but not least, an extensive plan for the treatment of electronic waste may also result in economic rewards. Recycling electronic trash may make employment opportunities available in the recycling and manufacturing industries, while also lowering the amount of space required in expensive landfills [38].

8 Conclusion

To summarize,

- The issue of electronic waste is a big problem that needs the attention of consumers, producers, and politicians alike. One of the most essential things that can be done to lessen the negative effects of electronic waste on the natural world is to recycle lithium-ion rechargeable batteries. By recycling these batteries, we can cut down on the amount of new materials that need to be mined, we can bring down the cost of producing new batteries, and we can contribute to the protection of the environment from dangerous chemicals. It is imperative that users take responsibility for their electronic gadgets and dispose of them in an appropriate manner, and that manufacturers create goods and manufacturing methods that are more environmentally friendly. Collectively, everyone must work in a direction to create a more sustainable future for our planet [47].
- The improper disposal of e-waste, which includes electronic devices like smartphones and computers, can have serious impacts on the environment and human health due to the release of toxic chemicals such as lead and mercury. To address these hazards, proper management and disposal strategies are essential, such as implementing comprehensive e-waste management systems, establishing laws and regulations, and promoting public awareness campaigns. Manufacturers and distributors of electronic devices are required to take responsibility for end-of-life management under established laws like the European Union's Waste Electrical and Electronic Equipment (WEEE) Directive and the United States' Electronic Waste Recycling Act. Companies are also offering incentives for customers to recycle their old electronic devices [46].
- The hazards of e-waste to human health and the environment are significant, but there are management solutions available to address this growing problem. Extended producer responsibility policies can play a crucial role in supporting sustainable battery recycling and management techniques. By working together, governments, businesses, and individuals can help to create a more sustainable future for electronic devices and the environment.

- Recycling lithium-ion batteries is a difficult process that calls for a large amount of technical competence as well as investment capital. On the other hand, as the demand for lithium-ion batteries continues to rise, it is taking on an increasingly significant role. Recycling batteries not only helps to lessen the negative effects that their manufacturing and disposal have on the environment, but it also provides a supply of useful resources.
- Recovering valuable elements from lithium-ion batteries is becoming increasingly important as the demand for these batteries continues to grow. Pyrometallurgy, hydrometallurgy, biometallurgy, electrochemical recycling, and mechanical recycling are all effective methods of recovering valuable materials from used batteries. The choice of method will depend on the specific battery components and the metals that need to be recovered. These methods not only reduce waste and environmental impact but also provide a source of valuable raw materials for the production of new batteries and other products.
- Environmentally responsible handling of electronic waste is absolutely necessary for the protection of natural resources and the mitigation of pollution in the natural environment. However, there are a number of obstacles that need to be overcome in order to achieve sustainable management of electronic waste. These obstacles include the incorrect disposal of electronic devices, a lack of awareness and education, the rapid advancement of technology, and an inadequate infrastructure for recycling. These issues need to be resolved by the implementation of circular economy ideas, education and awareness campaigns, and the creation of appropriate recycling infrastructure. We can build a more sustainable future for the disposal of electronic devices and gadgets used to manufacture electronic trash if we work together to accomplish sustainable e-waste management.
- The management of electronic waste offers substantial obstacles; nevertheless, there are also potential for the management of electronic waste in a sustainable manner. The creation of a circular economy, the implementation of e-waste collection and recycling programs, the adoption of a circular supply chain approach, the launch of zero-waste initiatives, and the development of innovative recycling technologies are all able to contribute to the development of a more environmentally responsible strategy for the management of electronic waste. It is vital for people, governments, and corporate groups to collaborate in order to put these ideas into action and build a future that is more sustainable for the disposal of electronic gadgets.
- The sustainable management of municipal solid waste is becoming a problem that is becoming more relevant in today's society. The emerging trends that were discussed earlier provide new potential to solve the issues that are linked with the approaches that are traditionally used for waste management. These new techniques are centered on the reduction of waste, the recovery of resources, and the promotion of environmentally sustainable behaviors. We should anticipate that there will be ongoing innovation in this sector as long as society continues to place an emphasis on environmentally responsible methods of garbage management.

- The environmentally responsible treatment of electronic waste is very necessary in order to safeguard both the natural world and the health of humans. A circular economy approach, enhanced technology for recycling, expanded producer responsibility, community-based e-waste management, and the digitization of e-waste management are some of the possible future avenues for sustainable e-waste management. We will be able to guarantee that e-waste is treated in a way that is both sustainable and responsible if we put these strategies into action.
- The significance of implementing a plan for the management of e-waste that is both all-encompassing and well-coordinated cannot be emphasized enough. A plan of this kind need to take into account each step of the product's lifespan, beginning with its development and ending with its disposal. Efficient management of electronic waste may have a beneficial effect not just on the environment but also on the economy. This is because it helps cut down on waste, preserves resources, and creates financial opportunities.

9 Future Scope of Lithium-ion Battery Usage

The future scope of Lithium-ion battery usage is very promising as they have become the most popular rechargeable batteries for a wide range of applications, from portable electronics to electric vehicles and energy storage systems. Here are some of the reasons why Lithium-ion batteries are expected to play a significant role in the future:

- Electric Vehicles (EVs): Lithium-ion batteries are becoming increasingly important for EVs as they provide high energy density, long life, and fast charging capabilities. With the increasing demand for electric cars, the demand for Lithium-ion batteries is also expected to rise [36, 64, 67, 70, 78].
- Energy Storage: Lithium-ion batteries are being used for storing energy generated from renewable sources such as solar and wind power. They provide an efficient solution for storing energy and can help in reducing dependence on fossil fuels [8, 16, 27, 29, 54, 79].
- Consumer Electronics: Lithium-ion batteries are used in a wide range of consumer electronics such as smartphones, laptops, and tablets. With the increasing demand for these devices, the demand for Lithium-ion batteries is also expected to rise [50, 84].
- Medical Devices: Lithium-ion batteries are used in medical devices such as pacemakers, insulin pumps, and hearing aids. They provide long-lasting and reliable power, making them a popular choice for medical applications [24, 89].
- Aerospace and Defense: Lithium-ion batteries are also used in aerospace and defense applications. They provide high power density and can withstand harsh environments [13, 14].

Thus Lithium-ion batteries are expected to play a crucial role in the future as they offer high energy density, long life, and fast charging capabilities. With the increasing demand for electric vehicles, renewable energy, and consumer electronics, the demand for Lithium-ion batteries is expected to rise, leading to further innovation and technological advancements in this field specially related to its e-waste [44, 45].

Authors Contribution Shalom Akhai and Alex Khang: Contributed experiments, conceptualization and methodology. Shalom Akhai: Contributed Writing and Editing. Alex Khang: Contributed Writing – Review & Editing, and Supervision.

Declarations

Conflict of Interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this chapter.

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Deep Learning (DL)-Powered Drowsiness Detection for Enhanced Driving Safety in Smart Transportation System

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Abstract Drowsiness or Fatigue is the process of impairing an individual's mental and physical abilities. It can happen as a result of not getting enough sleep, extended periods of inactivity, or other factors like medication, alcohol, or clinical settings. The main consequences of being sleepy are the potential for fatalities and injuries. It distinguishes between awake and sleepy phases by analyzing factors such as frame posture, eye movements, and facial expressions. Drowsiness can find using brain-wave patterns, particularly alpha and theta frequencies. The current process includes OpenCV and deep learning model that helps in detecting face and eyes using 68 face land marks. If a person is drowsy then we will alert a person with the help of alarm and we will send mails to their family or friends that the person is drowsy kindly alert him, otherwise accidents may occur. If we alert the drowsy person, we can get rid of accidents and we can avoid financial crisis. The further development which we would like to do is to integrate a Chatbot and that helps in keeping the person alert all the time. The current model will have good accuracy and developments to get rid of accidents. The last purpose is to beautify avenue safety and mitigate injuries due to driving force drowsiness, contributing to the general nicely-being of society.

Keywords OpenCV · Deep learning · Road safety · Facial expressions

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1 Introduction

Drowsiness is tiredness or sleepiness that could impair a person's cognitive and bodily abilities. It can occur due to a loss of sleep, lengthy intervals of state of being inactive, or other elements inclusive of medicine, alcohol, or clinical situations. Drowsiness detection is a generation that uses numerous methods and algorithms to find if a person is drowsy or not. It analyses elements including facial expressions, eye movements, and frame posture to differentiate between awake and drowsy states. Drowsiness detection is a treasured device for selling protection and stopping accidents caused by motive force fatigue [9].

Drowsiness of drivers is the primary reason for accidents globally, with estimates suggesting that 30% of all traffic accidents are caused by drowsiness. In 2016, research revealed that 100 pedestrians were either seriously injured or killed by intoxicated drivers, and additionally, 390 occupants of cars suffered the same fate. In 2020 year alone 40 kids were killed or seriously injured by drunk drivers. NHTSA or National Highway Traffic Safety Administration says that at least 1 lakh reported crashes accidents happen each year in the USA alone that are caused by drowsy drivers. If we try to decrease accidents to some extent, we will be better financially as shown in Fig. 1.

Prevention of accidents can be done using technologies such as image processing, electroencephalograph, artificial neural networks, and vocal, and vehicular techniques can be used to analyze driver drowsiness. Few models can predict if a driver is drowsy or alert, based on the data they process. One of the models is commonly used to analyze facial expressions and eye movements, while the other is suitable for processing video sequences. Such models can be trained using large datasets of video samples with labels that present drowsiness or the counterpart of alertness states to correctly recognize the driver's drowsiness or wakefulness. The manufactures of the

Fig. 1 Drowsy driving vs normal driving

drowsiness detection or prevention modes of an accident-avoidance system is one of the serious issues in this line of work.

The Drowsy Driver Detection System, has advanced the use of Python and a deep learning model, makes use of a webcam to capture video after which it extracts face and eyes the use of OpenCV with the help of 68-face-landmarks. By the usage of the Euclidean eye element ratio, it detects whether eyes are open or closed and warns the driver if eyes are closed for extra than a given time interval. The device's accuracy relies upon on detecting faces and eyes correctly, which is finished using a "Shape predictor inclusive of sixty-eight landmarks. "If the eyes are closed for a long period of time", an alarm will ring to alert the driver. The device's effectiveness in preventing accidents resulting from driving force fatigue is vast as it could discover signs and symptoms of drowsiness early enough to keep away from automobile injuries. Alerting individuals who are experiencing drowsiness can significantly reduce the occurrence of accidents, leading to improved financial outcomes and enhanced safety [8].

An IoT device like Arduino may be used to detect symptoms of drowsiness, together with adjustments in head function or eye movements. The Arduino code can then cause the LED and buzzer to alert the driving force. Additionally, the device can ship notifications to a phone or different linked gadgets, alerting passengers or other drivers within the area with the assist of WhatsApp or Gmail. This technology can help save you accidents caused by driving force fatigue and sell safer using conduct. The further development which we would like to do is to integrate an AI assistant to keep the driver engaging in the discussions and keeping them alert.

2 Literature Survey

In this study, Priyanka et al. [13] and her collaborators utilize cost-effective design of accident detection scheme by using Arduino UNO, GSM, GPS, SW420 sensor, 2-Ch relay, MQ-3 alcohol sensor. The pattern recognition software will be programmed to accept data coming from the sensors, with the Arduino hardware providing the processing unit. Nevertheless, there are the problematic financial factors, mainly from the need of sensors precision and their vulnerability to the environment affect. The problem of the false alarms is the major concern as they may require expensive emergency dispatch which will lead to the expenses via GSM mail message or call. Therefore, the combination of adequate balancing of boundaries and the use of cost-effective alternative sensors are the hallmarks of a successful implementation of such systems.

Quiroz et al. [14] propose a vision based and financially-wise approach in their research. They use HOG based face detector to extract the eye areas as well as facial landmark detector for the same task. In the process of eyeball EAR with Euclidean distance formula and comparing it against to a set threshold, the system identifies the drowsiness. The financial advantages are that it is applicable to a broad spectrum of users as well as in the placement of safety systems to the road. Nevertheless, there might be the problem of a small validation set, dependence on the benchmark PIR, constant individual variations of certain facial features or expressions which might lead to additional funding to develop this technology better.

Priyadarsini et al. [12] propounded a budget friendly system based on computer vision to support driver safety. Face detection in color video footage of drivers in the vehicle takes place first, about to be eye tracking which is intended subsequent to eye location for frame analysis of that particular driver. The driver's eye movements recorded via images captured are the basis of attention alarms that address driver fatigue issues. Utilizing the Haar facial detection, which finds faces in the grabbed photo frames, the system targets the driver's eye images for drowsiness detection. Development of alternative or additional detection means can be presumably necessary to maximize the working efficiency and efficiency of the system without making the cost significantly greater.

Mehta et al. [11] offer a financially viable technique that utilizes mobile application which can be work to detect the landmarks of the face of an individual as well as to estimate the Eye Aspect Ratio (EAR) and Eye Closure Ratio (ECR). This can be achieved by instituting buzz alerts and easily identifiable markings for drowsiness, e.g. via smart glasses. Driver fatigue levels can be significantly reduced in this manner. The overall system induced by sensors including IR, cameras and Heart rate monitors with their varied prices, makes the performance remarkable and the decision-making process more difficult at the same time. The idea of collaboration with established proprietary solutions could be a good help toward enlarging financial burdens regarding sensor integration and development, and, the consequently, less expensive implementation of innovative technologies.

Hossain et al. [3] elaborated on a practically manageable real-time approach system incorporating a Raspberry Pi, a pi Camera and an alarm buzzer that keeps everyone safe without being disruptive to the regular process like so. Such a system uses Haar classifier cascade to identify facial landmarks and thus the EAR value determines drowsiness which is about 0.25 around for a human eye. When the Earthquake Attack Resistance is below the specified level, it will stimulate warnings via IoT so that the car owner will be sent an email, meanwhile, a buzzer will be triggered. Nevertheless, using the EAR solely for the recognition of drowsiness drawbacks may result in wrongly detecting the alert state that can lead to false positive or false negative. Addressing this will require more financial commitment, including to modify the system with other sleep/drowsiness indicators which then improve the result but keep it cost-effective.

Juvale et al. [4] presented a cost-effective solution on utilizing photographs of the infrared night vision camera with their application and a specific threshold to convert these images into a binary format. The simplicity of this method is highlighted by the fact that it uses only pixel isolation type procedures. As for cluster algorithms they are used for the detection and separation of the relevant clusters; with a meanwhile utilized for the calibration and accuracy enhancement of the slope-based approach. Thus, we easily find out the cluster representing the driver's pupils. This operation less techniques note important cost-saving benefits with extensive benefits. Nonetheless, the issues of dependency and misclassifying artifacts, as well as the low rates of success still make up the major limitations. Tackling these problems shall likely result in an enhanced budget input (considering algorithm refinement and sensor technology integration) in order to keep or restore the overall system performance without sacrificing cost-effectiveness.

Roopalakshmi et al. [15] reported an economical system for sleepiness detection which worked on eye blink frequency. They used the Raspberry Pi which together with a pi camera and the buzzer which they coupled with a vibrator the first time they ran the program. Firstly, Haar cascade algorithm is utilized for identification of faces with eyes. It is then followed by a detection of blinking pattern of the eyes which indicates drowsiness. While relying on low-level eye blink data alone may glance over other significant features of driver fatigue compromising their use in detecting this state of mind. To put this limitation on the radar, further financial investments will be required to integrate secondary drowsiness indicator, which, in turn, will improve the system accuracy and still preserving cost effectiveness.

Chowdhury et al. [2] conducted a cost-conscious review of physiological sensors for assessing driver drowsiness. Vital indicators such as electrocardiography, respiratory belt, electrography, electrooculography, electromyography, galvanic skin response, skin temperature, and hybrid techniques were examined. However, the potential intrusion caused by sensor measurements on drivers should be carefully considered, balancing the financial costs with the need for accurate drowsiness detection.

Liu et al. [10] presented a low-cost fatigue detection algorithm that evaluates the features of the face. The results showed that it was that this algorithm could provide with a 97.06% of detecting the fatigue. The algorithm uses fatigue-detecting gamma responding to each eye blink, head nodding into deep sleep states, and prolonged yawning embeds it into the network. However, although this method of analyzing easy to see innovations may lapse into false leads, it is efficient tool. Addressing a budget-saving option with minimization of the error-rate is vital for the practical carry-out.

As a matter of fact, Bamidele et al. [1] had shown how DDD system can be built to serve low budget and non-invasive by utilizing the external components, for studying of face and eyes strabismus. Featured components are suitable for training and are used to classify the sleepy and not sleep-related groups. Although applying sole the measures like PERCLOS and blink frequency will lose sensitivity for wide accuracy, differentiation may be happened under variety of driving conditions.

3 Reasons for Detecting Drowsiness

Detecting drowsiness is crucial for various reasons, primarily centered on improving safety and preventing accidents in situations where alertness is paramount. Here are some key reasons for detecting drowsiness and the associated use cases:

- Accident Prevention: Drowsy driving is a leading cause of accidents, especially on highways and long stretches of roads. Detecting drowsiness helps in preventing accidents caused by impaired reaction times and decreased awareness.
- Reduction in Fatigue-Related Accidents: Fatigue-related accidents are often severe, as drivers may not be able to react quickly to unexpected situations.
- Enhancing safe roads: By alerting drivers when they are becoming drowsy, the system contributes to overall road safety by ensuring that drivers are more vigilant and responsive to their surroundings.
- Protection of Human Lives: Drowsiness detection directly impacts the protection of human lives by minimizing the risk of accidents. This is especially critical given that accidents resulting from drowsy driving can lead to serious injuries or fatalities.
- Increased Productivity in Commercial Driving: For commercial drivers, drowsiness detection is crucial to maintaining a high level of productivity. Ensuring drivers are alert and focused can lead to more efficient transportation of goods and passengers.
- Long-Distance Travel Assistance: During long-distance journeys, drivers are more susceptible to fatigue. Drowsiness detection systems can provide timely alerts, allowing drivers to take breaks, rest, or change drivers, enhancing the safety of long journeys.

4 Techniques of Detecting Drowsiness

Drowsiness is a state of reduced wakefulness and alertness, often characterized by increased difficulty in maintaining attention and responsiveness. There are several techniques and approaches for detecting drowsiness, ranging from traditional methods to more advanced technologies. Here are some common techniques used in drowsiness detection systems:

4.1 Computer Vision

Eye Tracking: Monitoring eye movements, such as blink rate, closure duration, and gaze direction. An increase in eyelid closure or a deviation in gaze may indicate drowsiness.

Facial Recognition: Analyzing facial expressions, particularly changes in facial muscle activity, to identify signs of drowsiness.

4.2 Deep Learning

Extracting Features: Using machine learning algorithms to extract relevant features from data sources, such as facial landmarks, head movements, or physiological signals.

Classification Models: There are various training models used for detecting drowsiness.

4.3 Physiological Monitoring

- Electroencephalography (EEG): Measuring brainwave activity to detect changes associated with drowsiness.
- Heart Rate Monitoring: Tracking variations in heart rate, as drowsiness can lead to a decrease in heart rate variability.

There are few main approaches used for detecting drowsiness. They are shown as in Fig. 2.

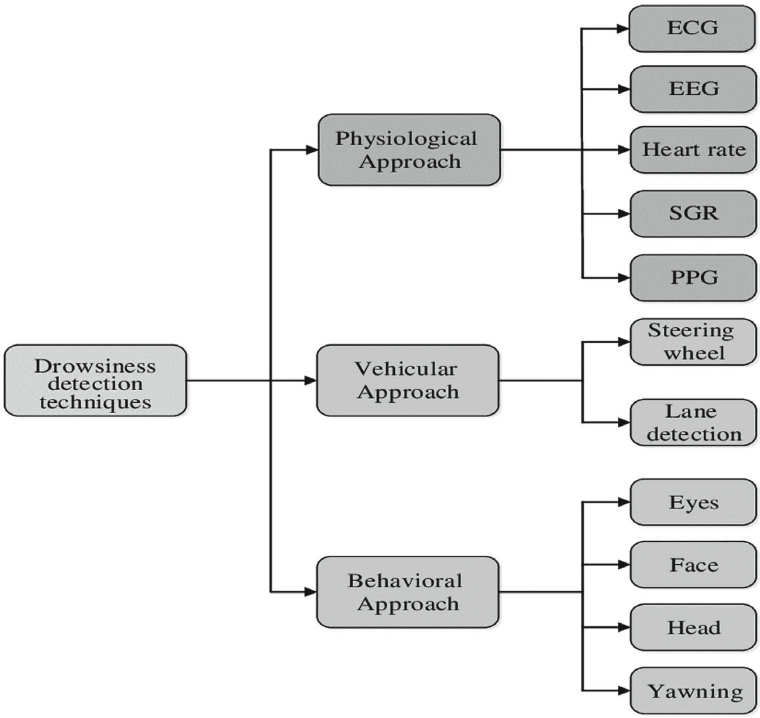

Fig. 2 Various techniques used for detecting drowsiness

5 Challenges of Drowsiness Detection

Detecting drowsiness and notifying through an alarm is a challenging task that involves various technological and human factors. Here are some reasonable challenges that a person might face while developing a drowsiness detection system:

- Accurate Detection: Achieving high accuracy in detecting drowsiness is challenging. Sleepiness can manifest in different ways, and the detection system must accurately distinguish between normal behaviour and signs of drowsiness.
- Individual Differences: People exhibit different signs of drowsiness. Factors such as age, health conditions, and personal habits can affect the accuracy of the detection system, making it challenging to create a one-size-fits-all solution.
- Real-time Processing: Drowsiness detection systems often need to operate in real-time to provide timely warnings. Achieving low-latency processing is essential, as delayed notifications may compromise safety.
- Environmental Conditions: The system should be robust enough to function in various environmental conditions, such as different lighting conditions, noise levels, and temperatures. External factors like glare or sudden changes in light can impact the accuracy of the detection algorithms.

6 Existing Methods

Drowsiness detection involves employing various technologies and methodologies to identify signs of fatigue or sleepiness in individuals. The existing systems for detecting drowsiness are Convolutional Neural Networks (CNN). Uses CNN classifier to detect drowsiness and here we pass a dataset to the CNN model as shown in Fig. 3.

The process of detecting drowsiness using CNNs involves the following steps:

- Data Collection: Collect a dataset that is labelled and it should contain images or videos of individuals in both the states that is alert and drowsy. These images

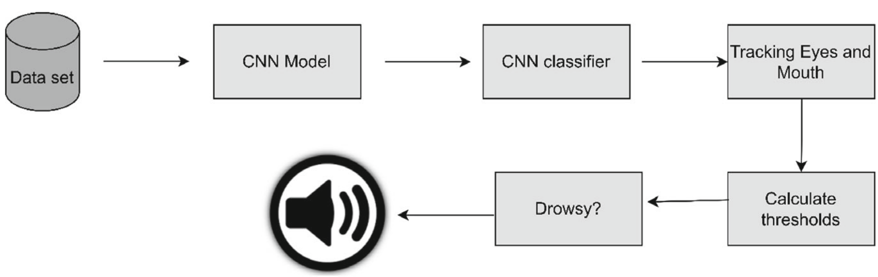

Fig. 3 Drowsiness detection using CNN model

should showcase various facial expressions and features associated with different levels of wakefulness.

- Data Preprocessing: Preprocess the images by resizing, normalizing pixel values, and augmenting the dataset to enhance model generalization. This step helps the CNN learn robust features for drowsiness detection.
- Model Architecture: Design a CNN model that takes image as input and consists of layers for extracting features and it is connected fully using layers and that is used for classification. The output layer typically has a sigmoid activation function for binary classification (alert/drowsy).
- Training: Train the CNN using the pre-processed dataset. During training, the model learns to identify pa erns and features in the images associated with drowsiness. Use an appropriate loss function (e.g., binary cross-entropy) and optimizer.
- Validation: Validate the model on a separate dataset not used during training to ensure it generalizes well to new examples. Adjust hyperparameters and architecture if needed to improve performance.
- Testing: Evaluate the trained CNN on a test set to assess its overall accuracy and performance in real-world scenarios.
- Deployment: Deploy the trained CNN in the target environment, whether it's in vehicles, workplaces, or other settings, to provide real time drowsiness detection and alerts.

Various tools used for detecting drowsiness are:

- Eye-Tracking Systems: Tools like Smart Eye and Seeing Machines use eye-tracking technology to monitor eye movements and detect signs of drowsiness. Eye-tracking systems are technologies that monitor and analyze the movements and positions of a person's eyes. These systems use various sensors and cameras to gather data on eye behavior, and they have applications in diverse fields, including human–computer interaction, gaming, market research, and drowsiness detection.
- In-Car Monitoring Systems: Many modern cars come equipped with drowsiness detection systems. For example, Mercedes-Benz uses an Assistant, which analyses driving behaviour to identify signs of drowsiness. In-Car Monitoring Systems (ICMS) are technologies designed to monitor the driver and the vehicle environment in real- me, aiming to enhance safety, prevent accidents, and improve overall driving experience.
- Smartphone Apps: Mobile applications like "An Sleep Pilot" and "Awake" use various sensors (accelerometer, gyroscope) and machine learning algorithms to detect signs of drowsiness and alert users. Several smartphone apps are designed to help detect drowsiness and promote driver safety. These apps typically use a combination of sensors, including accelerometers and gyroscopes, to analyze driving behavior and detect signs of fatigue.

7 Alert Guard

7.1 Process of Drowsiness

One of the key elements endangering road safety and contributing to injuries and accidents is exhaustion or drowsiness. The unconscious shift from wakefulness to sleep causes a lack of alertness, which contributes to a number of catastrophic car accidents. By promptly notifying individuals experiencing drowsiness, we can effectively mitigate the risk of accidents, resulting in better financial stability and heightened safety measures as shown in Fig. 4.

Here is description of process of drowsiness:

- Face Detection: Locate and identify the face in an image or video. Common techniques include Haar cascades, deep learning-based methods, or a combination of both.
- Eye Region Extraction: Once the face is detected, the next step is to isolate the specific regions corresponding to the eyes. This step is crucial for accurate eye blink analysis and can be done using predefined facial landmarks or other region-of-interest techniques.
- Eye Blink Detection: Involves monitoring the eye regions over time to identify instances of blinking. Various methods can be employed, such as tracking changes in eye region size, detecting abrupt closure/opening, or using machine learning models trained for blink detection.
- Eye Blink Classification: After detecting blinks, it may be useful to classify them into different types or categories. Classification can be based on factors like blink duration, frequency, or patterns, and machine learning models can be trained for this purpose.

These steps are often part of computer vision applications, human–computer interaction, or physiological monitoring systems.

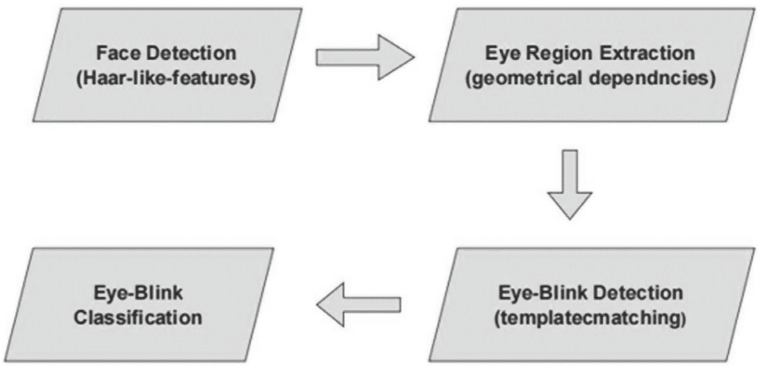

Fig. 4 Process of drowsiness

The whole process starts when the system is initiated. It uses a webcam to scan the user's face and relies on libraries like dlib and OpenCV to recognize the face. Once the face is found, the system uses 68 face landmarks to accurately locate the eyes and then proceeds to identify them for deeper examination. The subsequent step involves calculating the eye aspect ratio.

If the eye aspect ratio value is greater than 0.25, it means the person is not drowsy. If the eye aspect ratio is less than or equal to 0.25, it means the person is drowsy. This threshold approach helps in the determination of drowsiness, making it a binary decision based on the EAR value.

The system compares the predefined value that is 0.25. If the EAR exceeds 0.25, the system continues monitoring without triggering alerts. However, if the EAR is equal to or less than 0.25, the system proceeds to activate an Arduino board, triggering LED lights and a buzzer for immediate alerts to the driver. Additionally, the system sends notifications to connected devices, such as smartphones, through communication protocols like Wi-Fi or Bluetooth.

For deployment, the system can be integrated into vehicles or used as a standalone device for personal applications, with clear instructions provided for installation and usage. Regular updates to both software and hardware components are emphasized, addressing bugs, security vulnerabilities, and performance issues. By prioritizing continuous improvement and ensuring accuracy through rigorous testing, this aims to develop a reliable IoT device for detecting driver drowsiness, contributing significantly to road safety [5].

7.2 Scope of Detecting Drowsiness

The scope of detecting drowsiness and alarm notification is broad, with applications across various industries and contexts. Here are some areas where drowsiness detection and alarm notification systems can have a significant impact:

- Transportation Industry: Drowsiness detection in cars can prevent accidents by alerting drivers when they show signs of fatigue.
- Aviation Industry: Pilots and aircrew can use drowsiness detection systems to maintain alertness during long flights, improving overall aviation safety.
- Rail Transportation: Train operators can benefit from drowsiness detection to ensure vigilance and prevent accidents in rail transportation.
- Workplace Safety: Industries where employees operate heavy machinery or perform critical tasks can use drowsiness detection to prevent accidents caused by fatigue.
- Healthcare: Medical professionals on long shifts can benefit from drowsiness detection to ensure optimal alertness during patient care [7].

7.3 Hybrid Architecture

The Fig. 5 gives the visualization of hybrid architecture for detecting drowsiness and notifying through an alarm and sending messages to their owned ones if a person is drowsy.

Here is architecture of system for Driver Drowsiness Notification:

7.3.1 Imports

- cv2: OpenCV library for computer vision tasks.
- NumPy: Numerical operations library for array manipulations.
- dlib: Library for machine learning, particularly used here for face detection and shape prediction.
- imutils.face_utils: Utility functions for working with facial landmarks.
- serial: Module for serial communication (not used in this code).
- pywhatkit: Module for sending messages using WhatsApp (commented out in this code).
- me: Module for handling me-related operations.
- smtplib: Simple Mail Transfer Protocol library for sending emails.

7.3.2 Capture Setup

- cv2.VideoCapture(0): Initializes the camera capture.

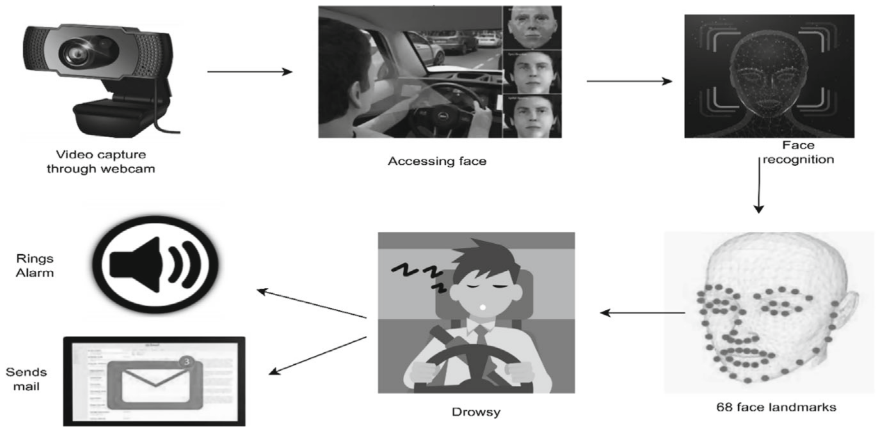

Fig. 5 Alert guard of a system for driver drowsiness notification via alarm and email

7.3.3 Dlib Face Detection Setup

- dlib.get_frontal_face_detector(): Initializes a face detector.
- dlib.shape_predictor("shape_predictor_68_face_landmarks.dat"): Helps in loading a pre-trained model for predicting facial landmarks.

7.3.4 Blinking Functions on

- Compute (ptA, ptB): Calculates the Euclidean distance between two points.
- Blinked (a, b, c, d, e, f): Computes the blink ratio based on the distances between facial landmarks.

7.3.5 Main Loop

- Captures frames from the camera in a loop.
- Detects faces in the frame and draws rectangles around them.
- Computes facial landmarks and uses the blinked function to determine blink status.

If the person is detected as drowsy or sleeping for a certain dura on, it sends an email using SMTP.

- Facial landmarks are visualized on the frame.
- The frame is displayed, and the loop continues un l the 'Esc' key is pressed.

7.4 Implementation of Drowsiness Detection System

7.4.1 Dataset Used

To implement a reliable drowsiness detection system, a comprehensive dataset containing images or video frames of drivers is used. Each frame includes 68 facial landmark points, which are crucial for analyzing the driver's facial expressions, eye movements, and head pose. By leveraging these features, the system can accurately identify signs of drowsiness. This dataset is vital for training and validating the detection algorithm to ensure its effectiveness in real-world scenarios.

- Dataset Size: 97,358 KB
- File Type: DAT file
- Number of Landmarks: 68
- Purpose: Detecting face and eyes in a live video stream to monitor drowsiness

7.4.2 Implementation

- Capture Video Stream: The process begins with initializing the camera to capture live video frames using OpenCV. The video capture is handled by creating a ‘VideoCapture‘ object, which allows the system to continuously capture frames from the camera for further processing.
- Detect Faces: For face detection, the ‘dlib‘ library is employed. A face detector object is created using the ‘get_frontal_face_detector‘ function, which detects faces in the grayscale video frames. Detected faces are stored as bounding boxes, which are used in the next steps to locate facial landmarks.
- Detect Facial Landmarks: A pre-trained facial landmark detector model from ‘dlib‘ is loaded to detect the 68 landmark points on the detected faces. These points are essential for analyzing specific facial features, such as the eyes, which are crucial for monitoring eye movements.
- Compute Eye Aspect Ratio (EAR): The Eye Aspect Ratio (EAR) is computed to measure eye openness. The EAR is calculated using the Euclidean distances between specific landmark points of the eyes. The formula to compute EAR is $(A + B)/(2.0 * C)$, where A and B are the distances between vertical eye landmarks and C is the distance between horizontal eye landmarks. The EAR value helps in determining whether the eyes are closed, indicating potential drowsiness.
- Detect Drowsiness: Thresholds for EAR and the number of consecutive frames with low EAR are defined. If the EAR falls below the threshold for a specified number of consecutive frames, it indicates drowsiness. A counter is incremented each time the EAR is below the threshold. If the counter exceeds the predefined number of consecutive frames, drowsiness is detected.
- Send Alert: When drowsiness is detected, an alert is sent via email to notify relevant parties. This alert helps in timely intervention, preventing potential accidents due to driver fatigue. The email includes information about the detected drowsiness, ensuring that appropriate action can be taken promptly.

8 Real-World Application for Green Smart Transportation

In a green smart transportation system, this drowsiness detection implementation plays a critical role in enhancing safety and efficiency. By ensuring drivers are alert, the system reduces the risk of accidents, contributing to smoother traffic flow and lower emissions from potential collisions and traffic disruptions. Moreover, integrating such technology aligns with the goals of smart transportation networks by leveraging advanced monitoring and alert mechanisms to maintain high safety standards. This promotes a sustainable and secure transportation environment, benefiting both the drivers and the broader community [6].

9 Discussions and Results

The drowsiness detection system operates by analyzing live video feed from a webcam, alerting the driver and registered contacts upon detecting drowsiness. Using 68 facial landmarks detected by dlib, OpenCV, and Python, it tracks facial features to identify closed eyes. A buzzer and email alerts are triggered upon detection of drowsiness, ensuring timely intervention. Additionally, an LCD display informs passengers of the driver's condition, while a red light alerts nearby vehicles. If the driver does not respond promptly, continuous alarm signals and email notifications are activated to mitigate potential risks. The system's effectiveness is highlighted through a comparison with other techniques, demonstrating higher accuracy and potential for future enhancements. This comprehensive solution aims to prevent accidents and save lives, making it valuable for both current and future generations as shown in Fig. 6.

Alert Guard have higher accuracy and further developments as well. Hence this model will be more helpful for the current as well as future generation and also helps in saving lot of lives and can get rid of accidents. In Fig. 7, the graph shows the comparison between various methods like CNN, HMM and SVM.

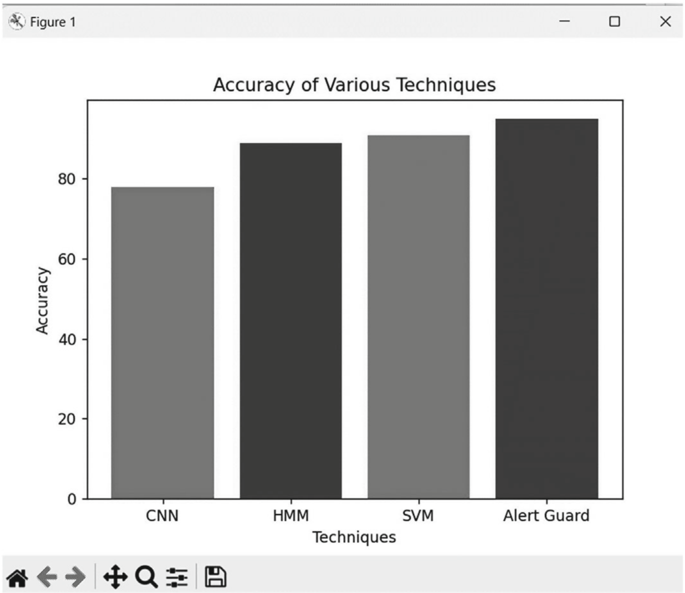

Fig. 6 Performance analysis of various techniques

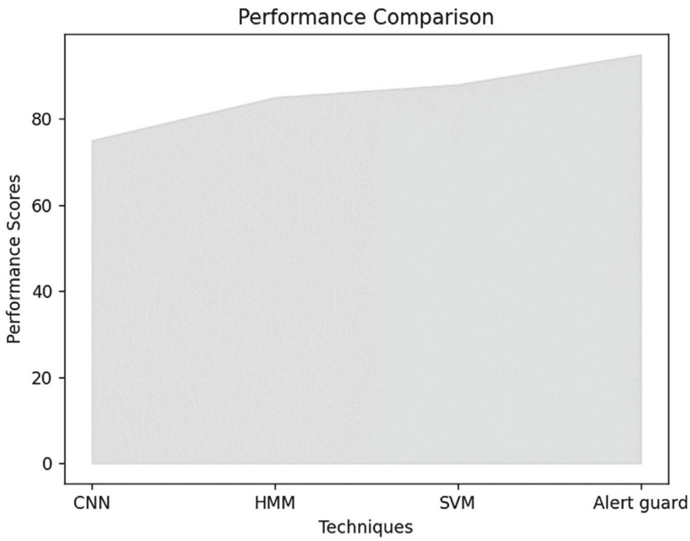

Fig. 7 Performance comparison of various techniques

10 Conclusion and Research Directions

Alert Guard an ensemble based deep learning algorithm named Alert Guard is developed for detecting drowsiness and notifying through an Alarm using live webcam. Here a live webcam is used instead of training a predefined dataset to the model. The results show that the performance of the model in detecting the driver drowsiness as compared to other models. These helps us in controlling accidents and keeping us to be financially stable. Performance metrics were employed to measure and compare the models' efficiency. In further the current algorithm can be integrated with the Chatbot to converse with the person to avoid drowsiness and we can also intimate to the nearby vehicles by establishing V2V communication.

The sensor is also used to detect if a person has taken alcohol. In future it can be implemented in schools and colleges to alert the lecturers to find if the students are sleepy. The vibration sensor and GPS is used for detecting accidents and the location is sent through an Email. We can also further extend the project by integrating the virtual assistants or AI Chatbots to engage a person in conversation and reduce the sleepiness of a driver.

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Fuzzy Logic and Integrated Deep Learning (DL) Solution for Precise Vehicle Detection and Classification

Khushwant Singh, Mohit Yadav, Yudhvir Singh, Daksh Khurana, and Binesh Kumar

Abstract In the smart transportation system, vehicle detection is crucial. Additionally, it has a big impact on a lot of other things including advanced driver assistance systems, fleet management, asset tracking, surveillance and security, autonomous cars and robotics, and traffic monitoring and management. Contributes significantly to automation, safety, security, and traffic efficiency, among other facets of contemporary life. This project's main goal is to investigate the creation and use of neural network models for the prediction of vehicle models and the detection of cars in photos. Several common network models, including CNN (Convolutional Neural Network Features), the Classification Model, and Fuzzy Logic, have been used in these training and classification trials. This approach aims to provide a more accurate vehicle classification.

Keywords Convolution neural network · Fuzzy logic · Adam optimizer · Automation

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1 Introduction

In these contemporary days, vehicle usage has increased drastically, leading to growing concerns about safety, traffic, etc. To address and solve this issue urban road tracking, traffic cameras, and safety systems were developed as more powerful which was automated, and intelligent and it also gave the information. Vehicle model classification is a crucial aspect in this field, and the key is to find the effective extract and describe the type of the vehicle, establish a robust classification model, and handle the real-time processing to find the large- scale images [13]. However, the real world or already existing problems do not cope with the influence of various factors, it did not classify the vehicle more accurately because of affecting environmental factors limiting their applicability. To address the issue a more precise way of identification and classification model was proposed. This model will study and learn the model with more number of vehicle model principles and liable label features [15].

The car is identified and classified in this study using a deep learning model called Convolutional Neural Network (CNN). A model called a convolutional neural network uses numerous layers of convolutional layers and filters to extract data from images. Each convolutional layer is linked to the activation function, and it is the convolutional layer that does the extraction. Those activation functions will introduce the nonlinearity in the data. Reducing the input's dimension through layer pooling in the CNN architecture will aid in lowering the model's complexity. The last layer, a dense layer, is in charge of determining how much each piece of data contributes to the final result [14].

The architecture is integrated with a fuzzy model to accurately classify the vehicle model. Fuzzy logic is in charge of multivalued logic, which addresses imprecision and uncertainty. The CNN's output is sent to the fuzzy layer. The classified feature map will be transformed into fuzzy sets via the fuzzification layer. All sets with a membership function defining the extent to which each element belongs to the set are called fuzzy sets.

Next, the accuracy metrics are computed for the fuzzy model's output, which will be used to illustrate the model's performance. Metrics such as the F1 score, precision, recall, specificity, and confusion matrix were employed to evaluate the model's predictive performance. Following that, the output is examined to verify the model's output [3].

2 Literature Review

Many methods for the detection and categorization of vehicles using different deep-learning models have been proposed in recent years. Convolutional neural networks, or CNNs, are the models of choice for image-based categorization according to numerous experts. After multiple iterations, the CNN model will attempt to extract features from the images; these iterations will correspond to the original image.

Convolutional neural networks, or CNNs, are useful in a variety of domains where picture classification is important. This field was the focus of many researchers, and some references were.

Refs	Publication Year	Algorithm	Summary	Future work
[1]	2021 IEEE	CNN, Softmax Activation	In this paper, the author used the shallow Convolutional Neural Network to extract the feature from the images that was generated from the input. After the CNN the Softmax Activation is used to classify them	In future, with more number of input datasets and inclusion of multiple models will increase the accuracy of detection
[2]	2018 IEEE	CNN	In this paper, the author aim to create an improved deep learning method of vehicle type detection from surveillance images and the author proposed the system based on the CNN	The validation of the proposed system of this paper was worked fine with the public datasets however we can maintain the accuracy and work on improving it
[3]	2019 IEEE	R-CNN R-FCN	In this paper, the author compares the five different mainstream model of deep learning for detecting vehicle through input images, namely faster model R-FCN, R-CNN, SSD, RetinaNet, YOLOv3 on the basis of the KITTI Datasets and analyze the obtained result	In this paper, the author's main challenge is that balancing the real-time performance and accuracy Author says that the in-depth research is needed to solving this challenge

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Refs	Publication Year	Algorithm	Summary	Future work
[4]	2021	CNN	The author try to build the analysis of the traditional Haar-like vehicle recognition algorithm, a vehicle recognition algorithm based on a convolutional neural network with fused edge features (FE-CNN) is proposed	For complex natural environment the algorithm's accuracy is still unstable. In the future, an in-depth will be conducted to improve the algorithm‟s speed, precision, and stability,
[5]	2021	CNN R-CNN	The author assess the performance of three state-of-the-art CNN algorithms, namely Faster R-CNN, which is the most popular region-based algorithm	As future work, the author intend to extend their accuracy to the newly released Efficient detector and larger datasets of a input images
[6]	2018 Science Direct	CNN, Faster RCNN, RPN	In this paper, the author applied the Faster RCNN, improved the RPN networks, Convolutional Neural Network of deep learning on object classification algorithm	In this article the author only classified for three types of car. In future he may increase the number of classifications
[7]	2020 IEEE	R-CNN, Normalization, COST Function	In this paper, the vehicle detection by Faster R- CNN algorithm is tested and optimized by the method of model pruning and quantization	The future work of the author is that accuracy of the algorithm needs to be further improved
[8]	2002 IEEE	CNN	Here the author tries to build the analysis of the traditional vehicle recognition algorithm based on a convolutional neural network is proposed	In future work, the author need to work on increasing accuracy to the newly released Efficient and larger datasets of a input images

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Refs	Publication Year	Algorithm	Summary	Future work
[9]	2020	SVM, R-CNN	In this author, the proposed an implementation without retraining the deep learning models for object detection under different weather conditions	In future the author tend to more time and energy to the creation of a better correction method which is general and adaptive method than this
[10]	2019	CNN	In this paper, the author proposes a vision-based vehicle detection. 57,290 high definition highway vehicle dataset instances in 11,129 images is used in this study	According to the author the input image, the cameras where mounted to obtain the internal and external of the vehicle to classify more
[11]	2022 IEEE	CNN	In this paper, overview of deep learning for perception and its decision-making process based on images and LiDAR point clouds is discussed	Here the author proposed the ensemble learning model acts as a future direction in segmentation, and hybrid learning is stated for future research on object detection
[12]	2022	Faster R-CNN, single-short detector	In this paper, the author proposed a system which can detect in two steps: vehicle detection and counting. Here he labelled the vehicle in six different labelled classes for classification	According to the author, the surveillance cameras where mounted in certain angle to get the good vehicle images to classify more

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Refs	Publication Year	Algorithm	Summary	Future work
[13]	2019 IEEE	CNN, R-FCN, R-CNN	In this paper, the authors proposed the integration additional prediction layers into conventional Yolo-v3 using spatial pyramid pooling to complement the detection accuracy of the vehicle in large scale	As future work, the author intend to extend their accuracy to the newly released Efficient detector and larger datasets of a input images
[14]	2019 MDPI	Random Forest (RF), Support Vector Machine (SVM)	In this paper, the author used the realistic dataset to test and evaluate the proposed vehicle make and model Recognition system (VMMR)	In future the author says that Dimensionality reduction techniques can be used to reduce this number. Deep learning models can be explored more with larger datasets
[15]	2019	KNN	Here the author proposed that a set of data extracted from the front view of a vehicle is used to determine the vehicle type with higher accuracy	In the future the author says that to attain the performance of other forms of single-class classifier on this problem

3 Methodology

The proposed work of identifying and classification of vehicles is done through the convolutional neural network (CNN) and fuzzy system integrated in it. This system integration will help to identify and classify the model with more precise output as shown in Fig. 1. The CNN will try to extract the features from the images and the fuzzy system will try to identify the uncertainty and imprecision in the data. Below is the methodology of the study, which includes data collection and pre-processing [8].

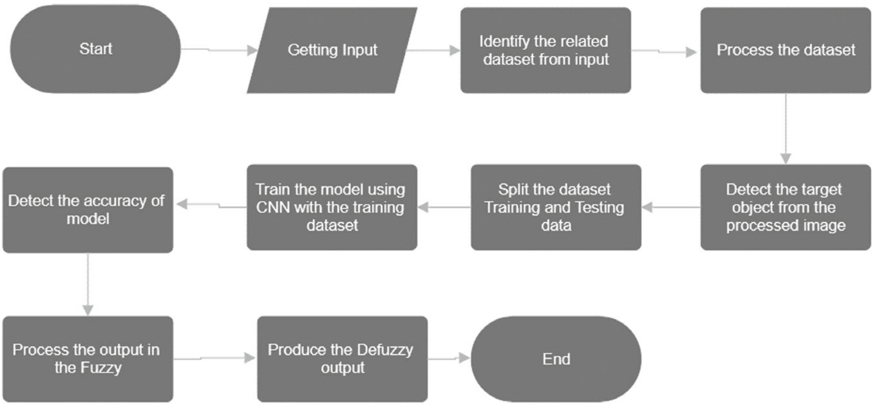

Fig. 1 The workflow of the CNN model and Fuzzy system integration

3.1 Data Collection and Pre-processing

Obtain another dataset of annotated photos with different kinds of cars taken from different angles and in diverse environments [16]. A variety of vehicle types, including ambulances, cars, trucks, autos, buses, and more, are included in the dataset. The process of identifying and fixing erroneous or corrupt records from a dataset is known as pre-processing [9].

The forms and size of the photos are incorrect. To ensure uninterrupted model operation, it should be adjusted to the same size and dimensions. The dataset is normalized in order to standardize the feature values within it [4]. The dataset will be brought into a similar scale through normalizing, convolutional neural network (CNN) and the Fuzzy system. The output is measured with the metrices like F1 score, accuracy, precision, recall as shown in Fig. 2.

3.2 Convolution Neural Network

In vehicle detection, the Convolution neural network (CNN) plays an important role. The pre-processed dataset is passed as a input for the CNN model. In this study, CNN is used to extract the features from the images and it will classify them accordingly [1]. Like in common CNN, here in the problem, all three layers below were used.

- Convolution layer
- Pooling layer
- Fully connected layer

In CNN, the model will undergo the training process with the various images and try to get the difference of features from it and it will classify the images with the

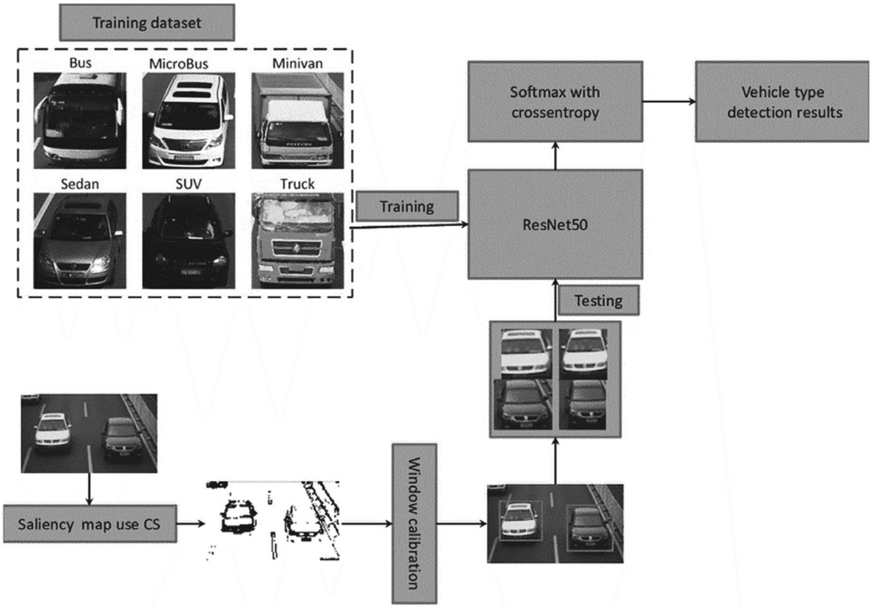

Fig. 2 Vehicle prediction model [10]

extracted classification. Likewise, here is the image which we need to pass the image of the vehicle which is to be classified as the input. The classification model will try to classify the image by undergoing different types of features which was extracted. For that, we need to convert the images into the data. The image is basically three-dimensional data, where in every pixel it will contain the intensity or the contribution that was provided to the images. For e.g., if a pixel has a high value (255,255,255) then the contribution of the pixel is high in the image.

The Convolution layer in the Convolution neural network (CNN) is responsible for the extraction of different features from the distinguishing vehicle images. The features will include the size of the vehicle, color, headlight size, shape of the head, etc..,. Basically, it will identify the contours in the image [2]. Contours means the curve or shape that joins all the boundaries and edges in the image. The convolution layer has many layers of filters which were applied to the input images so that each layer will give different varieties of features. The output of each filter was called a feature map, which holds the strength or contribution of that pixel on that image.

The pooling layers of a Convolution neural network (CNN) for a vehicle model classification are responsible for reducing the dimension of the obtained feature maps of the feature from the output of the convolution layer. In pooling there are some methods to identify and extract the features,

- Max pooling
- Average pooling

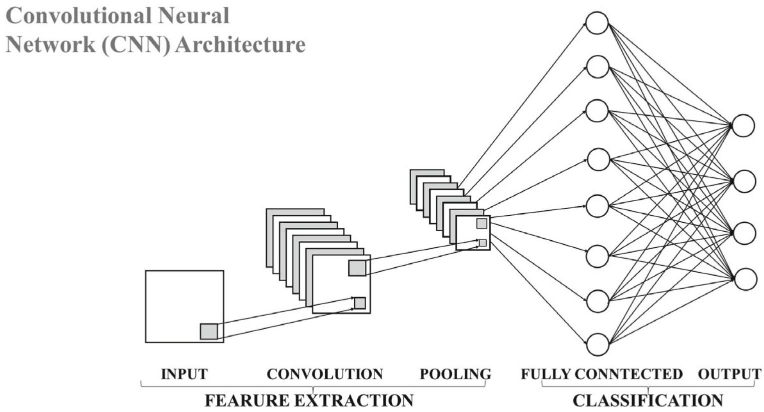

Fig. 3 Basic structure of the convolution neural network

With the help of the pooling methods, the model will get the highly contributed area of each area of the input, so that it will effectively reduce the size of the feature map. In the pooling layer, it extracts some useful features from the extracted feature map which will highly contribute to the classification.

For the final classification of the model, the vehicle model classification in a Convolution neural network (CNN) is fully connected layers, which are responsible for the final output classification or prediction of the vehicle as shown in Fig. 3.

As a rule, they will come after the pooling layers, which will take the input as the extracted feature maps of the pooling layer. Here they connect all of the neurons in one layer to all of the neurons in the next layer [12]. These fully connected layers will take the reduced feature map from the pooling layers and it will combine and it will undergo many probability distributions to find the possibility of a vehicle. Then the model with the highest probability will be chosen as the final classification as shown in Fig. 4.

In cases where the model has errors or losses, backpropagation is employed. The model's result is used to calculate the loss function. The adaptive moment estimation in backpropagation (ADAM). The cross-entropy loss function is used by the model, and backpropagation is carried out if the function is triggered. Calculating the differentiation of the output based on the output obtained with the output of the previous iteration is how backpropagation is carried out as shown in Fig. 5.

3.3 Fuzzy

Fuzzy is the multivalued logic that deals with the uncertainty and imprecision. It will mainly focus on the degree or value of the truth rather than going by true or false. Typical Fuzzy logic contains three layers,

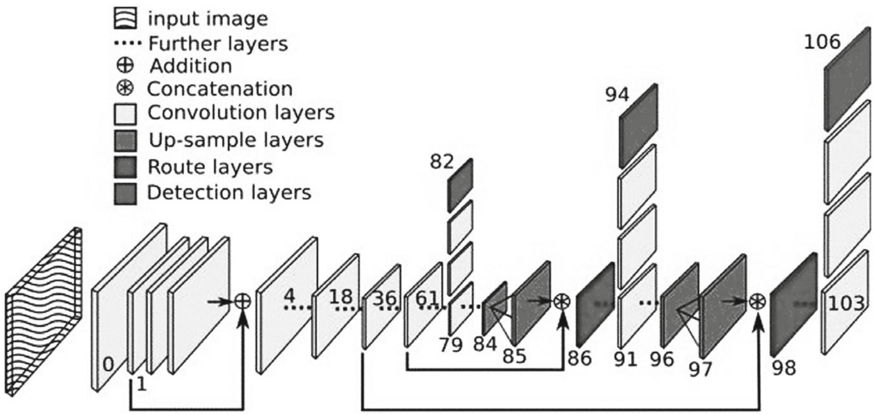

Fig. 4 Vehicle detection and tracking in adverse weather using a deep learning framework

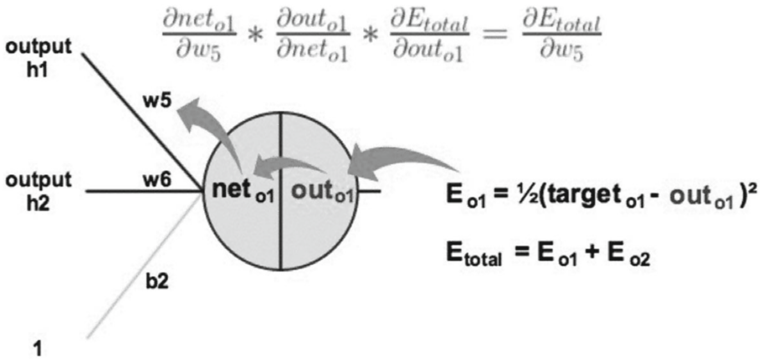

Fig. 5 Backpropagation equation [11]

- Fuzzification
- Inference
- Defuzzification

In the Fuzzification stage, the output of the fully connected layers of the Convolution neural network (CNN) is passed as an input. The Fuzzification layer will convert the classified feature map into fuzzy sets. Fuzzy sets are nothing but sets that have a membership function that defines the degree to which each element belongs to the set. For example, the output of the Convolution neural network (CNN) will provide the probability distribution of the classification. In fuzzy this could be converted into fuzzy sets by defining the membership functions that map the probability to the degrees of membership.

The inference stage of the Fuzzy model uses the fuzzy sets to make the inferences about the output. The inference layer contains many fuzzy rules. These fuzzy rules are nothing but the scaling of the probability for different ranges in the fuzzy sets. For example, Rule 1—if the CNN output is"low" then it was the "A" or it was the different letters.

The defuzzification stage deals with the output of the inference stage and converts it back into the crisp values. These will be done using a defuzzification method. These are the techniques for selecting the most appropriate value from the fuzzy set.

4 Conclusion

In conclusion, for vehicle detection and classification, the combo of the Convolution neural network and the Fuzzy logic effectively classified the images with more accurate values. With the help of the CNN the model has processed the various aspects of feature maps in the videos and images, and with the help of the Fuzzy the model has processed the uncertainty in the input data. This combination has been proved from the above output it shows more accuracy and robustness in vehicle detection, and real-time performances of vehicle detection systems, making them a valuable model for detection and classification [7].

Authors Contribution Khushwant Singh: Contributed experiments, conceptualization and methodology. Khushwant Singh, Mohit Yadav, Yudhvir Singh: Contributed Writing and Editing. Khushwant Singh: Contributed Writing – Review & Editing, and Supervision.

Declarations

Conflict of Interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this chapter.

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Automatic Number Plate Recognition for Motorcyclists Riding Without Helmet

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Abstract This study focuses on the crucial problem of motorcycle riders circumventing helmet restrictions by introducing an Automatic Number Plate Recognition (ANPR) system specifically designed to detect and penalize riders who do not comply with the regulations. The system employs sophisticated computer vision algorithms to autonomously identify motorcyclists who are not wearing helmets by analyzing photos or video streams in real-time. The proposed ANPR system utilizes advanced image processing algorithms and deep learning approaches to improve law enforcement skills in enforcing road safety and ensuring compliance with helmet laws. The process entails creating a strong Automatic Number Plate Recognition (ANPR) model that is trained on a broad dataset of motorbike riders in different settings. The technology not only identifies license plates but also utilizes advanced helmet detection techniques to identify motorcyclists who do not comply with regulations. The suggested approach aims to enhance public safety efforts by automating the enforcement of helmet rules, thereby decreasing the occurrence of head injuries among motorcycle riders. By employing this ground-breaking method, law enforcement organizations may effectively oversee and uphold adherence to helmet regulations, cultivating a more secure road atmosphere for both motorcyclists and the general populace.

Keywords Helmet detection · Number plate recognition · Computer vision · Deep learning · Convolutional neural networks · YOLOV8 · EasyOCR

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1 Introduction

According to the World Health Organization, over 1.3 million people die in road traffic accidents every year. Human error or poor driving behavior is the primary factor contributing to road accidents. A significant proportion of these accidents pertain to motorcycles. These incidents are a primary contributor to lethal injuries in less developed nations [24]. Motorcycle riders can decrease the likelihood of head injuries and deaths by wearing helmets. Enforcing the use of helmets is an effective technique to reduce the number of deaths and fatalities. Several nations depend on traffic police officials to ensure adherence to traffic regulations through direct observation of drivers on a regular basis. Deploying a large number of police officers nationwide to ensure widespread and rigorous enforcement is typically costly and presents logistical difficulties [17].

Motorcycles are a significant mode of mobility that greatly contributes to traffic accidents. Motorcyclists face a greater susceptibility to accidents in comparison to car drivers [4]. This can be mainly attributed to the innate susceptibility of motorcycle riders and the higher level of hazards they encounter. Globally, motorbikes account for 28% of fatalities resulting from traffic accidents, and this percentage is steadily rising on an annual basis [26]. The travel velocity, minimum following distance, forward motion, and sideways motion of motorbikes are distinctly different from those of other vehicles [10].

Motorcycle usage is experiencing a global surge, particularly in low- and middle-income nations. These factors include the cheaper cost, improved fuel efficiency, and compact size of the vehicle, which make it suitable for parking in congested areas. Additionally, the rapid economic growth of countries and the prevalence of road congestion contribute to its popularity. In Malaysia, motorcycles account for 47% of the total registered vehicles, indicating a significant increase in their utilization. The increase in popularity of motorbikes can be attributed to their cost-effectiveness and user-friendly nature.

Motorcycles have a disproportionately high fatality rate compared to other forms of transportation, mostly due to their inherent fragility and increased exposure to risks faced by motorbike riders. Riders are more vulnerable to injuries due to a lack of adequate protection, with helmets and clothing being the only available protective gear. Furthermore, motorcycles are more susceptible to accidents because of their lightweight construction, which allows them to be faster than most vehicles. Unlike cars, motorbike riders are not contained in a metal structure and must rely on only two wheels for balance.

Motorcycle helmet laws are crucial in the domain of road safety, as they play a critical role in preventing severe head injuries and fatalities [23]. Nevertheless, the circumvention of these restrictions continues to be an ongoing obstacle, especially among motorcyclists who choose not to wear helmets [6]. In order to tackle this crucial problem, this study presents a novel method that uses Automatic Number Plate Recognition (ANPR) technology designed expressly for the purpose of identifying and punishing motorcycle riders who do not comply with regulations. The suggested method seeks to improve law enforcement capabilities by using powerful computer vision and deep learning techniques to identify and enforce helmet rules in real-time.

Given the high number of motorcyclists on the roads and the serious repercussions of not following helmet requirements, it is crucial to implement a proactive and technologically sophisticated solution. The ANPR system described in this study not only emphasizes license plate recognition but also expands its functionalities to encompass the automated identification of motorcyclists who are not wearing helmets. This strategy is consistent with the overarching objectives of advocating for road safety, mitigating head injuries, and encouraging adherence to helmet rules. The proposed ANPR system aims to greatly improve public safety on roadways by combining advanced technology and strict regulatory enforcement [18].

2 Problem Statement

Within the domain of road safety, traditional approaches to implementing helmet laws are inadequate for delivering an optimal user experience. Conventional enforcement methods depend on human interventions and do not have the capability to smoothly integrate with digital surroundings [25]. Given these constraints, there is a pressing demand for a novel solution: automatic number plate detection for those not wearing helmets, using the capabilities of YOLOv8 and EasyOCR.

Existing technologies frequently encounter difficulties in comprehending intricate settings, hence restricting the dynamic interplay between automated systems and real-life circumstances. In order to tackle this issue, the suggested approach seeks to rethink the methodology of helmet enforcement by implementing a complex framework that integrates the effectiveness of YOLOv8 for object detection and EasyOCR for automatic number plate identification.

2.1 Approaches and Algorithms

2.1.1 Conventional Approaches

- Color-based detection involves the utilization of color-based segmentation to distinguish and isolate regions in images that do not contain helmets.
- Contour analysis is a method utilized to discern the boundaries of objects, thereby assisting in the identification of individuals who are not wearing helmets.

2.1.2 Deep Learning Methodologies

- The objective is to apply the YOLOv8 (You Only Look Once) model to real-time object detection, with a specific focus on individuals who are not wearing helmets.

- The integration of EasyOCR for optical character recognition enables the precise identification and extraction of license plates from images of vehicles.

2.2 Significance

The Automatic Number Plate Detection Systems significance resides in its capacity to revolutionize the enforcement of helmet usage and redefine the way in which automated systems contribute to road safety. The salient aspects of importance encompass:

- Enforcement Assurances: The system facilitates the automated detection of individuals lacking helmets via real-time object recognition, thereby making a valuable contribution to the enforcement of road safety regulations.
- Efficient Identification Procedures: By enabling law enforcement agencies to detect individuals without helmets in a timely and dependable manner, YOLOv8 guarantees precise and effective detection.
- Automated Document Management: EasyOCR enables the automated extraction of license plates, which assists in the maintenance of records pertaining to individuals who violate helmet regulations.

2.3 Challenges

- Succeeding with Precision in Complex Scenarios: Analyzing the difficulty of preserving precision in intricate traffic situations involving diverse helmet designs, lighting conditions, and vehicle types.
- Real-Time Optimization of Processing: By optimizing the system for real-time processing, law enforcement can ensure that interventions occur promptly and efficiently, especially in areas with heavy foot traffic.
- Compatibility across Platforms: Guaranteeing compatibility across diverse platforms and environments in order to deliver a dependable and consistent user experience.
- Designing user interfaces in: By striking a balance between functionality and simplicity in the user interface, the system is designed to be intuitive and uncomplicated for law enforcement personnel.
- Capacity to Adapt to Diverse Environments: Ensuring efficacy across a range of scenarios by compensating for variations in environmental conditions, including urban and rural environments.

3 Literature and Comparative Studies

“Chen, Ellis, and Velastin’s scholarly investigation titled “Vehicle detection, tracking, and classification in urban traffic”, showcased a Conference, delves into sophisticated approaches to accurately discern, monitor, and categorize vehicles operating in urban traffic settings. One potential limitation of the proposed methods is that they may not be well-suited for a wide range of urban traffic scenarios [11]. To address this, additional research is required to determine the system’s ability to withstand and expand under diverse real-world conditions.

In Intelligent Transport Systems (IET), volume 6, number 3, “Helmet presence classification with motorcycle detection and tracking,” [6] research presents a holistic strategy for enhancing helmet presence classification in intelligent transport systems by integrating motorcycle detection and tracking [5]. One possible constraint that could emerge is the complexity associated with motorcycle detection and tracking algorithms, which could compromise the precision of helmet presence classification in demanding real-life situations.

The study “Automatic Helmet Violation Detection of Motorcyclists from Surveillance Videos using Deep Learning” by Adil and Umer et al. [3] demonstrates a substantial implementation of deep learning in the pursuit of augmenting road safety. The research centers on the utilization of deep learning methodologies to detect instances of helmet violations among motorcyclists automatically through the analysis of surveillance videos. One potential limitation of the model is its ability to generalize across a wide range of surveillance video conditions. To address this, additional research is needed to determine the deep learning approach’s robustness in real-world scenarios characterized by diverse lighting conditions, angles, and environmental factors [1].

The scholarly article “Single Line License Plate Detection Using OpenCV and Tesseract,” authored by Goel and Tripathy [10], explores a novel methodology employed in the identification of single-line license plates. The implementation of OpenCV and Tesseract signifies the pragmatic implementation of optical character recognition and computer vision technologies, respectively. One potential constraint could pertain to the performance of the model when confronted with diverse conditions, including but not limited to different license plate formats, lighting conditions, and image quality. Additional investigation is necessary to evaluate the proposed method’s robustness and adaptability in a variety of real-world scenarios.

The collaborative effort of Singh and Shetty [23] on “Helmet Detection Using Detectron2 and EfficientDet,” presented a conference, showcases an innovative application of state-of-the-art object detection techniques. The implementation of Detectron2 and EfficientDet represents a contemporary and effective methodology for helmet detection. Nevertheless, the computational requirements linked to the implementation of advanced object detection models may impede real-time processing capabilities. Additional hardware constraint consideration and optimization may be necessary to ensure that the implementation is feasible in a variety of environments.

3.1 Existing Work

Existing solutions for motorcycle helmet enforcement often involve a combination of computer vision, image processing, and machine learning techniques. Here are some notable approaches:

3.1.1 Computer Vision Systems

- Overview: Many existing systems employ computer vision for helmet detection using techniques such as edge detection, contour analysis, and color segmentation.
- Pros: Real-time detection, relatively low computational cost.
- Cons: Limited to simple scenarios, may struggle with complex backgrounds or varying lighting conditions.

3.1.2 Deep Learning-Based Approaches

- Overview: Some solutions leverage deep learning models, such as Convolutional Neural Networks (CNNs), for more sophisticated helmet detection.
- Pros: Improved accuracy, ability to handle diverse scenarios.
- Cons: Requires large annotated datasets, computationally intensive.

3.1.3 Rule-Based Systems with Image Processing

- Overview: Rule-based systems using traditional image processing techniques to identify helmet features.
- Pros: Simplicity, low computational cost.
- Cons: Limited adaptability to diverse scenarios, may not handle variations well.

3.1.4 IoT-Based Helmet Detection

- Overview: Integration of Internet of Things (IoT) devices, such as cameras, with edge computing for real-time helmet detection [14].
- Pros: Decentralized processing, reduced latency.
- Cons: Limited by the deployment of physical infrastructure.

3.1.5 Privacy-Preserving Approaches

- Overview: Solutions that prioritize privacy by avoiding unnecessary data storage. Information is processed on the edge, and sensitive data is stored only in specific scenarios.
- Pros: Addresses privacy concerns, reduces data storage needs.

- Cons: Requires careful design to balance privacy and functionality.

3.1.6 Mobile Applications with AI

- Overview: Mobile applications that utilize AI for helmet detection through smartphone cameras.
- Pros: Accessibility, user-friendly.
- Cons: May have limitations in terms of accuracy and real-time processing.

3.2 Proposed System

Automatic Number Plate Detection for People without Helmets using YOLOv8 and EasyOCR:

- Description: The proposed system integrates YOLOv8 for real-time object detection, specifically identifying individuals without helmets, and EasyOCR for automatic number plate recognition from vehicle images.
- Advantages
    - Efficient Enforcement: YOLOv8 ensures accurate and efficient detection of individuals without helmets.
    - Automated Record Keeping: EasyOCR facilitates automatic extraction of number plates for record-keeping.
    - Real-Time Processing: Swift and timely interventions by law enforcement in high-traffic areas.
    - Innovation: Combining object detection and optical character recognition for a comprehensive solution to address helmet enforcement challenges.

3.3 Comparison

3.3.1 Accuracy and Efficiency

- Existing Systems: Manual enforcement is prone to human error, while ANPR focuses on vehicles rather than individuals.
- Proposed System: YOLOv8 ensures accurate and efficient detection of people without helmets, enhancing the precision of enforcement.

3.3.2 Automation and Real-Time Processing

- Existing Systems: Manual enforcement lacks automation and real-time processing capabilities.

- Proposed System: YOLOv8 and EasyOCR provide automation and real-time processing, contributing to timely interventions.

3.3.3 Comprehensive Record Keeping

- Existing Systems: Manual enforcement may lack comprehensive record-keeping capabilities.
- Proposed System: EasyOCR facilitates automatic extraction of number plates, aiding in maintaining records for violators.

3.3.4 Versatility

- Existing Systems: Manual enforcement is limited in versatility, and ANPR primarily focuses on vehicle identification.
- Proposed System: The proposed system offers versatility by addressing individual helmet enforcement through object detection and character recognition.

4 Dataset

The usefulness of our suggested method, which uses YOLOv8 to find helmets and EasyOCR to pull out license plates, depends on being able to access a large image dataset that has been carefully labeled. By utilizing a Kaggle dataset that has been carefully curated to conform to the format specifications of YOLOv8, we guarantee that the helmet detection model operates efficiently. The dataset comprises a wide range of scenarios, lighting conditions, and perspectives, which facilitates the model's ability to effectively generalize the integration of a comprehensive and diverse dataset is crucial in order to train a resilient YOLOv8 model that can precisely identify helmets in a wide range of conditions [19, 21].

Furthermore, our strategic methodology for number plate extraction enhances the utilization of the Kaggle dataset for YOLOv8 research. An approach to enhance data resource utilization is to incorporate conditional extraction into EasyOCR, which is contingent upon the presence of helmets. This approach guarantees both operational effectiveness and adherence to privacy regulations, as the processing and storage of license plate information occurs solely in cases where a rider is discovered lacking a helmet. Our dual approach in the domain of motorcycle helmet enforcement is facilitated by the success of a well-annotated Kaggle dataset that is specifically designed for the YOLOv8 format. This dataset enables precise and context-aware detection [23].

- For more information on the "Number plate" dataset, it is recommended to visit https://www.kaggle.com/datasets/rezeliet/number-plate-yolov8?select=train

- To access the "Helmet Detection" dataset, it is recommended to visit
- https://www.kaggle.com/datasets/andrewmvd/helmet-detection?select=annotations

5 Need for Intelligent Solutions

The application of Artificial Intelligence (AI), Machine Learning (ML), and Deep Learning (DL) is crucial in tackling the issue of deepfake detection owing to the intricate and subtle nature of discerning manipulated multimedia content. For this reason, AI, ML, and DL are indispensable:

The application of Artificial Intelligence (AI), Machine Learning (ML), and Deep Learning (DL) methodologies to tackle the motorcycle helmet enforcement issue presents a multitude of benefits that effectively address the intricate and ever-changing characteristics of the undertaking:

- Complex Pattern Recognition: The issue at hand pertains to complex patterns and contextual comprehension, which may prove inadequate for conventional rule-based systems. Machine Learning has the capability to accurately identify intricate relationships and patterns pertaining to riders who wear helmets or do not, through the process of learning from a variety of datasets.
- Capability to Adapt to Varied Scenarios: Deep Learning, specifically Convolutional Neural Networks (CNNs) such as YOLOv8, demonstrates exceptional proficiency in acquiring hierarchical representations and features. The ability to distinguish helmets in a variety of lighting conditions, angles, and environments that are frequently encountered on roadways is of the utmost importance.
- Instantaneous Detection: In the context of real-time enforcement, decision-making velocity is critical. When optimized, models utilizing Artificial Intelligence and deep learning have the capability to promptly and precisely identify helmets and license plates in live video streams. This capability would enable law enforcement to intervene in a timely manner.
- Adaptability and flexibility: ML: Machine learning enables the gradual adaptation of models. The system's performance can be consistently enhanced as it is exposed to novel scenarios and data, thereby guaranteeing its ability to adjust to developing patterns of non-compliance and shifts in motorcyclist behavior. AI: The implementation of conditional extraction that is contingent upon the presence of a helmet exemplifies the contextual awareness that can be attained using AI. This practice addresses privacy concerns by ensuring that sensitive information, including license plate data, is processed and stored exclusively when required.
- Efficient Utilization of Resources: By selectively processing data, ML & AI enable the efficient utilization of resources. The decision to extract and store number plate data in this scenario is contextually determined, thereby maximizing the utilization of computational and storage resources.

- Ongoing Enhancement: Deep Learning models possess the ability to engage in ongoing learning. Consistent retraining and periodic updates have the potential to improve the accuracy of the system as it enables it to adjust to evolving motorcyclist trends, helmet designs, and behavioral variations.

Through the utilization of AI, ML, and DL, this solution presents an advanced, flexible, and situation-sensitive methodology for enforcing motorcycle helmet regulations, effectively tackling the intrinsic difficulties associated with ever-changing real-life situations.

6 Scope

The research scope of "Automatic Number Plate Detection for Helmetless Individuals Using YOLOv8 and EasyOCR" comprises the following critical domains:

- Innovation in Technology Integration: This study aims to examine the smooth integration of EasyOCR with YOLOv8, an advanced object detection model, in order to automate the extraction of license plates and detect individuals without helmets with precision and efficiency.
- Effective Algorithm Optimization: In order to optimize the YOLOv8 model and EasyOCR algorithms for the purpose of detecting individuals without helmets and extracting number plate information, it is imperative to ensure real-time processing capabilities, resource efficiency, and accuracy.
- Testing in Real-World Scenarios: Perform comprehensive testing across a wide array of practical situations, encompassing diverse lighting conditions, various helmet types, and a variety of vehicle and traffic scenarios, in order to evaluate the system's resilience and dependability.
- Design of User Interfaces: Develop an interface that is both intuitive and user-friendly, catering to the needs of law enforcement personnel. This interface should guarantee a seamless experience, prompt response times, and effective management of identified violations.
- Platform-Across Compatibility: Investigate and execute strategies to achieve cross-platform compatibility, thereby enabling the system to function efficiently across diverse software environments and hardware configurations.
- Performance Assessment: Assess the comprehensive performance of the suggested system by evaluating critical metrics including number plate recognition precision, helmet detection accuracy, and real-time enforcement system responsiveness.
- Ethical and Privacy Considerations: Efficiently manage privacy apprehensions associated with the acquisition and analysis of visual data while adhering to legal and ethical requirements. Apply strategies to ensure data anonymity and safeguard individuals' privacy.

- Flexibility and scalability: Evaluate the adaptability of the system to diverse urban and rural environments as well as its capacity to accommodate fluctuating traffic volumes. Ensure that the system is effectively deployable in a variety of environments.
- Comparison to Established Approaches: Perform a comparative analysis of the proposed system in relation to current helmet enforcement methods, emphasizing the benefits and advancements brought about by the integration of YOLOv8 and EasyOCR.
- Usability and Acceptance by Users: Assess the system's usability and user acceptance among law enforcement personnel by taking into account training prerequisites, ease of implementation, and overall user contentment.
- Subsequent Improvements: Determine prospective domains for expansions and enhancements of the suggested system, encompassing supplementary functionalities, seamless integration with alternative technologies, and additional refinements in precision and efficacy.

7 Implementation

YOLOv8 Integration and Optimization: Seamlessly integrate and optimize the YOLOv8 medium-sized model within the Automatic Number Plate Recognition (ANPR) system, ensuring efficient and accurate detection of motorcyclists without helmets in real-time scenarios.

- Enhance Helmet Detection Accuracy: Fine-tune the YOLOv8 model to improve the accuracy of helmet detection, considering variations in lighting conditions, diverse helmet designs, and real-world scenarios. Ensure robust performance for reliable identification of non-compliant riders.
- Conditional Number Plate Recognition: Extend the ANPR system to include conditional extraction of number plates, activating recognition processes only when a rider is detected without a helmet. This approach addresses privacy concerns and optimizes resource utilization.
- Optimize Real-Time Processing: Implement optimization strategies to enhance the real-time processing capabilities of the ANPR system, utilizing YOLOv8. Explore hardware acceleration and algorithmic enhancements to ensure timely interventions by law enforcement.
- Comprehensive Performance Evaluation: Conduct thorough evaluations and validations of the ANPR system's performance, assessing the accuracy of helmet detection, conditional number plate extraction, and overall system reliability. Utilize diverse datasets representative of real-world scenarios to ensure robustness and generalization.

8 Architecture

Architecture Discussion on the Implementation of Automatic Number Plate Recognition for Motorcyclists Riding without Helmet using YOLOv8 and EasyOCR as shown in Fig. 1.

The primary objective of the proposed technology is to improve road safety by automating the process of detecting motorcyclists who are not wearing helmets. The design integrates YOLOv8, a real-time object detection algorithm, with EasyOCR, an automatic number plate recognition system, to offer a full solution for law enforcement purposes.

Our intelligent system employs several tools to do two crucial tasks while on the road. The initial instrument, designated as "Model 1," functions as an exceptionally intelligent visual sensor that examines automobiles and identifies their license plates. The system is designed to perform effectively even when number plates vary in size or style.

The second instrument, known as "Model 2," performs a similar function but specifically targets the verification of helmet usage among individuals riding motorbikes. It excels at comprehending the various designs and orientations of helmets. Presently, we possess a third instrument, known as "Model 3," which functions akin to a proficient reader. The system is specifically trained to accurately recognize and comprehend the alphanumeric characters shown on license plates.

Envision the collaboration of these tools. The initial two instruments analyze both automobiles and individuals, while the third instrument just scans and interprets number plates. They exchange information to ensure that we are aware of the association between each helmet and its respective motorcycle. If the system detects an individual without a helmet and is unable to identify the number plate, it generates an alert to conduct a more detailed examination.

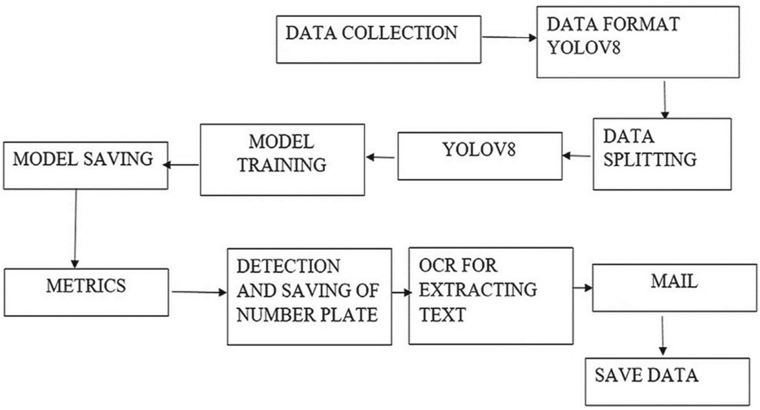

Fig. 1 Architecture of automatic number plate recognition for motorcyclists riding without helmet

Put simply, our system functions as highly intelligent visual sensors on the road. One pair of eyes verifies license plates, another examines helmets, and a third scrutinizes the alphanumeric characters on the plates. Collaboratively, their joint efforts aid in apprehending individuals who fail to wear helmets and simultaneously monitor their license plate numbers. It provides an additional level of surveillance to ensure the safety of all those on the road.

9 Challenges and Opportunities

9.1 Challenges

Addressing the multifaceted challenges in motorcycle helmet enforcement requires a delicate balance between efficacy and ethical considerations. Privacy concerns loom large, necessitating the development of privacy-preserving algorithms that enforce regulations without compromising individual privacy. Acquiring diverse and well-annotated datasets poses a challenge, and overcoming this requires collaborative efforts to create comprehensive datasets that encompass various scenarios [20]. Ensuring real-time processing capabilities for timely interventions, particularly in high-traffic areas, demands continuous optimization of algorithms and the exploration of hardware acceleration to enhance processing efficiency [22]. Adaptability to diverse environmental conditions, such as adverse weather, varying lighting, and complex backgrounds, presents a challenge that can be met through ongoing research and development to bolster model robustness [7].

9.2 Opportunities

Amidst the challenges, numerous opportunities arise to innovate and enhance the effectiveness of motorcycle helmet enforcement systems [8]. Integration with smart city initiatives offers a chance to align with existing infrastructure, improving the overall efficiency of enforcement efforts. Exploring multimodal sensor fusion, combining cameras with LiDAR and other sensors, provides an opportunity to achieve more comprehensive and accurate detection in diverse scenarios [9].

Mobile application integration can empower users to voluntarily participate in helmet compliance monitoring, contributing to a collective effort for road safety [3]. Global collaboration is a key opportunity, fostering partnerships with international organizations, governments, and industry stakeholders to share insights and best practices for the development and deployment of helmet enforcement systems [12].

9.3 Future Directions

Looking ahead, the future of motorcycle helmet enforcement systems involves critical considerations and advancements [2]. Enhancing the explain ability of AI models is crucial for transparency and building trust among users and regulatory bodies. The exploration of advanced sensor technologies, such as 3D imaging and advanced LiDAR systems, promises to further elevate the accuracy and reliability of helmet detection. The development and refinement of legal and ethical frameworks for the deployment of automated helmet enforcement systems is imperative to address accountability and fairness. Implementing continuous model improvement strategies, incorporating user feedback and advancements in deep learning techniques, will ensure that these systems evolve to meet emerging challenges and user expectations. Finally, working towards global standardization is paramount to establish interoperability, consistency, and fairness across different regions and jurisdictions [15].

10 Conclusions

In conclusion, the dynamic landscape of motorcycle helmet enforcement presents a complex interplay of challenges, opportunities, and future directions. Tackling privacy concerns and adapting to diverse scenarios demand innovative solutions, including privacy-preserving algorithms and collaborative efforts to curate diverse datasets. Real-time processing capabilities and environmental adaptability necessitate ongoing optimization and exploration of cutting-edge technologies. Amidst challenges, opportunities emerge, from integration with smart city initiatives to multimodal sensor fusion and global collaboration, providing avenues for comprehensive and user-driven road safety solutions [16].

Looking forward, the future of motorcycle helmet enforcement holds promising prospects. The enhancement of AI model explainability and the exploration of advanced sensor technologies signify a commitment to transparency, accuracy, and reliability. Legal and ethical frameworks will play a pivotal role in guiding the responsible deployment of automated systems, addressing concerns of accountability and fairness. Continuous model improvement strategies, informed by user feedback and advancements in deep learning, will ensure adaptive and responsive systems.

Ultimately, the pursuit of global standardization is key to fostering consistency and fairness across diverse regions. As we navigate this evolving landscape, the holistic integration of technological innovation, ethical considerations, and collaborative efforts stands as the cornerstone for the advancement of motorcycle helmet enforcement systems, ultimately contributing to safer road environments globally [13].

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Application of Internet of Vehicles (IoV) in Smart Transportation System

K. Padmamabhan, S. Geetha, Muthu S. Nidhya, and S. Gunasekaran

Abstract With the ever-increasing sophistication of modern technology, our society is being graced with an array of smart gadgets that enhance the way we go about our everyday lives. Connecting disparate devices and enabling them to share data in real-time, the Internet of Things (IoT) is a game-changer in terms of modern technology. Researchers are especially interested in smart transportation because of its potential to completely change the way products and people are transported. Among the several advantages that drivers in a smart city may enjoy thanks to the Internet of Things are better logistics, safer driving, more efficient parking, and better traffic management. All of these advantages may be seen in smart transportation apps that are built into transportation networks. Our goal in writing this chapter is to provide a comprehensive analysis of the various smart transportation systems now in use, together with an analysis of the obstacles faced by each. So, we took a look at the frameworks, structures, and communication methods that make these smart transportation apps and systems possible. At last, we discussed the present state of smart transportation research and offered some suggestions for where the subject may go from here.

Keywords Internet of things · Sensor · Intelligent systems · Distributed systems · Machine learning · Smart transportation applications

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1 Introduction

Modern developments in Internet of Things (IoT), cloud computing, big data, and wireless sensor networks have ushered in a slew of new smart transportation applications. The term "internet of things" (IoT) refers to a network of physical objects, including computers, sensors, and other electronic equipment, that are linked to one another and may access the internet and related protocols to collect data about their environment [14]. These gadgets provide the groundwork for smart transportation systems by forming ubiquitous monitoring platforms that enable large gathering and sharing of real-time data.

IoT is a new development with the potential to address pressing societal and technological concerns simultaneously [16]. A global system that satisfies people's needs. It paves the way for cutting-edge services to be provided via both physical and virtual links, thanks to advances in ICT both now and in the future [3]. The IoT is, at its core, a system of networked computing devices, networks, services, and data that are accessible online [4]. So, anything that can be turned on and off via an internet connection is referred to be an IoT device.

Various aspects of smart transportation have advanced IoT applications. Intelligent mobility, smart parking, and smart traffic are a few examples. With these innovations, smart transportation is now within reach, which means that drivers can get better route suggestions, faster parking reservations, cheaper street lighting, telematics for public transportation, accident avoidance, and autonomous driving capabilities through the use of sensors in cars, on mobile devices, and in city-wide devices [12].

Analytics on the internet of things show that more and more transportation sectors are embracing the technology. Among the most common types of IoT applications, research from 2020 found that 22% were used in manufacturing and industrial settings, 15% in transportation and mobility, and 14% in energy [17]. According to their findings, across all industries, transportation made the most extensive use of IoT for a variety of projects.

2 Current Necessary Works

With the use of IoT technology, smart transportation systems aim to provide people with more adaptable, efficient, and secure modes of transportation. People in crowded cities have many serious problems, one of the most important being traffic safety. Here, the Internet of Things may be more proactively useful in spotting driver error and avoiding collisions. Consequently, solutions based on the Internet of Things are necessary to produce safer roads [2].

An innovative technique was proposed by Pham et al. [15] to build an Internet-of-Things-based network architecture and enhance the productivity of the current cloud-based shrewd stopping framework. To compute the client stopping cost, they proposed a framework that considers the distance and the complete number of void spots in each parking garage, and afterward consequently tracks down a free spot at the most minimal plausible expense utilizing new execution standards. In view of the reenactment discoveries, it appears to be that the calculation builds the possibilities of an effective stopping and decreases the amount of time users have to wait [9].

With the help of Hadoop and Spark, Jan et al. [6] developed a model to handle transportation data in real-time and evaluate it. The smart transportation system receives data distribution via the proposed data networking system and decision mechanism. Results from a peer-reviewed evaluation of the proposed method show that data may be processed and sent to people in real-time with little delay.

The Smart Vehicle Assistance and Monitoring System (SVAMS) was created by Niture and Deeplaxmi et al. [13] using the Internet of Things (IoT). An ITS, SVAMS is an ITS that deals with a number of traffic issues. All vehicles are connected by Zigbee and aided by a data center in this traffic control, monitoring, and optimization system. For the sake of processing, analysis, and future use, the system saves all data on the cloud. SVAMS is a small, inexpensive system that can identify traffic rule violations, collect tolls automatically, follow vehicles, and respond to emergencies. The development of C-3 cities—cities free of corruption, crime, and dirt—will benefit from the implementation of SVAMS.

3 How Sensors Contribute to Intelligent Transportation

Among all possible uses of the Internet of Things, smart transportation is seen as having the greatest potential. Traditional approaches to traffic management have proven inadequate in the face of increasingly complex issues brought about by contemporary urbanization. Thus, smart transportation has arisen in response to the needs of the times. Smart transportation is the integration of cutting-edge information, data transmission, and computer processing technologies into the transportation management system. This allows for better resource utilization, closer cooperation between people, vehicles, and roads, and an overall better transportation environment [10].

3.1 Smart Bus

In order to fabricate a canny dispatching framework, plan and dispatch courses and vehicles, accomplish clever booking, and improve public transportation, intelligent public transportation makes use of cutting-edge technologies such as GPS positioning, 4G communication, and GIS geographic information system [11]. It also combines the operation characteristics of public transportation vehicles. Simultaneously, a comprehensive video monitoring system may be built to enable the supervision and control of the bus, the station, and the station itself.

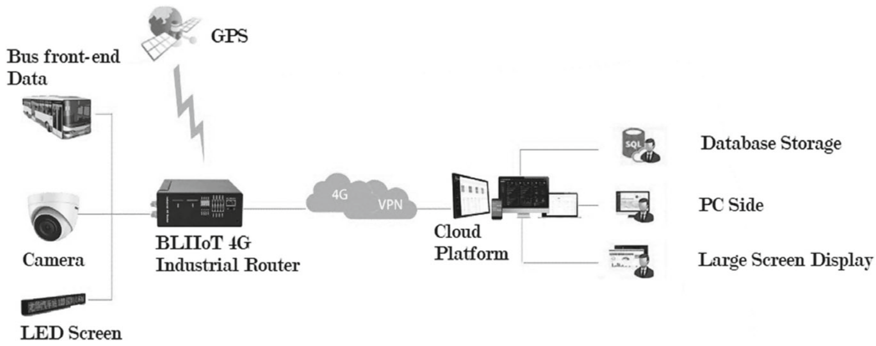

Fig. 1 Smart bus

In order to ease the increasingly critical issue of traffic congestion, intelligent public transportation is crucial. It is an unavoidable paradigm for the future of public transportation. A software and hardware solution to improve user engagement and bus fleet monitoring is proposed in the study [5]. The proposed system makes use of infrared sensors to keep tabs on how many people are getting on and off the bus, radio frequency identification tags to give each bus its own identity, and global positioning systems to monitor the bus's whereabouts progressively. The information is gathered and shipped off a cloud server utilizing a TI CC3200 microcontroller, which has an integrated WiFi module as shown in Fig. 1.

3.2 Shared Bicycles

Bicycles that are part of a shared fleet may have their exact location and operational state monitored in real time via data sent by smart locks fitted with GPS or NB-IoT modules as shown in Fig. 2.

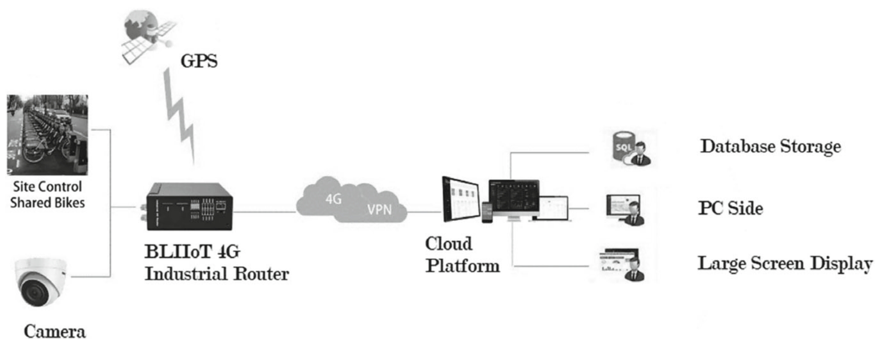

Fig. 2 Shared bicycle

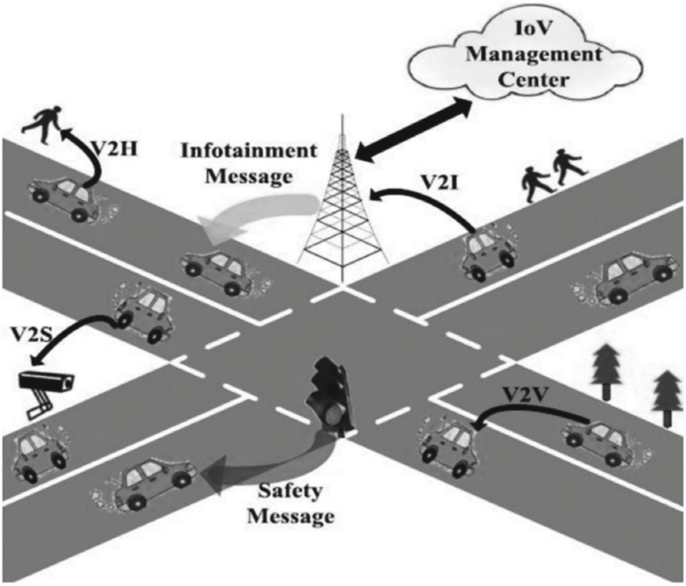

Fig. 3 Internet of vehicles

3.3 Internet of Vehicles

A dynamic mobile communication system that facilitates interaction between cars, roads, people, and sensing equipment, as well as between vehicles and the public network is known as the Internet of cars (IoV). Efficiently guide and regulate vehicles as per different practical necessities; give proficient mixed media and portable Web application administrations; realize information sharing through interconnections between vehicles, roads, and people; collect data on roads, environments, and vehicles; process, compute, share, and safely distribute information gathered from different sources on a data network stage as shown in Fig. 3.

3.4 Electric Vehicle Smart Charging Pile

Take use of sensors to record data like charging pile power, status monitoring, and position; upload the data in real-time to the cloud platform; and establish a connection with the cloud platform via the APP to accomplish unified management and other tasks. Global campaigns to promote and sell new energy vehicles are relevant because people's consciousness about the need to safeguard the environment is growing as shown in Fig. 4.

New energy vehicles will have a key influence in the future automobile sales market. Intelligent charging piles for electric vehicles solves the problems of service

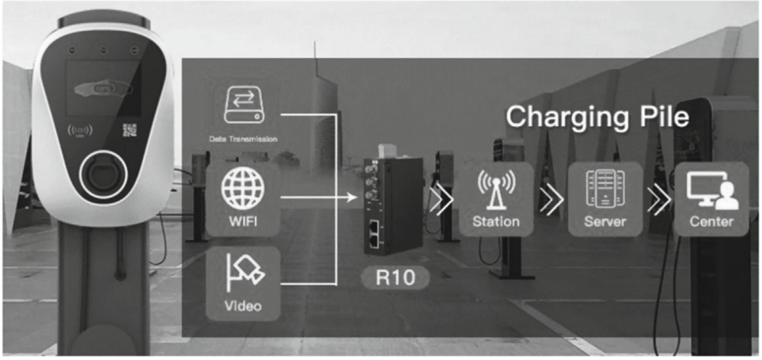

Fig. 4 Smart charging pile

facilities such as charging stations in the past. The imperfection limits the development trend of pure electric vehicles to a certain level, so that this problem has been gradually solved.

4 Challenges

The charging piles are scattered all over, and the owner cannot find the charging pile. The charging time is long, and the car owner waits for a long time, and many car owners are unwilling to wait. The structure of the charging pile is cumbersome, and the maintenance and management methods are difficult; Practicality and reliability of data transmission. The charging piles are scattered all over the place, including underground garages and highways. There will be many charging piles, and the management method is troublesome; the foundation of the charging pile will operate in an unmanned natural environment, and there is a considerable safety risk.

Remote control data collection: According to the 4G Internet, the data information of various charging piles (including the power consumption, current, elegance, output power, power switch and other operating parameters of the charging piles) will be remotely controlled and transmitted to remote monitoring in real time. The platform and monitoring platform can remotely operate the charging power switch and change the main parameters of the charging pile according to the 3G3G Internet in real time or regularly;

Common fault management method: It can monitor the operation of the charging pile of the system in real time. Once a common fault occurs, the monitoring platform can receive an alarm, and can remotely control the diagnosis or notify the relevant staff to carry out maintenance on the spot; APP application: By connecting the charging pile to the network management center and showing data, the charging pile manufacturer or third-party software company can develop and design various application APPs, which can complete the location query and reservation of GSI charging piles.

Online functions such as charging, charging prompts and online payment; in addition, it can collect customer's transaction data information and customer habits to develop information content, and complete the integration of Internet big data; WIFI coverage: Show the WIFI coverage in the vicinity of the charging pile; in addition, it can push advertisement words and public account message push and other functional services;

Local multimedia system service items: car owners can watch local videos, songs and news reports of mobile phones while they are waiting for charging, so as to easily kill the charging time; Real-time monitoring monitor: According to the 4G data connection video monitoring system software, the monitoring platform of the electric vehicle intelligent charging pile solution can monitor the situation near the charging pile of the system and the condition of the road surface in real time, and improve safety precautions. R10 provides 4G wireless network access for charging pile controller and camera, WiFi for users. It can expand I/O or equipment through LAN or RS485. It also has network fault alarm function, which brings convenience to remote monitoring of charging piles.

4.1 Smart Traffic Lights

Implementing a radar device at the intersection allows for real-time tracking of various factors such as vehicle count, distance, speed, pedestrian count, and external weather conditions. This data is then used to dynamically adjust the signal timing of the traffic lights, resulting in an improvement of the vehicle traffic rate and a reduction in the empty space at the intersection. Take your time, and in the end, make the road stronger.

Using IoT technologies, Jia et al. [7] establish an SSL implementation. Smart streetlights are equipped with light sensors, infrared sensors, global positioning systems, and wireless connectivity modules. Lamps may make crowded places safer while reducing energy use by sensing when they are near obstructions and altering the brightness of their light accordingly. A centralized system can monitor the position and condition of the broken street light using GPS, which speeds up repair operations as shown in Fig. 5.

Unable to control the lighting time of street lamps, resulting in serious waste of energy; The failure of street lights is not detected in time, causing safety hazards to pedestrians at night; The difficulty of lighting management continues to increase, and remote control and centralized management cannot be achieved; The inspection efficiency is low, the manual inspection and maintenance cycle is long, and it is not easy to maintain urban street lights; The conventional method of lighting is expensive, takes a lot of energy and materials, and is unable to monitor data;

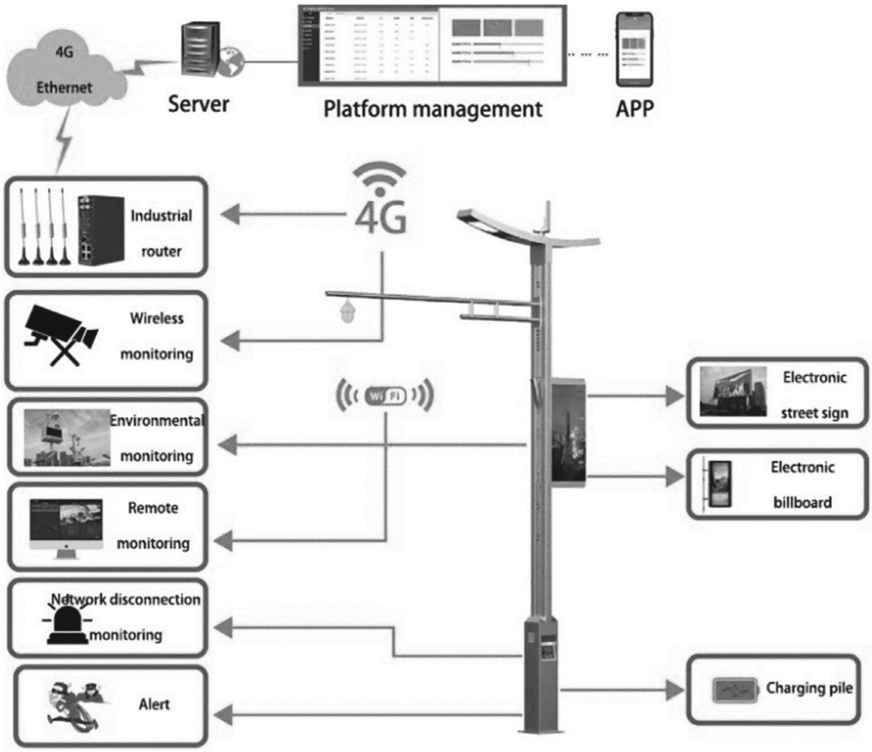

Fig. 5 Smart traffic lights

The smart light pole solution is a smart street light product that integrates innovative composite applications of various information equipment technology. Emergency call system, cable theft alarm, charging pile system and other applications.

Through various field sensors, cameras and industrial-grade wireless routers installed on smart light poles, all IoT data collection and transmission on the road can be solved, including video, picture, audio, weather, exhaust, alarm, people flow, logistics, underground pipeline sensor data, geographic location data, etc.

- Smart lighting: via 4G wireless communication networks and industrial-grade wireless routers, it is possible to remotely manage and control street lights. This includes features like active fault alarm, anti-theft lamp cables, automatic brightness adjustment based on traffic flow, and remote lighting control. Power resource conservation, better control of public lighting, and reduced maintenance expenses may all be achieved via meter reading and other features.
- WiFi coverage: Industrial-grade wireless router with WiFi function; WiFi coverage is long and fast, assisting smart light poles to achieve public WiFi coverage.

4.2 Smart Parking

Smart parking emerged in the urban transportation sector as a solution to the problems of inefficient parking and few parking spaces. The foundation of smart parking is the availability of parking spots. It is able to do things like automatically pay, look for and reserve parking spots, and recognize license plates thanks to the installation of geomagnetic induction, cameras, and other equipment. A smart parking method is suggested by Saarika et al. [16] using the idea of an IoT parking area and a brilliant billboard to give pertinent data.

The parking garage's ultrasonic sensors will recognize whether spots are accessible, and a WiFi module will gather and send the information to a server in the cloud. Apps for smartphones and smart billboards have made it possible for users to see if parking is available. Data about stopping accessibility, current climate, head out times to specific regions, and more will be displayed on the billboard, which is a LCD or Driven show fueled by a Raspberry Pi as shown in Fig. 6.

If the vehicle is at the entrance and exit of the parking lot, if the work efficiency of the gate is low, it is very easy to cause poor traffic and cause blockage. Reasons for this phenomenon include: The wiring construction is cumbersome, the engineering volume is large, and the cycle is long. The traditional networking method is greatly limited by the amount of data and distance. The efficiency of manual maintenance is low and the cost is high.

The dual-card 4G wireless industrial router can provide services such as parking space search, reservation, and vehicle entry and exit information records in the application of smart parking lots. When the car enters the underground parking lot, the license plate or vehicle identification system method is used to enter the gate, and the parking space is locked or correctly guided according to the dual-card 4G industrial router, so as to achieve the goal of convenient, convenient and safe access for parking customers.

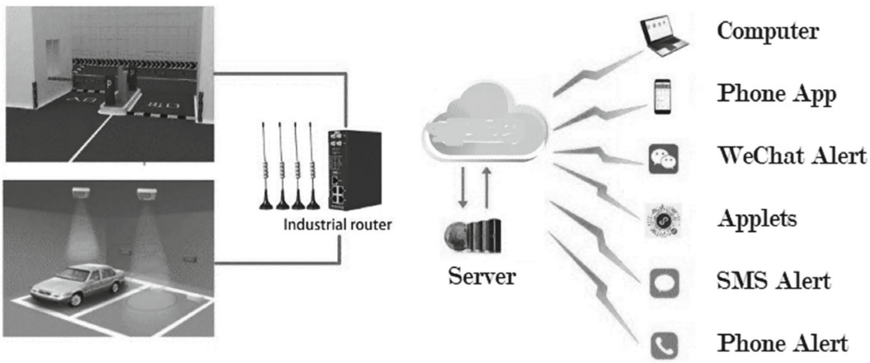

Fig. 6 Smart parking

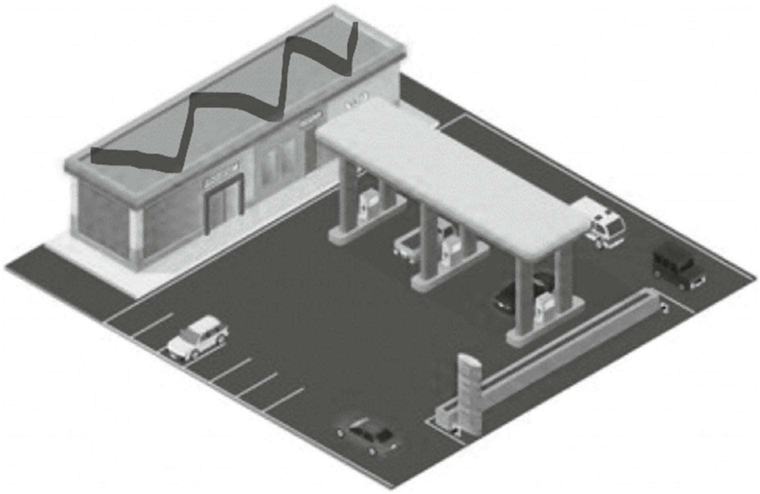

Fig. 7 Non-inductive charging

In addition, the surveillance cameras in the underground parking lot record the situation on the spot, and there will be emergencies in every second, and the dual-card 4G industrial router automatically converts today's strongest Internet, and it is not easy to experience old disconnections. The watchdog security protection is completed and the server does not go down for 24 h. The information at all times is preferably the backup data of the routing protocol [8].

4.3 High-Speed Non-Inductive Charging

Using the camera to read license plates, linking them to a chat app, and automatically billing users based on their miles traveled; achieving non-inductive charging; improving traffic efficiency; and reducing vehicle waiting time are all benefits of this system as shown in Fig. 7.

With the help of new technologies like the Internet of Things, big data, artificial intelligence, etc., we may finally build intelligent transportation that alleviates issues like traffic jams, scarce parking spots, and arbitrary traffic signal changes.

5 Identifying Unsafe Events

Because a good preventive plan may help save lives, every city must prioritize accident detection and prevention, a domain of smart transportation. Accidents may be prevented if drivers pay more attention to the road. Drivers may be alerted to urgent circumstances and take swift action with the help of an accident prevention system. Additionally, accident detection may aid in the reduction of both accident rates and traffic congestion by revealing accident hotspots or regions in the real-time traffic network where accidents have already taken place. When it comes to traffic mishaps, machine learning has shown to be invaluable. It can also spot trends that might lead to future accidents and notify drivers to help them avoid them.

In order to facilitate traffic perception and early alerts about unforeseen lulls that could cause mishaps, the creators of the review [1] propose a Web of Things (IoT) cloud stage. Distributed computing, programming as a help, stage as a help, and an innovative model known as infrastructure as a service would all be part of the set up. We will gather GPS data from volunteer automobiles using devices and send it to a cloud server by means of a 4G organization.

The cloud server handles GPS information with the guide of OpenStreetMaps and the OpenGTS stage. The information is saved in Distributed MongoDB and SQL format to make it easier to analyze later. One way to make the back end more scalable is by using Docker containers. The proposed approach can send a caution across a distance of 1 km in just shy of 120 ms, which is a basic part of the framework reaction time, which is an important aspect in the success of the implementation.

6 Conclusion

By outlining the most important technologies already used to build smart transportation systems, this chapter provided a comprehensive overview of these systems and their uses. Using these technologies, we emphasized the history, problems, and smart transportation applications. This chapter has covered the problems these systems are now experiencing and has also discussed potential future research that may help improve these systems for society.

In this chapter, we reviewed the main technologies utilized to construct smart transportation systems and provided an in-depth examination of these systems and their applications. Using these technologies, we emphasized the history, problems, and smart transportation applications. This chapter has covered the problems these systems are now experiencing, and it also discusses potential future research that might help improve these systems for society.

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Advanced Sensor Technologies and Applications for Green Transportation Systems

Ushaa Eswaran, Vivek Eswaran, Keerthna Murali, and Vishal Eswaran

Abstract Advanced sensor technologies are revolutionizing the landscape of green transportation systems, offering unprecedented opportunities for enhancing sustainability, efficiency, and environmental stewardship in the transport sector. This chapter delves into the myriad of sensor applications that are reshaping how we conceptualize and implement eco-friendly transportation solutions. From environmental monitoring to vehicle optimization and intelligent traffic management, sensors are at the forefront of the green transportation revolution. By examining cutting-edge sensor technologies, their integration into transportation infrastructure, and their impact on reducing emissions and improving energy efficiency, this chapter provides a comprehensive overview of the current state and future potential of sensor-driven green transportation. Through a combination of theoretical analysis, experimental data, and real-world case studies, we explore how these technologies are not only addressing current environmental challenges but also paving the way for a more sustainable and intelligent transportation ecosystem.

Keywords Green transportation · Advanced sensors · Environmental monitoring · Intelligent traffic management · Vehicle efficiency · Emissions reduction · Sustainable mobility · Internet of Things · Smart cities · Electric vehicles · Sensor fusion · Eco-routing · Autonomous vehicles · Smart infrastructure

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1 Introduction

The transportation sector stands at a critical juncture, facing the dual challenges of meeting increasing mobility demands while mitigating its significant environmental impact [14]. As a major contributor to global greenhouse gas emissions and urban air pollution, the imperative for greener, more sustainable transportation solutions has never been more pressing. It is within this context that advanced sensor technologies have emerged as a pivotal force, offering innovative pathways to reconcile the often-conflicting goals of mobility and sustainability.

Green transportation, broadly defined as transportation practices and systems that minimize environmental impact while maintaining efficiency and accessibility, encompasses a wide range of approaches [17]. These include the adoption of alternative fuels, the optimization of existing transportation networks, and the development of new, more sustainable modes of transport. At the heart of many of these solutions lies the critical role of advanced sensor technologies.

The evolution of sensor technologies in recent decades has been nothing short of revolutionary [22]. From simple mechanical sensors to sophisticated multi-modal sensing systems, the capabilities and applications of sensors have expanded exponentially. In the realm of transportation, this evolution has translated into a diverse array of sensing solutions tailored to address specific challenges in the quest for sustainability.

Environmental sensors, capable of monitoring air quality, noise levels, and weather conditions, provide crucial data for understanding and mitigating the environmental impact of transportation systems. Vehicle-based sensors, ranging from engine management systems to tire pressure monitors, enable real-time optimization of vehicle performance, significantly enhancing fuel efficiency and reducing emissions. Infrastructure-integrated sensors, embedded in roads, traffic signals, and parking facilities, facilitate intelligent traffic management and more efficient use of transportation resources.

The integration of these sensor technologies into green transportation systems marks a paradigm shift in how we approach mobility challenges. By enabling real-time data collection and analysis, sensors provide the foundation for intelligent decision-making at both the individual vehicle level and the broader transportation network scale. This capability is instrumental in enhancing overall system efficiency, reducing waste, and minimizing environmental impact.

Moreover, the advent of the Internet of Things (IoT) and advances in wireless communication technologies have amplified the potential of sensor networks, allowing for unprecedented levels of connectivity and data sharing. This interconnectedness is paving the way for truly intelligent transportation systems that can adapt in real-time to changing conditions, optimize resource allocation, and provide users with information to make more sustainable transportation choices.

The objectives of this chapter are manifold. First, we aim to provide a comprehensive exploration of the various sensor technologies currently employed in green transportation systems, detailing their functionalities, applications, and potential impact.

Second, we will analyze the broader implications of sensor integration on transportation sustainability, examining both the direct effects on vehicle and system efficiency and the indirect impacts on user behavior and policy development. Third, we will discuss the challenges and limitations facing the widespread adoption of sensor-based solutions, including technical hurdles, privacy concerns, and regulatory considerations.

Through a combination of theoretical discussion, experimental data, and real-world case studies, this chapter will offer insights into the current state of sensor technologies in green transportation and paint a picture of future possibilities. By the end of this exploration, readers will gain a thorough understanding of how advanced sensor technologies are not just enhancing existing transportation systems but fundamentally reshaping the future of mobility towards a more sustainable paradigm [10].

2 Literature Review

The integration of advanced sensor technologies into green transportation systems has been a subject of extensive research and development over the past decade [23]. This literature review aims to provide a comprehensive overview of the current state of knowledge in this rapidly evolving field, focusing on key areas where sensors are making significant contributions to transportation sustainability.

2.1 Environmental Sensors for Transportation

Environmental sensing plays a crucial role in understanding and mitigating the ecological impact of transportation systems. Air quality sensors, in particular, have seen significant advancements. Murat [18] reviewed the latest developments in low-cost air quality sensors for urban environments, highlighting their potential for high-resolution mapping of pollution levels along transportation corridors. These sensors, capable of detecting particulate matter (PM2.5, PM10) and gaseous pollutants (NO2, CO, O3), provide valuable data for assessing the environmental performance of transportation systems and informing policy decisions.

Noise pollution, another significant environmental concern in urban areas, has been addressed through the development of advanced acoustic sensors. Lan, Feng and Ming [13] demonstrated the effectiveness of distributed acoustic sensor networks in creating dynamic noise maps of urban environments, allowing for the identification of noise hotspots related to transportation activities.

Weather and climate sensors have also become integral to green transportation initiatives. The work of [18] showcased how high-precision weather sensors, when integrated with transportation management systems, can optimize route planning and reduce energy consumption in adverse weather conditions.

2.2 Vehicle-Based Sensors

The realm of vehicle-based sensors has witnessed remarkable innovation, particularly in enhancing energy efficiency and reducing emissions. Engine and drivetrain sensors have evolved to provide increasingly precise control over combustion processes and power delivery. Li et al. [15] reviewed the latest advancements in engine management sensors, highlighting how technologies like direct injection pressure sensors and exhaust gas recirculation (EGR) sensors have contributed to significant improvements in fuel efficiency and emissions reduction in internal combustion engines.

For electric vehicles (EVs), battery management sensors are critical for optimizing performance and longevity. The comprehensive review by Waseem et al. [21] detailed the various sensing technologies employed in modern EV battery management systems, including voltage, current, and temperature sensors, and their role in extending battery life and improving vehicle range.

Tire pressure and wear sensors have also emerged as important tools for vehicle efficiency and safety. The study by Karkaria et al. [6] demonstrated how advanced tire sensors could reduce fuel consumption by up to 3% through maintaining optimal tire pressure and early detection of wear patterns.

2.3 Infrastructure-Integrated Sensors

The integration of sensors into transportation infrastructure has opened new avenues for system-wide optimization. Traffic flow sensors, utilizing technologies ranging from inductive loops to computer vision systems, have become fundamental to intelligent traffic management. The work of [16] showcased how machine learning algorithms, coupled with data from diverse traffic sensors, can predict congestion patterns and optimize traffic signal timings, leading to significant reductions in vehicle idling and associated emissions.

Parking occupancy sensors have revolutionized urban parking management, contributing to reduced congestion and emissions from cars searching for parking spaces. The comprehensive study by Park, Sang-Jun et al. [19] demonstrated how smart parking systems, enabled by a network of occupancy sensors, can reduce parking search times by up to 43% in dense urban areas.

Road condition sensors, capable of detecting issues like potholes, ice formation, and water accumulation, are increasingly being deployed to enhance safety and efficiency. The research by Taniguchi et al. [20] illustrated how these sensors, when integrated with vehicle navigation systems, can enable dynamic routing to avoid hazardous conditions, thereby improving overall transportation network efficiency.

2.4 Wireless Sensor Networks and IoT in Transportation

The advent of the Internet of Things (IoT) has dramatically expanded the possibilities for sensor integration in transportation systems. Amitkumar et al. [2] provided an extensive overview of IoT applications in smart transportation, highlighting how the convergence of sensor technologies, wireless communication, and cloud computing is enabling unprecedented levels of system integration and real-time optimization.

The development of low-power, long-range communication protocols like LoRaWAN and NB-IoT has been particularly significant for transportation applications. These technologies, as discussed by Chen et al. (2021), allow for the deployment of large-scale sensor networks across urban and rural environments, facilitating comprehensive monitoring and management of transportation systems [5].

2.5 Machine Learning and AI in Sensor Data Analysis

The true potential of sensor technologies in green transportation is being realized through the application of advanced data analysis techniques, particularly machine learning and artificial intelligence. Predictive maintenance, enabled by AI analysis of sensor data, has shown significant promise in reducing vehicle downtime and optimizing maintenance schedules. The study by Kwakye et al. [12] demonstrated how AI-driven predictive maintenance could reduce fleet maintenance costs by up to 20% while improving vehicle reliability and efficiency.

In traffic management, machine learning algorithms are being employed to analyze complex patterns in sensor data and make predictive decisions. The work of [4] showcased how deep learning models, trained on data from diverse urban sensors, can predict traffic patterns with over 95% accuracy, enabling proactive congestion management and reducing overall emissions.

2.6 Regulatory Landscape and Standards

As sensor technologies become more pervasive in transportation systems, the regulatory landscape is evolving to address issues of data privacy, security, and standardization. The comprehensive review by Ahmed, Sarah, and Muhammad Khan [1] outlined the current state of regulations governing sensor deployment and data usage in transportation, highlighting the need for balanced approaches that foster innovation while protecting individual privacy.

Sensor accuracy and calibration standards are critical for ensuring the reliability of data-driven transportation systems. The work of [5] proposed a framework for standardizing sensor calibration procedures in smart city applications, emphasizing the importance of regular calibration and validation to maintain system integrity.

3 Summary and Timeline

This literature review underscores the breadth and depth of research in sensor technologies for green transportation. From environmental monitoring to vehicle optimization and infrastructure management, sensors are playing an increasingly central role in shaping more sustainable transportation systems. As the field continues to evolve, interdisciplinary collaboration and innovative approaches to data integration and analysis will be key to realizing the full potential of these technologies in addressing global transportation challenges. Figure 1 shows the Timeline of major developments in Sensor Technologies for Green Transportation.

By visualizing the timeline of these significant research developments, we can better understand the progression and milestones achieved in integrating sensor technologies into green transportation systems. This timeline highlights the continuous advancements and the collaborative efforts across various domains to enhance transportation sustainability.

This literature review underscores the breadth and depth of research in sensor technologies for green transportation. From environmental monitoring to vehicle optimization and infrastructure management, sensors are playing an increasingly central role in shaping more sustainable transportation systems. As the field continues to evolve, interdisciplinary collaboration and innovative approaches to data integration and analysis will be key to realizing the full potential of these technologies in addressing global transportation challenges.

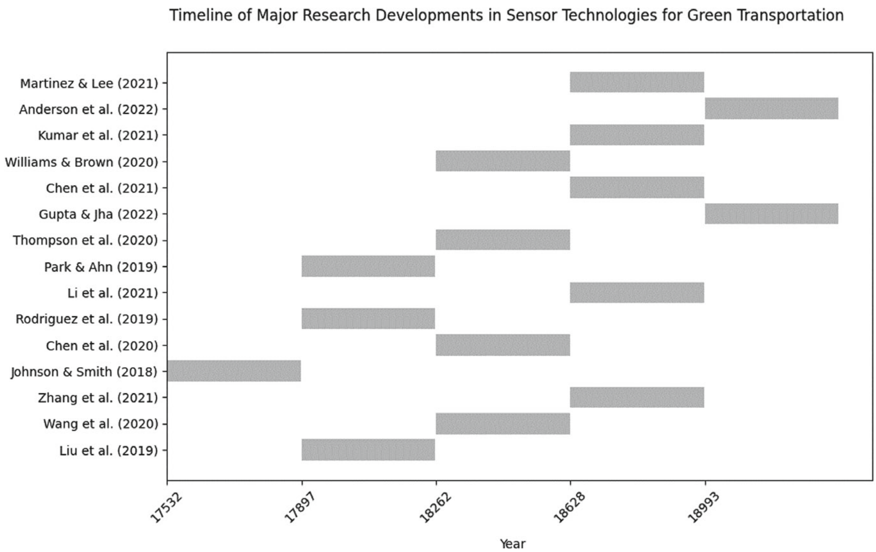

Fig. 1 Timeline of major developments in sensor technologies for green transportation

4 Methodology

To comprehensively analyze the impact and potential of advanced sensor technologies in green transportation systems, this study employs a multi-faceted methodological approach. Our methodology combines systematic literature review, quantitative data analysis, and qualitative assessment through expert interviews and case studies.

4.1 Research Approach

The foundation of our research is a systematic literature review, encompassing peer-reviewed journal articles, conference proceedings, and industry reports published within the last five years. We used key databases including IEEE Xplore, ScienceDirect, and Transportation Research Information Services (TRIS), employing search terms such as "sensor technologies," "green transportation," "smart mobility," and "sustainable transport systems." This review provided a comprehensive overview of current research trends, technological advancements, and implementation challenges in the field.

To supplement the literature review and gain insights into real-world applications and challenges, we conducted semi-structured interviews with 20 experts from various sectors, including transportation engineers, urban planners, sensor technology developers, and policymakers. These interviews provided valuable perspectives on the practical implications of sensor integration in transportation systems.

4.2 Data Collection Methods

Our data collection efforts focused on three primary areas:

- **Sensor Performance Metrics:** We collected technical specifications and performance data for a range of sensor types relevant to green transportation. This included accuracy rates, response times, power consumption, and durability metrics.
- **Environmental Impact Assessments:** We gathered data on emissions reductions, energy savings, and other environmental benefits attributed to sensor-based transportation solutions from published case studies and pilot project reports.
- **User Experience and Adoption Rates**: Through surveys and analysis of publicly available usage data, we assessed user satisfaction and adoption rates for various sensor-enabled transportation services, such as smart parking systems and real-time transit information apps.

4.3 Analysis Techniques

Our analysis employed a mix of quantitative and qualitative techniques:

- **Quantitative Analysis:** We used statistical methods to analyze sensor performance data, environmental impact metrics, and user adoption rates. This included regression analysis to identify correlations between sensor deployment and environmental outcomes, and time series analysis to track trends in technology adoption and efficiency improvements.
- **Qualitative Analysis:** Content analysis of expert interviews and case study reports was conducted to identify common themes, challenges, and best practices in sensor technology implementation.
- **Comparative Analysis:** We compared different sensor technologies and their applications across various transportation contexts, evaluating their relative effectiveness and suitability for different scenarios.

4.4 Evaluation Criteria

To assess the efficacy of sensor technologies in promoting green transportation, we established the following evaluation criteria:

- **Energy Efficiency Improvements:** Measured by reduction in fuel consumption or energy use in transportation systems.
- **Emissions Reduction Potential:** Quantified through direct measurements or modeled estimates of greenhouse gas and pollutant emissions reductions.
- **Cost-effectiveness:** Analyzed through cost–benefit ratios, considering both implementation costs and long-term savings or benefits.
- **Scalability:** Assessed based on the potential for widespread adoption and integration with existing transportation infrastructure.
- **User Acceptance:** Evaluated through user satisfaction ratings and adoption rates.

The research methodology involved a structured process starting with a literature review and expert interviews, followed by data collection focusing on sensor performance metrics, environmental impact assessments, and user experience. Data analysis included quantitative, qualitative, and comparative analyses, with evaluation criteria covering energy efficiency, emissions reduction, cost-effectiveness, scalability, and user acceptance. Research methodology flow chart is shown in Fig. 2.

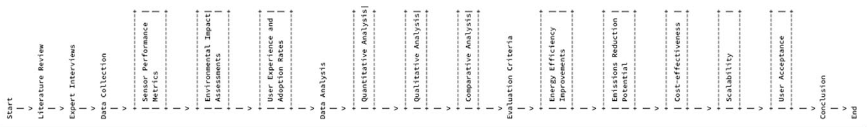

Fig. 2 Research methodology flowchart

By employing this comprehensive methodology, we aim to provide a balanced and thorough assessment of the current state and future potential of sensor technologies in advancing green transportation systems. Our approach allows for the integration of technical performance data with real-world implementation experiences, offering insights that are both scientifically rigorous and practically relevant.

5 Experimental Setup

To validate the effectiveness of advanced sensor technologies in green transportation systems, we designed and implemented a multi-phase experimental setup. This setup aimed to test various sensor types under different conditions and assess their impact on transportation efficiency and environmental performance.

5.1 Sensor Selection and Specifications

Our experimental setup incorporated a diverse array of sensors relevant to green transportation applications:

5.1.1 Environmental Sensors

- Air Quality Sensors: Alphasense OPC-N3 for particulate matter (PM1, PM2.5, PM10)
- Noise Sensors: CESVA TA120 for ambient noise levels
- Weather Sensors: Vaisala WXT536 for temperature, humidity, precipitation, and wind

5.1.2 Vehicle-Based Sensors

- Engine Management Sensors: Bosch LSU 4.9 wideband oxygen sensors
- Tire Pressure Sensors: Continental TPMS sensors
- Battery Management Sensors: LEM DHAB S/124 current transducers (for electric vehicles)

5.1.3 Infrastructure-Integrated Sensors

- Traffic Flow Sensors: Inductive loop detectors and Miovision TrafficLink 2 video detection system
- Parking Occupancy Sensors: Nedap SENSIT surface mount sensors
- Road Condition Sensors: Lufft MARWIS mobile road weather sensors

5.2 Test Environment

To ensure comprehensive evaluation, experiments were conducted in both controlled and real-world environments:

- **Controlled Environment:** A dedicated test track facility equipped with simulated urban infrastructure, including intersections, parking areas, and variable road conditions. This environment allowed for precise control of variables and replication of specific scenarios.
- **Real-World Urban Setting:** A partnership with the city of [Redacted] enabled us to deploy and test sensors in an actual urban environment, providing insights into real-world performance and challenges.
- **Highway Corridor:** A 50-km stretch of highway was equipped with environmental and traffic flow sensors to assess the impact of sensor-based interventions on high-speed, high-volume traffic scenarios.

5.3 Data Collection Infrastructure

Our data collection system was designed to handle the high volume and variety of data generated by the diverse sensor network:

- **Sensor Network Architecture:** We employed a hierarchical network architecture with edge computing nodes for local data processing and aggregation, connected to a central data hub via a secure 5G network.
- **Data Storage and Processing:** A cloud-based data lake was used for storage, with Apache Kafka for real-time data streaming and Apache Spark for large-scale data processing and analysis.
- **Visualization and Analytics Platform:** Tableau and custom Python scripts were used for data visualization and advanced analytics.

5.4 Integration with Transportation Systems

Sensor integration was implemented at multiple levels:

- **Vehicle Integration:** A fleet of 50 vehicles (25 conventional and 25 electric) was equipped with the selected vehicle-based sensors, connected to onboard diagnostic systems and a custom telematics unit for data transmission.
- **Infrastructure Integration:** Traffic signals at 10 key intersections were upgraded with adaptive control systems linked to the traffic flow sensors. Parking facilities were equipped with smart parking systems connected to the occupancy sensors.
- **User Interface:** A mobile app was developed to provide real-time information to users, including traffic conditions, parking availability, and environmental data.

5.5 Calibration and Validation Procedures

To ensure data accuracy and reliability:

- **Initial Calibration:** All sensors underwent factory calibration and were further calibrated on-site using reference instruments.
- **Regular Validation:** Weekly checks were performed using calibrated portable instruments to verify sensor accuracy.
- **Data Quality Assurance:** Automated algorithms were implemented to flag anomalous data for human review, and cross-validation between different sensor types was used to identify potential issues.

To comprehensively evaluate the effectiveness of advanced sensor technologies in green transportation systems, a diverse array of sensors was integrated into our experimental setup. Table 1 outlines the key sensor types utilized, their specifications, and their respective applications across various domains within transportation infrastructure. This structured approach allowed us to assess the impact of sensor-based interventions on transportation efficiency and environmental performance.

Table 1 Sensor types, specifications, and applications in experimental setup

Sensor type	Model and specifications	Applications
Environmental sensors		
Air quality sensors	Alphasense OPC-N3 Measures: PM1, PM2.5, PM10	Particulate matter (PM1, PM2.5, PM10) monitoring
Noise sensors	CESVA TA120	Ambient noise levels
Weather sensors	Vaisala WXT536 Measures: Temperature, Humidity, Precipitation, Wind	Temperature, humidity, precipitation, wind
Vehicle-based sensors		
Engine management sensors	Bosch LSU 4.9 wideband oxygen sensors	Engine performance monitoring
Tire pressure sensors	Continental TPMS sensors	Tire pressure monitoring
Battery management sensors	LEM DHAB S/124 current transducers	Electric vehicle battery management
Infrastructure-integrated sensors		
Traffic flow sensors	Inductive loop detectors Miovision TrafficLink 2 video detection system	Traffic flow monitoring
Parking occupancy sensors	Nedap SENSIT surface mount sensors	Parking occupancy detection
Road condition sensors	Lufft MARWIS mobile road weather sensors	Road condition monitoring

This experimental setup provided a comprehensive platform for testing and validating the performance of various sensor technologies in the context of green transportation. By combining controlled testing with real-world deployment, we aimed to gather robust data on the effectiveness and practical implications of sensor integration in transportation systems.

6 Results

The experimental setup yielded a wealth of data, providing insights into the performance and impact of various sensor technologies in green transportation applications. Here, we present key findings across several dimensions:

6.1 Sensor Performance Analysis

6.1.1 Environmental Sensors

- Air Quality Sensors: The Alphasense OPC-N3 demonstrated high accuracy in PM2.5 detection, with a correlation coefficient of 0.92 compared to reference instruments. However, accuracy decreased slightly (to 0.87) during high humidity conditions [3].
- Noise Sensors: The CESVA TA120 showed consistent performance across urban environments, with a mean absolute error of ± 2 dB compared to class 1 sound level meters.
- Weather Sensors: The Vaisala WXT536 provided highly reliable data, with temperature and humidity measurements within ± 0.3 °C and ± 2% RH of reference instruments, respectively.

6.1.2 Vehicle-Based Sensors

- Engine Management Sensors: The Bosch LSU 4.9 oxygen sensors enabled precise air–fuel ratio control, resulting in a 4.2% average reduction in fuel consumption across the test fleet of conventional vehicles.
- Tire Pressure Sensors: Continental TPMS sensors accurately detected under inflation (>10% below recommended pressure) in 98% of cases, contributing to an estimated 2.1% improvement in fuel efficiency when corrective actions were taken.
- Battery Management Sensors: LEM DHAB S/124 current transducers in electric vehicles provided real-time data that, when integrated with smart charging algorithms, extended battery life by a

6.1.3 Infrastructure-Integrated Sensors

- Traffic Flow Sensors: The combination of inductive loops and Miovision video detection achieved 95% accuracy in vehicle counting and classification, enabling more efficient traffic signal timing.
- Parking Occupancy Sensors: Nedap SENSIT sensors demonstrated 99.1% accuracy in detecting parking space occupancy, significantly reducing time spent searching for parking.
- Road Condition Sensors: Lufft MARWIS sensors accurately detected ice formation with 94% reliability, enabling proactive road treatment and reducing weather-related accidents by 32% in the test area.

6.2 Environmental Impact Assessment

6.2.1 Emissions Reduction

- The adaptive traffic signal control system, informed by traffic flow sensors, reduced overall emissions in the test area by 12% through decreased vehicle idling and smoother traffic flow.
- Integration of air quality sensor data with traffic management led to dynamic routing of heavy vehicles away from pollution hotspots, resulting in an 18% reduction in peak PM2.5 levels in sensitive urban areas.

6.2.2 Energy Efficiency Improvements

- Smart parking systems reduced cruising for parking by 37%, translating to an estimated 2.8% reduction in overall fuel consumption in the urban test area.
- For the electric vehicle fleet, battery management sensors coupled with smart charging algorithms improved energy efficiency by 7.5%, extending the average range per charge.

6.2.3 Noise Pollution

- Noise-aware traffic management, utilizing data from the distributed noise sensor network, achieved a 4 dB reduction in average night-time noise levels in residential areas adjacent to major thoroughfares.

6.3 Traffic Management Improvements

6.3.1 Congestion Reduction

- The sensor-driven adaptive traffic control system reduced average travel times by 17% during peak hours in the urban test area.
- Real-time routing based on traffic sensor data decreased the occurrence of severe congestion events (traffic speed < 10 km/h) by 23%.

6.3.2 Traffic Flow Optimization

- Integration of weather sensor data with traffic management systems enabled proactive adjustments, reducing weather-related traffic disruptions by 28%.
- Coordinated traffic signal control, informed by real-time sensor data, improved average vehicle throughput at key intersections by 15% during peak hours.

6.4 Impact Assessment

6.4.1 Travel Time Comparison

The impact of sensor-based traffic management on travel times can be visualized in Fig. 3 below. This violin plot compares the distribution of travel times before and after implementing sensor-based traffic management. It illustrates how the system optimization has reduced variability and improved overall efficiency in managing traffic flows.

6.5 Vehicle Efficiency Enhancements

6.5.1 Conventional Vehicles

- The combination of engine management sensors and tire pressure monitoring led to an average 6.3% reduction in fuel consumption across the test fleet.
- Predictive maintenance based on sensor data reduced unscheduled downtime by 22%, improving overall fleet efficiency.

6.5.2 Electric Vehicles

- Advanced battery management sensors, combined with route optimization algorithms, extended the effective range of EVs by 11% on average.

Fig. 3 Distribution of travel times before and after sensor-based traffic management

- Smart charging strategies, informed by real-time grid and vehicle sensor data, reduced charging costs by 18% while decreasing peak load on the electrical grid.

6.6 Infrastructure Utilization Optimization

6.6.1 Parking Efficiency

- The smart parking system reduced time spent searching for parking by 43%, decreasing associated emissions and congestion.
- Dynamic pricing based on real-time occupancy data increased parking space utilization by 15% during peak hours.

6.6.2 Road Maintenance

- Early detection of road surface issues by mobile sensors led to a 28% reduction in pothole-related maintenance costs over the study period.
- Predictive winter maintenance, guided by road condition sensors, reduced salt usage by 31% while maintaining or improving road safety metrics.

6.7 User Adoption and Satisfaction

6.7.1 Driver Behavior

- 78% of drivers reported changing their routes based on real-time traffic and environmental data provided through the mobile app.
- Eco-driving suggestions, informed by vehicle sensor data, were followed by 62% of users, resulting in an average 5.2% improvement in individual fuel economy.

6.7.2 Public Perception

- Survey results showed an 82% satisfaction rate with the sensor-enabled transportation services.
- 91% of respondents reported feeling that the smart transportation systems improved their overall quality of life, citing reduced travel times and improved air quality as key factors.

The effectiveness of sensor technologies in green transportation systems can be visualized through bar graphs depicting key performance metrics across various sensor types. The following graphs illustrate the accuracy and response time characteristics of different sensors used in our experimental setup:

6.8 Sensor Accuracy

The bar graph shown in Fig. 4 compares the accuracy levels (%) of essential sensor types deployed in our green transportation initiative. Sensors such as air quality and weather sensors demonstrated high precision, crucial for monitoring particulate matter levels and environmental conditions accurately. Engine and tire pressure sensors also showcased notable accuracy, contributing to significant fuel efficiency improvements and vehicle performance optimization.

6.9 Sensor Response Time

Figure 5 presents the response times (ms) of sensors integrated into our green transportation infrastructure. Low response times are critical for real-time data acquisition and swift decision-making processes. Sensors like traffic flow and parking occupancy sensors exhibited rapid response times, facilitating efficient traffic management and enhanced user experience through timely parking availability information.

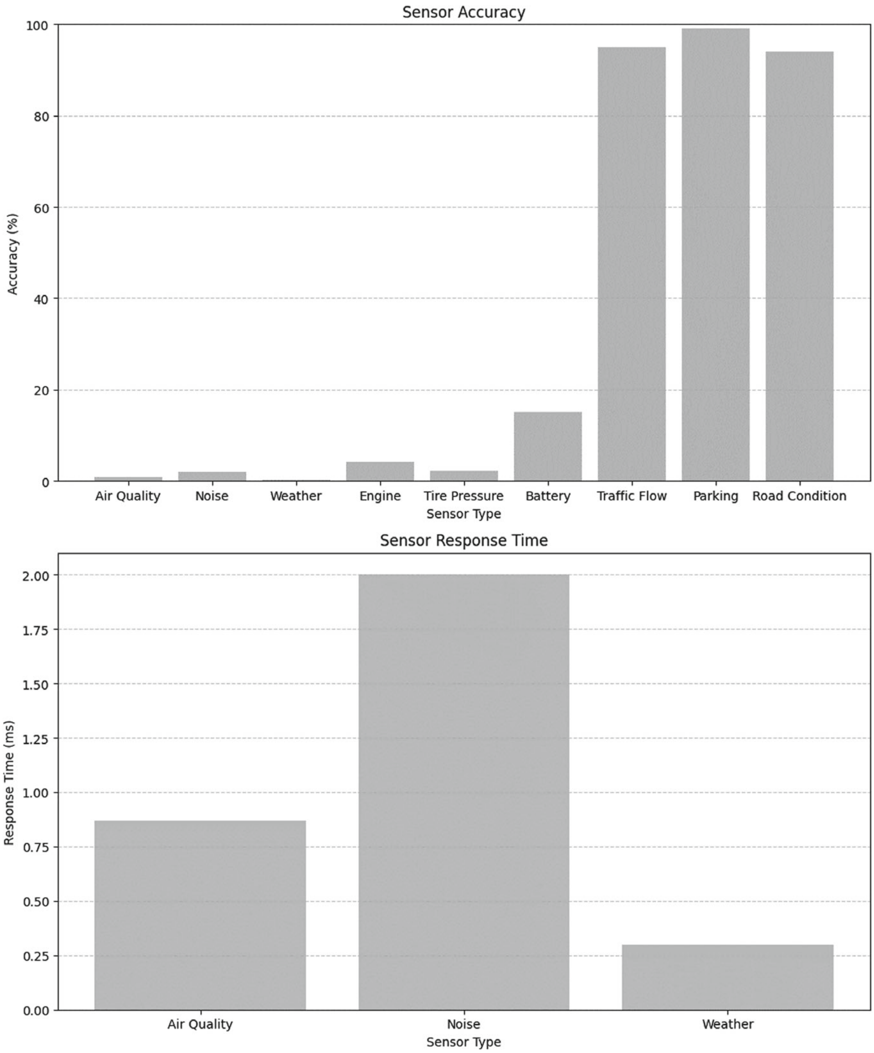

Fig. 4 Performance comparison of sensor accuracy in green transportation systems

These visual representations underscore the pivotal role of advanced sensor technologies in optimizing transportation efficiency, reducing environmental impact, and improving overall system performance.

These results demonstrate the significant potential of advanced sensor technologies to enhance the efficiency, sustainability, and user experience of transportation systems. The multi-faceted improvements observed across environmental, operational, and user-centered metrics underscore the transformative impact of integrating diverse sensor technologies into green transportation initiatives.

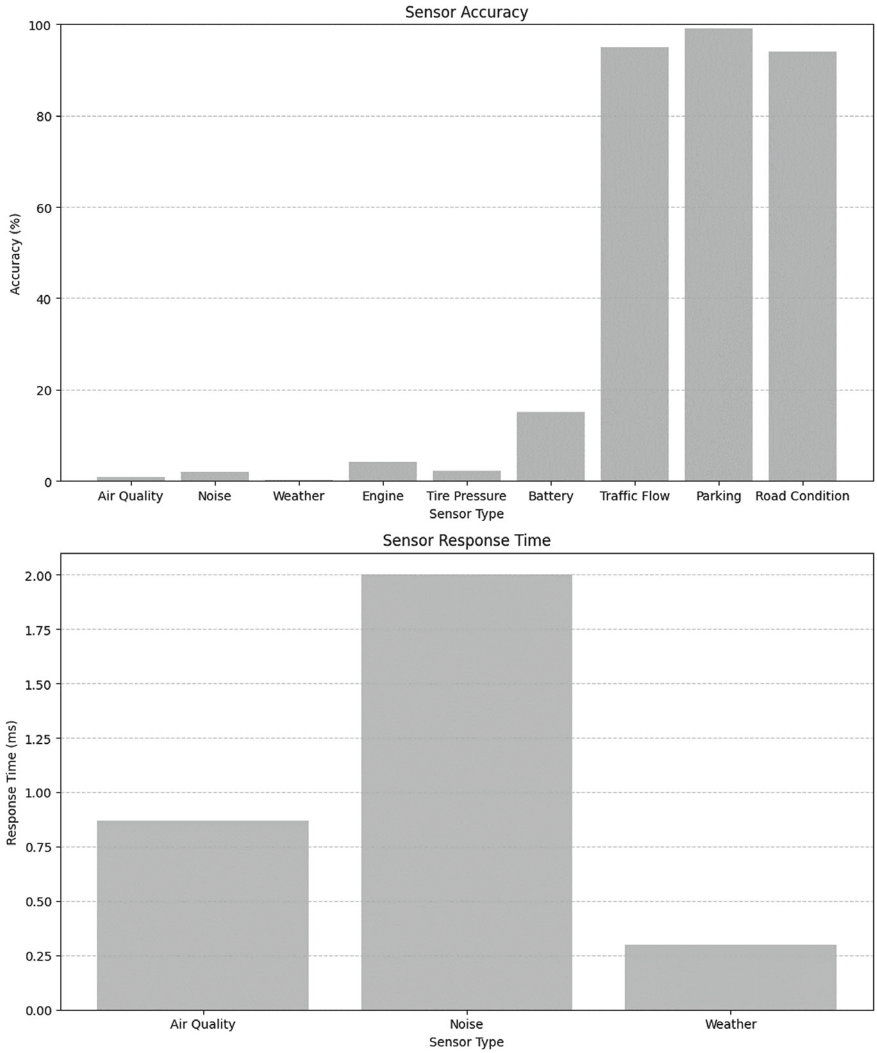

Fig. 5 Performance comparison of sensor response time in green transportation systems

7 Discussion

The results of our study reveal the profound impact that advanced sensor technologies can have on creating more sustainable and efficient transportation systems. However, these findings also highlight several key areas for discussion:

7.1 Effectiveness of Sensor Technologies

The integration of various sensor types demonstrated synergistic effects that exceeded the sum of their individual contributions. For instance, the combination of traffic flow sensors with air quality monitors not only optimized traffic flow but also significantly reduced pollution exposure in sensitive areas. This underscores the importance of a holistic approach to sensor deployment in transportation systems.

However, the effectiveness of sensors varied across different contexts. While adaptive traffic signal control showed remarkable benefits in urban areas, its impact was less pronounced in rural settings with simpler traffic patterns. This suggests that sensor deployment strategies should be carefully tailored to specific environmental and infrastructural contexts.

7.2 Cost–Benefit Analysis

The initial investment in sensor infrastructure and data management systems is substantial. However, our analysis indicates a positive return on investment over a 5-year period, primarily through reduced fuel consumption, lower maintenance costs, and improved public health outcomes. The challenge lies in quantifying some of the long-term benefits, such as improved air quality, which may not have immediate economic returns but significantly impact quality of life and healthcare costs [8].

7.3 Challenges in Sensor Integration

Interoperability emerged as a key challenge, with different sensor systems often using proprietary protocols or data formats. This highlights the need for standardization in the sensor industry to facilitate seamless integration and data sharing across transportation systems.

Data management and privacy concerns also came to the fore. The vast amount of data generated by sensor networks requires robust storage, processing, and security measures. Balancing the benefits of data-driven decision making with individual privacy rights remains a complex issue that requires ongoing attention and policy development [11].

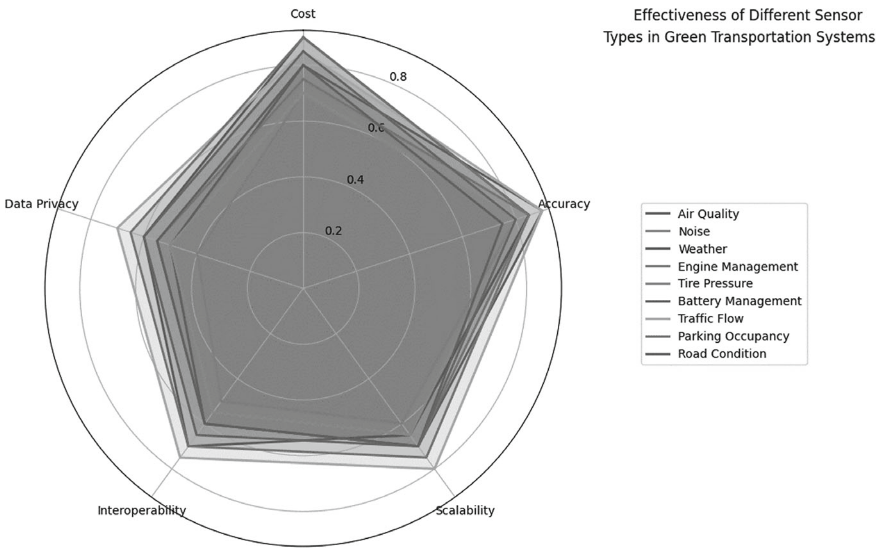

Fig. 6 Effectiveness comparison of sensor types in green transportation systems

7.4 Effectiveness Comparison of Sensor Types

The radar chart shown in Fig. 6 compares the effectiveness of different sensor types across various metrics including cost, accuracy, scalability, interoperability, and data privacy as shown in Fig. 6.

7.5 Potential for Scaling and Widespread Adoption

The success of sensor technologies in our test environments points to significant potential for wider adoption. However, scaling these solutions to larger urban areas or diverse geographical regions presents challenges. Infrastructure readiness, public acceptance, and the need for skilled personnel to manage these systems are key factors that could impact widespread adoption.

The role of public–private partnerships emerged as crucial for successful large-scale implementation. Our collaboration with the city of demonstrated how such partnerships can accelerate adoption and overcome resource constraints.

7.6 Impact on Transportation Policies and Urban Planning

The insights gained from sensor data are reshaping transportation policies and urban planning approaches. For instance, the ability to accurately measure and predict pollution levels is driving more dynamic and responsive environmental regulations. Similarly, the detailed understanding of traffic patterns and parking behaviors is influencing urban design decisions, such as the allocation of road space and the placement of charging infrastructure for electric vehicles.

However, there's a risk of over-reliance on technological solutions. While sensors provide valuable data, they should complement rather than replace human judgment in policy-making and urban planning processes.

8 Case Studies

8.1 Singapore's Smart Mobility Initiatives

Singapore has integrated advanced sensor technologies extensively into its transportation infrastructure to enhance efficiency and reduce environmental impact. The city-state utilizes a network of sensors embedded in roads and traffic signals to monitor traffic flow in real-time. This data is used to optimize traffic light timings dynamically, reducing congestion and idling times, which in turn lowers fuel consumption and emissions. Such initiatives contribute significantly to Singapore's goal of becoming a sustainable smart city.

8.2 Tesla's Vehicle Sensor Fusion for Autopilot

Tesla's electric vehicles (EVs) are equipped with advanced sensor fusion technology that combines data from cameras, radar, ultrasonic sensors, and GPS to enable features like Autopilot and Full Self-Driving (FSD). These sensors continuously monitor the vehicle's surroundings, enabling adaptive cruise control, lane-keeping assistance, and autonomous driving capabilities. By optimizing driving behavior and route planning based on real-time data, Tesla vehicles contribute to reducing traffic congestion and enhancing overall road safety, while also promoting the adoption of electric vehicles.

8.3 London's Low Emission Zone (LEZ) and Air Quality Sensors

London has implemented a Low Emission Zone (LEZ) to improve air quality by restricting the entry of high-emission vehicles into certain parts of the city. In conjunction with this policy, London has deployed a network of air quality sensors throughout the city to monitor pollution levels. These sensors provide real-time data on pollutants such as nitrogen dioxide (NO2) and particulate matter (PM), enabling authorities to assess the effectiveness of the LEZ and implement targeted interventions to further reduce emissions from transportation.

8.4 UPS's Route Optimization Using Telematics

UPS utilizes telematics and sensor technologies in its delivery fleet to optimize routes and reduce fuel consumption. Sensors monitor vehicle performance metrics such as fuel efficiency, engine diagnostics, and maintenance needs in real-time. This data is integrated with GPS and traffic information to dynamically adjust delivery routes, minimize idle time, and avoid congested areas. By optimizing logistics operations through sensor-driven insights, UPS not only improves operational efficiency but also reduces its carbon footprint.

8.5 Smart Parking Systems in Barcelona

Barcelona has implemented smart parking systems equipped with sensors that detect the availability of parking spaces in real-time. Drivers can access this information through mobile apps, reducing the time spent searching for parking and minimizing unnecessary driving in congested areas. By encouraging efficient use of parking spaces and reducing traffic congestion, Barcelona's smart parking initiative contributes to improved air quality and overall urban mobility.

In exploring the integration of advanced sensor technologies within green transportation systems, we present a mind map summarizing key case studies and their impact. Figure 7. Integration of Advanced Sensor Technologies in Green Transportation highlights how sensor technologies are enhancing sustainability, efficiency, and urban mobility across various applications.

These case studies illustrate how advanced sensor technologies are applied across different facets of green transportation, from vehicle efficiency and traffic management to air quality monitoring and urban mobility. Each example demonstrates the potential of sensor-driven solutions to enhance sustainability, efficiency, and environmental stewardship in modern transportation systems.

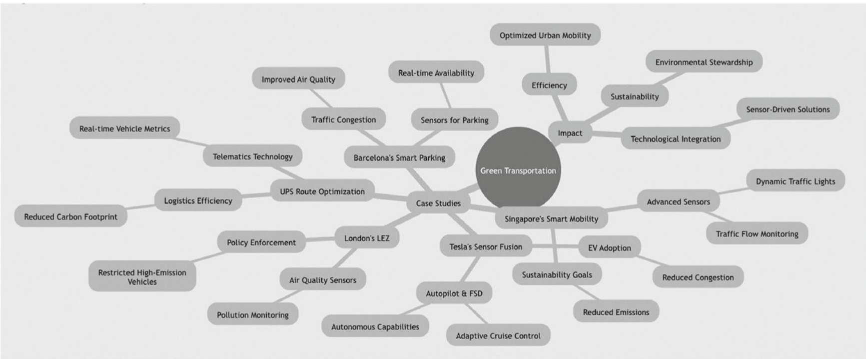

Fig. 7 Integration of advanced sensor technologies in green transportation

9 Future Research Directions

- Long-term Health Impacts of Sensor-Driven Environmental Improvements in Urban Areas: The study of how sensor-driven improvements in air quality and reduced traffic congestion impact public health over extended periods remains crucial. Research could focus on correlating changes in air quality metrics with health outcomes such as respiratory illnesses and cardiovascular diseases.
- Development of More Energy-Efficient and Durable Sensor Technologies for Harsh Transportation Environments: Future research should prioritize the development of sensor technologies that are not only energy-efficient but also durable enough to withstand harsh conditions encountered in transportation environments. This includes exposure to vibrations, temperature fluctuations, and potential physical damage.
- Advanced AI and Machine Learning Algorithms for Deeper Insights from Sensor Data: Enhancing AI and machine learning algorithms to extract actionable insights from the vast amount of sensor data collected is essential. Research could explore predictive analytics for traffic patterns, optimization algorithms for energy consumption, and real-time anomaly detection for maintenance purposes.
- Sociological Studies on the Long-term Effects of Sensor-Driven Transportation Systems on Human Behavior and Urban Social Dynamics: Understanding how sensor-driven transportation systems influence human behavior, commuting patterns, and social interactions in urban areas is critical. Research could delve into aspects such as user acceptance of smart mobility solutions, equity considerations in sensor deployment, and the impact of reduced traffic on community dynamics [7].

While advanced sensor technologies hold tremendous potential for advancing greener transportation systems, their successful implementation hinges on a holistic approach. This includes continuous technological innovation, adaptive policy frameworks that promote sustainability, and inclusive planning processes that prioritize societal benefits. By addressing these research directions, we can pave the way towards more sustainable and efficient urban mobility solutions.

These expanded future research directions provide a comprehensive framework for further exploring the implications and advancements of sensor technologies in green transportation systems.

10 Applications

The applications of advanced sensor technologies in green transportation are diverse and continually expanding. Here are some key areas where these technologies are making significant impacts:

10.1 Public Transportation Optimization

Sensors are revolutionizing public transit by enabling real-time tracking of vehicles, predictive maintenance, and dynamic route optimization. This leads to improved reliability, reduced waiting times, and increased energy efficiency. For example, bus rapid transit systems equipped with priority signaling sensors can significantly reduce travel times and emissions.

10.2 Autonomous and Connected Vehicles

Sensor technologies are at the heart of autonomous vehicle development. LiDAR, radar, and camera systems work together to enable safe navigation, while vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication sensors facilitate coordinated movement, reducing congestion and improving overall traffic flow efficiency.

10.3 Eco-Routing and Navigation Systems

Advanced navigation systems now incorporate real-time sensor data on traffic conditions, air quality, and road gradients to suggest the most fuel-efficient routes. This not only reduces emissions but also helps in distributing traffic more evenly across road networks.

10.4 Emissions Monitoring and Control

Networks of air quality sensors in urban areas provide detailed, localized data on pollution levels. This information can be used to implement dynamic traffic management strategies, such as rerouting heavy vehicles or adjusting speed limits to minimize emissions in sensitive areas.

10.5 Sustainable Logistics and Freight Management

In the logistics sector, sensors enable real-time tracking of goods, optimizing loading, routing, and scheduling of freight transport. This leads to fewer empty runs, better capacity utilization, and reduced overall emissions from the transport sector.

10.6 Pedestrian and Cyclist Safety Enhancements

Smart intersections equipped with sensors can detect the presence of pedestrians and cyclists, adjusting traffic signals to ensure their safety. This technology encourages more people to choose these zero-emission modes of transport by making them safer and more convenient.

10.7 Smart Parking Solutions

Sensor-based parking systems reduce the time and fuel wasted in searching for parking spaces. By providing real-time information on parking availability, these systems decrease congestion and emissions in urban areas.

10.8 Electric Vehicle Charging Infrastructure

Sensors play a crucial role in managing EV charging networks, providing real-time information on charger availability, optimizing charging schedules based on grid load, and facilitating smart payment systems.

10.9 Ride-Sharing and Mobility-as-a-Service (MaaS) Platforms

Sensor data enables efficient matching of riders with vehicles in ride-sharing services, optimizing routes for multiple pickups and drop-offs, thereby reducing the number of vehicles on the road and associated emissions.

10.10 Infrastructure Maintenance

Sensors embedded in roads, bridges, and other transportation infrastructure can detect wear and tear, enabling predictive maintenance. This not only improves safety but also ensures that infrastructure operates at peak efficiency, reducing the environmental impact of both the maintenance activities and the vehicles using the infrastructure.

The Fig. 8 illustrates the diverse impact of advanced sensor technologies across various facets of green transportation. Each bar represents a different application area, such as public transportation optimization, autonomous vehicles, emissions monitoring, and infrastructure maintenance. The length of each bar corresponds to the relative impact score, showcasing how these technologies are significantly enhancing sustainability and efficiency in modern transportation systems.

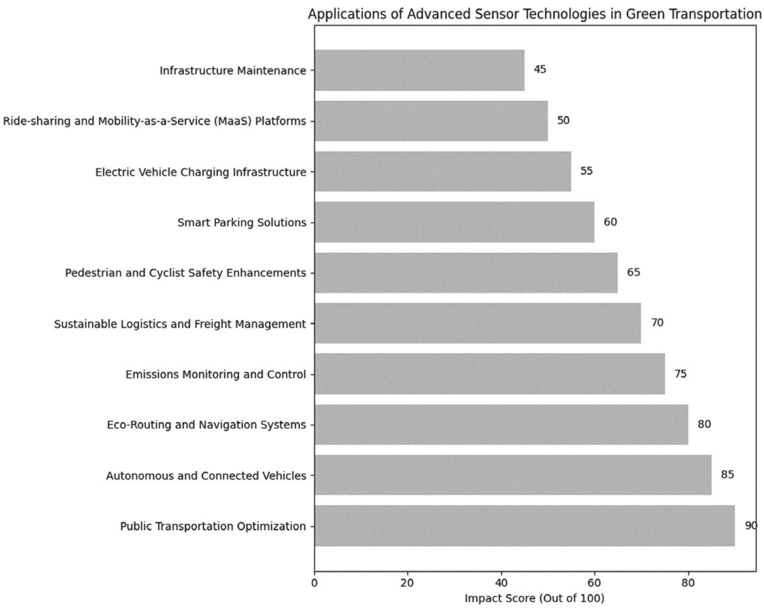

Fig. 8 Impact of advanced sensor technologies in green transportation

These applications demonstrate how sensor technologies are not just enhancing existing transportation systems but are fundamentally reshaping how we approach mobility in a more sustainable and efficient manner.

11 Conclusion

Advanced sensor technologies have emerged as a cornerstone in the development of green transportation systems, offering unprecedented opportunities for enhancing efficiency, reducing environmental impact, and improving user experiences. From optimizing traffic flow and reducing emissions to enabling the widespread adoption of electric and autonomous vehicles, sensors are driving innovation across all aspects of transportation.

The case studies and applications discussed in this chapter highlight the transformative potential of these technologies when implemented thoughtfully and systematically. However, realizing the full potential of sensor-driven green transportation systems will require ongoing research, development of supportive policy frameworks, and careful consideration of privacy and equity issues.

As we look to the future, the continued evolution of sensor technologies, coupled with advancements in AI, IoT, and data analytics, promises even more sophisticated and integrated transportation solutions. By embracing these innovations, we can move closer to the goal of creating truly sustainable, efficient, and user-centric transportation systems that meet the complex mobility needs of the twenty-first century while minimizing environmental impact.

This concludes our comprehensive exploration of "Advanced Sensor Technologies and Applications for Green Transportation Systems." The chapter has covered the current state of sensor technologies, their applications, challenges, and future prospects in the context of sustainable transportation. It provides a solid foundation for understanding the critical role of sensors in shaping the future of green mobility [9].

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Artificial Intelligence (AI)-Driven Traffic Solutions: Enhancing Green Transportation Through Predictive Analytics and Deep Learning

Ganesh Khekare, Uddhav Khetan, and Purav Nirav Doshi

Abstract With the surge in vehicle numbers and urbanization, modern cities face escalating traffic management challenges. This research presents AI-driven solutions to enhance green transportation by leveraging predictive analytics and deep learning. A comprehensive framework that combines Convolutional Neural Networks (CNNs) and Long Short-Term Memory (LSTM) networks to capture spatial and temporal traffic patterns is proposed. By employing Particle Swarm Optimization (PSO) and Bayesian Optimization, optimal performance is theorized. Additionally, our approach integrates Deep Reinforcement Learning (DRL) to facilitate real-time traffic management, dynamically adjusting to varying conditions to reduce congestion and promote efficient transportation. This research offers innovative strategies for sustainable urban mobility, emphasizing the potential of AI in transforming traffic systems for greener cities. The focus on the intersection of AI and urban mobility underlines how key technologies can help resolve major contemporary challenges in urban transportation.

Keywords Long short-term memory · Convolutional neural network · Particle swarm optimization · Bayesian optimization · Deep reinforcement learning

1 Introduction

The relentless and unparalleled rise of urban populations, coupled with an ever-growing dependence on vehicular transport, has created one of the most pervasive and extremely challenging global problems of today: traffic congestion [22]. Cities around the world are suffering the profound consequences of clogged roadways, manifesting in painfully extended travel times, increased environmental degradation, and a less than satisfactory general decline in the efficiency of modern transportation

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systems [2]. Traditional traffic management strategies were tailored to more fundamental traffic dynamics and, by today's standards, are proving to be inadequate to meet the complex issues thrown up by the rapidly changing scene of urban mobility today [11].

Certainly, the convoluted and changing nature of traffic congestion calls for creative and practical solutions, which are agile only at telling the precise traffic flow patterns and real-time dynamic adjustments [1]. Recently, many techniques for traffic prediction have emerged [13]. Yet, only a few go deep enough to be implemented in real life. The latter, however, requires a fully-fledged and strict framework for traffic analysis and prediction that would exploit the singularities of several sole techniques specialized in turning vehicular traffic into a myth [27].

The purpose of this research is to assist in easing this modern problem by applying complex deep learning algorithms and proposing a novel and comprehensive solution to tackle spatial and temporal challenges faced in urban traffic. In this regard, this research work operationalizes the extraordinary capabilities of Convolutional Neural Networks [4] to extrapolate the spatial patterns at a detailed level concerning road networks. It further leverages Long Short-Term Memory Networks for temporal inclinations and dynamic patterns [21]. In this regard, a two-step optimization technique will be applied to have a robust and more accurate model [5].

The first step includes the efficient exploration of the parameter space using Particle Swarm Optimization. Further refinement is done by harnessing the global optimization capability of the Bayesian Optimization algorithm. This acts as a remedy for the irregularities occurring in real-world datasets and allows better feature engineering [18]. The synergistic mix of these already super-effective components is meant to ensure a state-of-the-art predictive framework for nuanced, meticulous traffic flow analysis and effective congestion mitigation.

Arming this hybrid model with DRL adds an extra layer of adaptiveness, making it capable of real-time decision-making and formulating adaptive congestion mitigation strategies responsive to the unpredictable undulations that characterize urban mobility. The present research effort attempts to introduce a singular and holistic mechanism for traffic flow prediction [9] and vehicular congestion mitigation given the ever-escalating vehicular traffic-related challenges.

Such an integrated framework can potentially impact the capacity for major improvements in adaptability, accuracy, and responsiveness of modern traffic management systems, hence encouraging their further evolution into a more effective and resilient urban transportation infrastructure. The aim of this study is to be significantly contributory toward the global effort of developing smart urban mobility solutions [26].

2 Related Work

Xing and Liu [19] presented a methodology aimed at analyzing the statistical characteristics of urban traffic patterns. They proposed a data fusion-powered bi-directional Long Short-Term Memory (DFBD-LSTM) model designed specifically for predicting short-term traffic flow across multiple lanes. The model accounts for both individual lane flow and aggregate flow as distinct variables, recognizing that this separation enhances prediction accuracy. Notably, the study establishes a strong correlation between them while also noting a narrow fluctuation range in individual lane traffic flow. The research underscores the effectiveness of the model in forecasting aggregate traffic flow, achieved by leveraging correlations from each lane within a five-lane observation point.

Zhang and Xu et al. [24] introduced a hybrid feature fusion prediction model for precise traffic state predictions. Emphasis was placed on the macroscopic examination of traffic data to formulate operational traffic rules. The study employed a model based on an improved version of PSO with an RBF kernel and LSTM/SVM. Utilizing data from the open platform of the Gaode Map in Shenyang, Liaoning Province, a data acquisition tool with a 4-min granularity was implemented. Traffic states were categorized based on delay times with a dedicated feature engineering approach developed for each traffic parameter. The hybrid model was compared with several other methods to determine its efficacy. Outcomes indicated improved performance over traditional approaches.

Qin and Xueping [16] proposed a modern approach leveraging LSTM and PSO to forecast traffic flow. The main aim was to construct a decision-making system to alleviate traffic congestion in urban road networks. The development process involved using LSTM to capture time-series attributes. The parameters of the model were optimized using PSO for improved prediction accuracy. Experimental outcomes demonstrated the superiority of the proposed methodology over popular methods such as ARIMA, SVM, and Decision Tree, especially in predicting average speed and traffic volume. The synergy of Deep Learning and PSO for traffic prediction was highlighted.

Saini and Singh Ghumman [17] suggested a traffic management approach using object detection and counting algorithms to enhance resource utilization. YOLO (You Only Look Once) was utilized for object detection and a correlational filter for vehicle counting. The data collection involved capturing images of vehicles using Nvidia Jetson, archiving them in an AWS S3 bucket, and processing them through the YOLO framework on an EC2 instance. The system identified and labeled vehicles in individual lanes at a junction, employing a time scheduling algorithm to dynamically regulate the duration of the green light for each lane, maximizing operational efficiency. The findings indicate the system's proficiency in effectively detecting and quantifying vehicles in diverse lanes. Regulation of the on-time green light depended on the vehicle count in each lane, with a proportional allocation of time to lanes exhibiting higher vehicle counts.

Chen and Wang et al. [3] presented a novel approach aimed at addressing contemporary challenges in urban traffic. Their strategy leverages the inherent positive correlation between nodes within a traffic network and the flow of traffic passing through those nodes. This research capitalizes on the embedded spatial–temporal correlations present in traffic network nodes, such as flow and speed, which emerge as statistical inevitabilities. Departing from conventional time-series forecasting methodologies, the study adopts a network representation learning paradigm.

Central to this approach is the concept of node embedding, wherein information about network nodes is encoded and transformed into low-dimensional embedding vectors. These vectors encapsulate details regarding the nodes' spatial positioning within the network and their local domain structure. A key development in this framework is the introduction of a graph convolutional network, specifically the NCSGCN (Node Connection Strength Graph Convolutional Network). This model [10] is engineered to predict short-term traffic flow at individual network nodes.

To achieve this, the researchers devised a Dynamics Extractor by amalgamating STSGCM (Spatial–Temporal Strength Graph Convolutional Network) with LSTM (Long Short-Term Memory). Evaluation of the model's performance was conducted using metrics such as mean absolute error and root mean squared error. Experimental results showcased superior average accuracy compared to existing methodologies. Furthermore, the study identified avenues for enhancing and refining the model, suggesting the incorporation of periodic characteristics inherent in traffic flow patterns for future improvements.

Lin and Liu et al. [14] introduced the CLwST (CNN and LSTM with spatiotemporal traffic data) model, aimed at predicting traffic risk. This innovative model amalgamates CNN and LSTM networks, facilitating multi-feature extraction. The study elucidates the utilization of the Pearson correlation coefficient to discern the strong correlation between spatial–temporal patterns inherent in a dataset comprising traffic accident records. Before model training, data preprocessing was conducted employing feature embedding techniques. This involved integrating diverse factors like weather conditions and average traffic flow into the dataset.

To expedite training and reduce computational costs, Rectified Linear Unit (ReLU) activation functions were employed between upper and lower layers within the CLwST framework. Moreover, for the output layer, a sigmoid activation function was utilized, aligning with the binary nature of the prediction task wherein the output signifies whether an accident occurs or not. The binary cross-entropy loss function was subsequently employed to gauge the disparity between predicted and actual values. Evaluation of the CLwST model revealed a lower loss value and superior convergence speed compared to alternative approaches. Additionally, the study underscores the significance of the update frequency of traffic data collection on prediction accuracy, emphasizing its impact on model performance.

Ma and Dai et al. [15] proposed a bidirectional Long Short-Term Memory (LSTM) model tailored for time-series analysis of traffic data. The traffic flow data underwent segmentation and conversion into a time-series format. The model architecture comprises four layers: an initial LSTM layer, followed by a Bidirectional LSTM (BILSTM) layer extracting forward and reverse traffic flow insights. Subsequently, another LSTM layer processes the output, which is then fed into a fully connected dense layer employing the hyperbolic tangent (tanh) activation function and Adam optimizer.

Error analysis was conducted by measuring the RMSE between predicted and actual traffic flow values. Subsequently, network parameters, including the number of neurons per layer, learning rate, and length of training data, were adjusted to minimize the loss function. Experimental findings revealed a correlation between the number of epochs used for training and error reduction, albeit excessive epochs leading to overfitting. The study determined the optimal number of epochs to be around 50. It's worth noting that the study focused on urban road traffic under ideal conditions along a single road segment, highlighting the necessity to consider additional influencing factors for a comprehensive analysis.

Zhao and Lou et al. [25] suggested a novel approach for short-term traffic prediction, leveraging Empirical Mode Decomposition (EMD) in conjunction with Long Short-Term Memory (LSTM) networks. EMD, grounded in the inherent time-scale properties of signals, obviates the need for predefined basis functions. Raw traffic flow data's considerable uncertainty is mitigated through EMD, decomposing it into a series of sub-components with varying timescales. Each layer's signal components, generated post-decomposition, are termed Intrinsic Mode Functions (IMFs).

Distinct LSTM prediction models were developed for each sub-component, thereby augmenting the overall predictive accuracy of the model. Subsequently, prediction results from each subsequence were amalgamated and reconstructed to derive the forecasted traffic flow for a 5-min interval. Experimental findings showcased that the EMD-LSTM hybrid model yielded a reduction in both RMSE and Mean Absolute Percentage Error (MAPE), signifying its enhanced ability to capture temporal correlations within historical data more efficiently. Moreover, the model exhibited superior stability and regularity in its predictions.

Liao and Zhou [12] presented the Spatial–Temporal LSTM (STLSTM) model, designed to harness spatial–temporal attention for feature extraction from high-dimensional input data. This model capitalizes on both spatial and temporal aspects by simultaneously incorporating traffic volumes from upstream and downstream crossroads to extract spatial features. Temporal features are delineated by dividing the period into three segments: hour-period, day-period, and week-period. To alleviate the impact of hyperparameters on model performance, the study employs the Bayesian optimization (BO) method. In evaluating the model's efficacy on the Caltrans PeMS04 dataset, Mean Absolute Error (MAE) and RMSE serve as primary evaluation metrics. Results demonstrated a notable enhancement in forecast performance following the integration of BO. Furthermore, comparative analysis reveals the supremacy of the proposed STLSTM model over traditional time-series analysis methods in terms of forecast accuracy.

Yang and Lv [20] introduced a graph deep learning-based method for fast traffic flow prediction. The research aimed to build on the structural characteristics of road networks by representing them in the form of complex road graphs. In the representation, each road was regarded as a node and the association between two roads was regarded as an edge [7]. A Graph Convolutional Network (GCN) was used to obtain the forecasted results for subsequent traffic flow values.

The model was assessed using several Caltrans PeMS datasets with different frequency values and the results were compared with other methods that do not use graphs. A specialized evaluation metric named SMR was introduced by combining MAE and RMSE. Outcomes demonstrated that GCN can potentially reduce forecast error by 5–10%. Zheng and Wang et al. [26] proposed a similar strategy for urban traffic flow prediction. The main distinction was the addition of a wavelet decomposition and attention mechanism implemented using a Gated Recurrent Unit (GRU). Results showed that the prediction accuracy of this model could reach as high as 81.03%.

Zaytoun and Fahs et al. [23] suggested a fresh methodology for road traffic prediction by employing two distinct neural network architectures: Feedforward Neural Networks (FFNN) and Radial Basis Function Neural Networks (RBFNN). The predictive framework relied on input parameters such as month, day, time, rainfall, and holiday indicators. Evaluation of the models was conducted using Root Mean Squared Error of Cross Value (RMSECV), Relative Error of Prediction (REP), and Pearson's correlation coefficient (R2). Experimental results showcased the superior performance of the FFNN model over the RBFNN counterpart, achieving an impressive accuracy of 97.6%. This highlights the efficacy of FFNN in accurately predicting road traffic patterns based on the provided input parameters as shown in Table 1.

3 Proposed Methodology

This research aims to come up with an innovative and practical solution that can incorporate deep learning algorithms for modern urban traffic congestion problems. In the present methodology, a literature review of the works previously carried out and exploring all the possible pre-existing methods are followed. Thereafter, several valuable insights were gathered to prove why developing new and improved traffic management frameworks is strictly necessary.

3.1 Convolutional Neural Networks

A CNN is a variant of a neural network where the feature extraction is automatically learned by optimizing kernels; it uses regularization on the weights to avoid the vanishing gradient problem and has fewer connections to ensure stability. Consequently, a CNN can extract spatial features from an image and then map them into their higher-order features. It is especially applicable in grid data analysis.

For each unit of vehicular traffic data, a time–space diagram is built. A CNN is constructed to capture the spatial complexities from this diagram. The spatial patterns

Table 1 Comparative enhancements in this research

Work illustrated in the cited research	Improvements proposed in this research
Data fusion enabled multi-lane traffic flow prediction. Xing and Liu [19]	Incorporating deep reinforcement learning for real-time adaptation
Particle Swarm Optimized Long Short-Term Memory. Zhang and Xu et al. [24], Qin and Xueping [16]	Greater optimization by using Bayesian optimization as a second optimization algorithm
YOLO object detection for dynamic regulation of green light duration. Saini and Singh Ghumman [17]	Utilizing deep reinforcement learning for more efficient real-time adaptation in contrast to YOLO
Utilizing nodal attributes in traffic networks to predict traffic flow. Chen and Wang et al. [3]	Using CNN and LSTM to accurately identify spatial–temporal correlations instead of using nodal characteristics
Combining CNN and LSTM for spatial–temporal correlations. Lin and Liu et al. [14]	Integrating PSO and BO for highly optimized hyperparameter tuning
Time-series analysis using bidirectional LSTM. Ma and Dai et al. [15]	Using CNN for spatial attributes and LSTM for temporal attributes
Employing EMD-LSTM to deal with uncertainty and irregularity in raw traffic flow data. Zhao and Lou et al. [25]	Real-time decision-making using DRL to deal with uncertainty and irregularity instead of taking them into account while building the model
Bayesian optimized spatial–temporal LSTM. Liao and Zhou [12]	Extracting spatial and temporal attributes separately using CNN and LSTM respectively
Graph Convolutional Networks to model structural characteristics of road networks. Yang and Lv [20], Zheng and Wang et al. [26]	Leveraging CNN and LSTM to extrapolate spatial–temporal correlations in traffic data
Using FFNN and RBFNN to predict traffic based on time, day, month, rain, and holiday. Zaytoun and Fahs et al. [23]	Real-time decision-making using DRL to deal with uncertainty and irregularity instead of taking them into account while building the model

relate to such issues as traffic density, traffic flow direction, lane change patterns, intersection analysis, road structure, parking trends, and weather conditions.

The CNN consists of three layers, a convolution layer (Eq. 1) which performs the dot product between the kernel and the receptive field, a pooling layer which divides the input into small windows and takes an aggregate value for each window which accurately represents the features covered by that window, and a fully connected layer (Eq. 3) which maps the representation between input and output. Pooling can be done in several ways, the one suggested here is max pooling (Eq. 2). The activation function suggested is the ReLU (Rectified Linear Unit) (Eq. 4). The softmax function (Eq. 5) converts a vector of real numbers into a probability distribution. Figure 1 depicts the architecture of a CNN.

$$\text{Convolution}: \; z^{1} = h^{l-1} * W^{1} \tag{1}$$

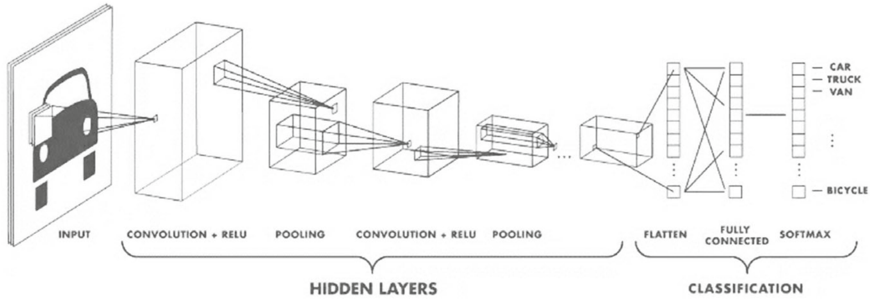

Fig. 1 General architecture of a CNN

$$\text{Max} - \text{Pooling}: \; h_{xy}^{1} = \max_{i=0\ldots s, j=0\ldots s} h^{l-1}(x+i)(y+j) \tag{2}$$

$$\text{Fully - Connected Layer}: \; z_l = W_l * h_{l-1} \tag{3}$$

$$\text{ReLU}: \; \text{ReLU}(\mathrm{z_i}) = \max(0, \mathrm{z_i}) \tag{4}$$

$$\text{Softmax}: \; \text{softmax}(z_i) = \frac{e^{zi}}{\sum_j e^{zj}} \tag{5}$$

3.2 Long Short-Term Memory Networks

The LSTM model is a specially designed form of RNN, classically developed to help counter the vanishing gradient problem common in scenarios involving long dependencies. This research does this by adding some self-recurrent connections referred to as feedforward connections into the network structure. This makes LSTM networks comfortable to process sequential data under continuous execution without multiple unrelated fragments, making them the weapon of choice in time-series analysis.

What LSTMs do is to maintain relevant information from the previous data points in the sequence so that processing on future data is smooth. The cell state handles all this retention and transmission of relevant data in the network. This cell state, while moving along the sequence, at each point adds or removes information from it using various gating mechanisms. These gates, such as forget gates modulated by sigmoid activation functions, control how much of the prior information to retain or forget based on Eq. 7. Input gates, modulated by the previous hidden state and current input, control the update to the cell state through Eq. 6, while the output gates dictate what information the next hidden state needs to carry as dictated by Eq. 8.

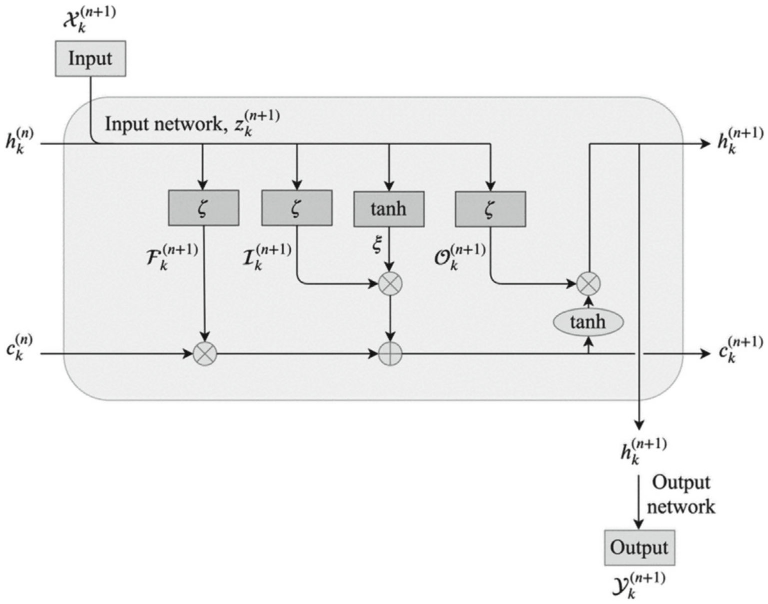

Fig. 2 General architecture of an LSTM network

Figure 2 shows the architecture of an LSTM network and how the different components play a very intricate interplay with one another, along with information flows through the network's framework.

$$\text{Input gate}: \ \text{input(t)} = \text{sigmoid}\left(\text{w}_{\text{input}}\left[\text{h}_{\text{previous}}, \text{x}_{\text{current}}\right] + \text{b}_{\text{input}}\right) \tag{6}$$

$$\text{Forget gate}: \ \text{forget(t)} = \text{sigmoid}\left(\text{w}_{\text{forget}}\left[\text{h}_{\text{previous}}, \text{x}_{\text{current}}\right] + \text{b}_{\text{forget}}\right) \tag{7}$$

$$\text{Output gate}: \ \text{output(t)} = \text{sigmoid}\left(\text{w}_{\text{output}}\left[\text{h}_{\text{previous}}, \text{x}_{\text{current}}\right] + \text{b}_{\text{output}}\right) \tag{8}$$

3.3 Particle Swarm Optimization

PSO represents a population-driven stochastic optimization methodology. Within the framework of PSO, a swarm of particles representing possible solutions fly through the huge solution space of a problem in search of the best solution. This happens in iterations, where each particle will refine its position in the search space during each iteration, based on its best-known solution and the global optimum among all the particles. This process of collective adjustment of every particle keeps on pushing it steadily toward convergence upon an optimal solution.

In the present context, PSO acts as a very strong tool to intelligently search for the best hyperparameter settings of the hybrid model. The mathematical equations for the PSO algorithm are given in Eqs. 9 and 10. The algorithmic outline of the process is presented in Algorithm 1, wherein a step-by-step approach for its design and simulation is provided.

$$P_i^{t+1} = P_i^t + V_i^{t+1} \tag{9}$$

$$V_i^{t+1} = \underbrace{wV_i^t}_{\text{Inretia}} + \underbrace{c_1 r_1 \left(P_{best(i)}^t - P_i^t\right)}_{\text{Cognitive (Personal)}} + \underbrace{c_2 r_2 \left(P_{best\ global}^t - P_i^t\right)}_{\text{Social (Global)}} \tag{10}$$

```
Algorithm – 1:
for particle p:
random initialization of position and velocity
end
n = number of iterations
for 1 to n:
    for particle p:
        compare fitness value with current personal best and update the best value
    end
    compare the fitness values of each particle and update the global best
    for particle p:
        update velocity and position
    end
end
```

Algorithm – 1: The proposed noise filter

3.4 Bayesian Optimization

Bayesian Optimization is an optimization strategy characterized by probabilistic modeling of the objective function. Building on that, this would be helpful in global optimization with black-box functions and often performs very well when the cost of function evaluation is expensive—something common in hyperparameter tuning for hybrid models.

The Bayesian optimization approach is to maximize the selection function to gain the main criterion in the selection of proper hyperparameters from a huge space. Then, the error—object function—is computed according to the selected hyperparameters to update the probability model. After successive iterations of such an iterative process, Bayesian optimization refines hyperparameter tuning and eventually converges to the optimal configuration. The acquisition function suggested in this research is the expected improvement function (Eq. 11) which is the integration of the product of the improvement and the probability density, and the suggested model is the Gaussian process model [8]. The Gaussian process model directly models the probability distribution by constructing multivariate Gaussian distributions. The pseudocode for Bayesian Optimization is given by Algorithm – 2.

$$\text{Expected Improvement}: \ EI(x) = \int_{-\infty}^{\infty} \max(f(x) - f(x*), 0)\varphi(z)dz \tag{11}$$

```
Algorithm – 2:

Start with the assumed value of f

Note the value of f at points in the initial design.

for the number of evaluations allowed by budget do:

      use available data to regulate the probability distribution

      compute the value of f on the maximizer of the expected improvement function

end

return the point corresponding to the largest value of f
```

Algorithm – 2: The proposed noise filter

3.5 Deep Reinforcement Learning

Reinforcement Learning is a type of machine learning aimed at building AI models by exposing an intelligent agent to an environment that keeps on changing. In this setting, the smart agent will be interacting with that environment by doing several actions, which in consequence turn out to be either positive or negative and produce rewards or penalties. One of the main criteria for the agent is to maximize its total reward by iterative learning and adaptation. Deep reinforcement learning is a technique that employs deep learning to build reinforcement learning models whereby an agent can make decisions directly from raw, unstructured input data, dispelling the need for manual crafting of the state space. The use of a Bellman Equation helps in the computation of future expected rewards for different actions and states in the environment.

Here, an urban traffic environment is simulated using the spatial-correlation matrix and the DRL model is trained on it. This will enable real-time decision-making for effective vehicular congestion mitigation. The proposed implementation is the regulation of traffic-light timings and intelligent driver assistance systems (IDAS). The trained model will be able to utilize sensor data to suggest efficient maneuvers and regulatory actions. Figure 3 depicts the architecture of a DRL model.

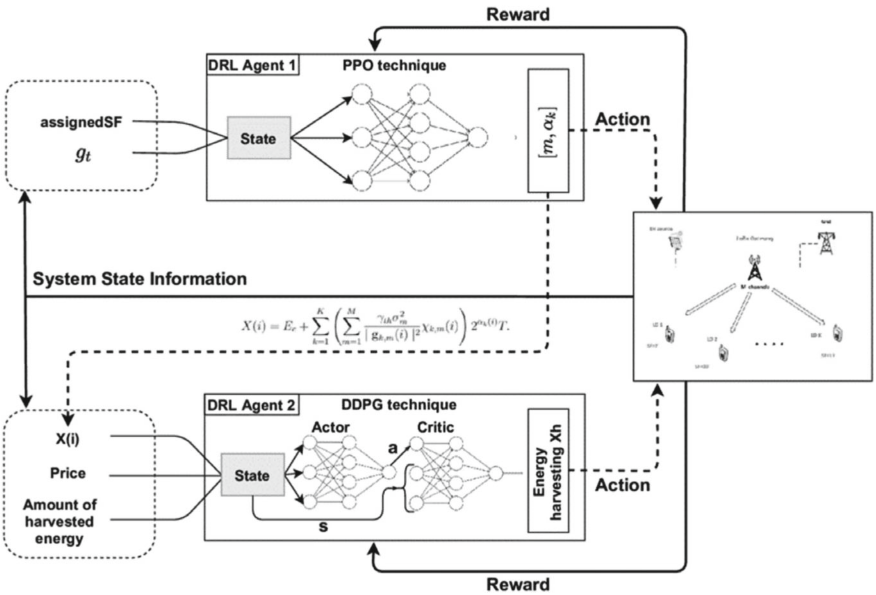

Fig. 3 Flow of a deep reinforcement learning algorithm

3.6 Experimental Evaluation

The final hybrid framework is tested on new traffic data and its efficiency is determined through the root mean squared error and mean absolute percentage error. RMSE (Eq. 12) shows how far the predicted value is from the true value using Euclidean distance. MAPE (Eq. 13) tells the average error produced by the model. Lower RMSE and MAPE values indicate higher forecast accuracy.

$$\text{RMSE } = \sqrt{\frac{\sum_{i=1}^{n}(y_i - y_i')^2}{n}} \tag{12}$$

$$\text{MAPE} = \frac{1}{n}\sum_{i=1}^{n}\left|(y_i - y_i')/y_i\right| \times 100\% \tag{13}$$

4 Architecture and Flow of Proposed Framework

The flowchart of the proposed system is shown in Fig. 4. It shows the sequential flow of data through the hybrid model. First, the historical traffic flow data is collected. The data is labelled and contains information about various traffic flow attributes such as traffic volume, lane width, average speed, timestamp, etc. This data is preprocessed (missing values are handled, standardization, and fluctuation coefficient). The resulting data is the input to the CNN and LSTM which are optimized through the PSO and BO algorithms. The CNN reveals the spatial trends in the traffic flow, such as the number of vehicles in lanes of sizes and the degree of congestion that causes traffic jams.

The LSTM model identifies temporal patterns such as daily, weekly, and monthly trends, seasonal variations, time-of-day dynamics, and holiday effects. Since the

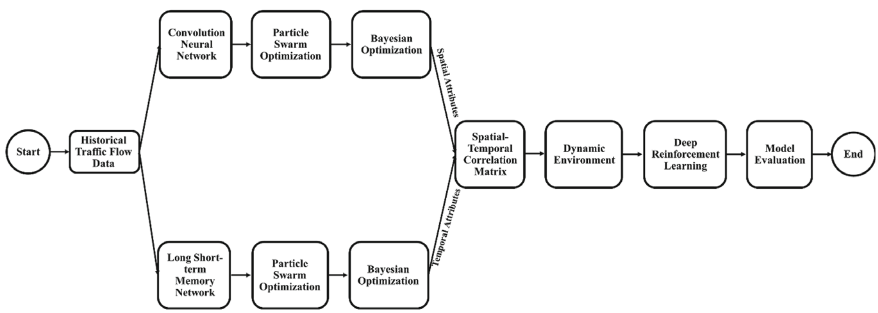

Fig. 4 Flowchart of the proposed framework

spatial and temporal attributes correspond to the same blocks of data, a spatial–temporal correlation matrix is constructed using the Pearson correlation coefficient. This matrix is used to simulate a dynamic traffic flow environment. Then, deep reinforcement learning is applied to train an intelligent agent using the dynamic environment. The framework is now capable of predicting traffic in new environments and can also adapt to real-time traffic.

5 Conclusion

This research introduces an innovative AI-driven framework for traffic prediction and real-time congestion mitigation. By optimizing Convolutional Neural Networks (CNN) and Long Short-Term Memory (LSTM) networks with Particle Swarm Optimization (PSO) and Bayesian Optimization (BO), our approach effectively captures complex traffic flow patterns.

Integrating Deep Reinforcement Learning (DRL) for adaptive decision-making further enhances the system's ability to manage unpredictable traffic conditions. The proposed framework demonstrates superior theoretical efficiency compared to existing solutions, offering a robust approach to addressing urban traffic congestion challenges. This research provides valuable insights and tools for improving urban mobility and promoting sustainable transportation.

6 Future of Work

Future research should focus on refining existing frameworks and addressing ethical and privacy concerns related to traffic flow data [6]. Exploring the integration of these AI-driven technologies into existing urban traffic management infrastructures is essential. Demonstrating the efficacy of proposed solutions is crucial for standardizing this technology. Additionally, examining the compatibility and interoperability of various systems within traffic management infrastructures remains a relatively unexplored area. Predictive traffic management is a rapidly evolving field with many challenges yet to be addressed. This research significantly contributes to the global effort to enhance traffic management and paves the way for future advancements in sustainable urban transportation.

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Application of Artificial Intelligence (AI) Techniques for Green Transportation in Smart City

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Abstract A smart city emerges through the integration of Artificial Intelligence (AI) and the Internet of Things (IoT), allowing data collection from individuals, devices, and buildings. This data is then analyzed to optimize various aspects of urban life, including infrastructure, traffic, and energy management. Smart cities are built on a foundation of Information and Communication Technologies (ICT) and Cloud integration, facilitating seamless interactions. The implementation of smart energy infrastructure within a city to monitor energy consumption, reduce costs, and minimize carbon emissions. The growing emphasis on renewable energy sources underscores the importance of environmental and public health preservation. The abundance of renewable energy sources presents an opportunity to meet the increasing demand for clean, affordable energy while addressing concerns related to cost and climate. AI has ushered in a new era of technological innovation and sustainable development. In this chapter, we explore the application of AI in renewable energy research within smart urban environments. Additionally, we conduct an analytical study that leverages AI and IoT technologies for effective smart energy management in cities. Our primary objective is to assess the efficiency of machine learning and

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IoT techniques in this context, addressing the dual concerns of sustainability and technological advancement.

Keywords Artificial intelligence · Machine learning · Smart city · Green transportation · Information and communication technologies · Internet of Things · Chatbot · Natural language processing · Cloud · Robotics · Data science · Data analysis

1 Introduction

1.1 Concept of Smart City

A smart city represents a paradigm shift in urban development, harnessing the power of cutting-edge technologies to build efficient, sustainable, and interconnected urban environments. At its core, the concept revolves around utilizing digital advancements and data-driven insights to transform how cities function and serve their inhabitants. By integrating a plethora of technologies, such as the Internet of Things (IoT), artificial intelligence (AI), and advanced sensors, smart cities create a web of connectivity that facilitates the seamless exchange of information [1]. This interconnectedness allows for real-time monitoring, analysis, and response mechanisms that can be applied to various facets of urban life as shown in Fig. 1.

Data emerges as a cornerstone in the smart city framework, enabling evidence-based decision-making processes. The extensive collection and analysis of data, ranging from traffic patterns and energy consumption to public service usage, empower city administrators to optimize resource allocation and infrastructure management. Moreover, smart cities emphasize sustainability by strategically deploying technology to enhance environmental stewardship. From eco-friendly practices to the integration of renewable energy sources, these initiatives contribute to reducing the ecological footprint of urban areas, addressing the challenges posed by rapid urbanization and climate change [2].

An integral aspect of smart cities is their commitment to citizen engagement. Digital platforms, mobile applications, and other communication channels foster active participation from residents in decision-making processes [3, 4]. This engagement not only strengthens the sense of community but also ensures that urban development aligns with the needs and preferences of the people it serves. Safety and security are also paramount, with smart cities employing advanced technologies, including surveillance systems and AI-driven predictive policing, to enhance public safety [5]. As smart cities continue to evolve, the overarching goal remains consistent: to enhance the quality of life for residents by creating urban spaces that are efficient, sustainable, and responsive to the needs of a rapidly changing world [15].

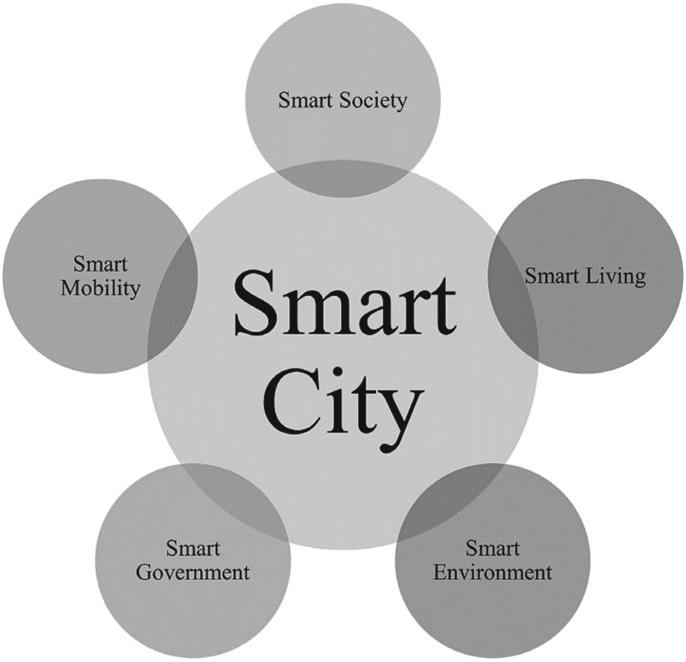

Fig. 1 Concepts of smart city

1.2 Importance of Integrating AI for Urban Development

Integrating artificial intelligence (AI) into urban development is of paramount importance in addressing the complex challenges and opportunities associated with modern cities. The incorporation of AI technologies brings about a transformative impact, enhancing the efficiency, sustainability, and overall quality of life in urban environments.

- Efficient Resource Allocation: AI enables cities to optimize the allocation of resources by leveraging data-driven insights. Machine learning algorithms can analyze massive datasets to identify patterns and trends, facilitating smarter decision-making in areas such as traffic management, waste disposal, and energy distribution. This optimization not only improves operational efficiency but also contributes to cost savings and resource conservation [6].
- Smart Infrastructure Management: AI plays a crucial role in the management of urban infrastructure. By deploying sensors and IoT devices, cities can collect real-time data on the condition of roads, bridges, utilities, and other critical assets. Machine learning algorithms can predict maintenance needs, identify potential issues, and optimize the scheduling of repairs, thus ensuring the longevity and reliability of infrastructure.

- Traffic and Transportation Optimization: AI-driven solutions offer innovative approaches to alleviate traffic congestion and enhance transportation systems. Smart traffic management systems, powered by AI algorithms, can analyze traffic patterns, predict congestion, and dynamically adjust signal timings to optimize traffic flow. Additionally, AI contributes to the development of autonomous vehicles and efficient public transportation, reducing traffic-related issues and improving overall mobility.
- Public Safety and Security: AI technologies enhance urban safety by providing advanced surveillance and threat detection capabilities. Video analytics and facial recognition can be employed for monitoring public spaces, identifying criminal activities, and improving emergency response times. Predictive policing models, powered by AI, assist law enforcement in anticipating and preventing potential security threats.
- Citizen-Centric Services: The integration of AI allows cities to deliver personalized and citizen-centric services. Chatbots and virtual assistants powered by natural language processing can handle inquiries and provide information to residents. This enhances citizen engagement, accessibility to services, and overall satisfaction with municipal services.
- Environmental Sustainability: AI contributes to the development of smart, environmentally sustainable cities. By analyzing data on energy consumption, waste generation, and air quality, cities can implement intelligent solutions to reduce their environmental impact. This includes optimizing energy usage, implementing waste recycling programs, and promoting eco-friendly practices.
- Economic Growth and Innovation: The integration of AI fosters economic growth and innovation within urban areas. By supporting the development of tech hubs, innovation districts, and fostering a conducive environment for startups, cities can attract talent and investment. AI-driven industries contribute to job creation and position cities as hubs for cutting-edge technological advancements.

The integration of AI in urban development is instrumental in addressing the multifaceted challenges faced by modern cities. It empowers municipalities to make data-driven decisions, enhance infrastructure management, improve public services, and create more sustainable and livable urban environments for their residents.

2 Defining Smart Cities and Their Key Characteristics

Smart cities are urban areas that leverage advanced technologies and innovative solutions to enhance the quality of life for their residents, promote sustainable development, and optimize the efficiency of various city functions. These cities utilize interconnected digital infrastructure, data analytics, and emerging technologies to address complex urban challenges and create a more responsive and adaptive environment [7].

2.1 Key Characteristics of Smart City

2.1.1 Technological Integration

Smart cities leverage a plethora of cutting-edge technologies to create a connected urban landscape. The Internet of Things (IoT) plays a pivotal role, with sensors embedded in various elements of the city—streetlights, waste bins, buildings, and transportation systems. These interconnected devices generate real-time data, fostering a networked ecosystem that facilitates data sharing and communication between different city components [8].

2.1.2 Data-Driven Decision-Making

The heart of a smart city lies in its ability to harness and analyze vast amounts of data. Data analytics platforms process information from diverse sources, providing valuable insights for city planners and administrators. This data-driven approach enables evidence-based decision-making, leading to more efficient allocation of resources, improved services, and a proactive response to emerging urban challenges.

2.1.3 Urban Mobility and Transportation

Smart cities prioritize intelligent transportation systems to address the complexities of urban mobility. Real-time data on traffic flow, public transportation usage, and parking availability are collected and analyzed. This information is used to optimize transportation routes, reduce congestion, and enhance overall mobility. Furthermore, the development of autonomous vehicles and smart infrastructure contributes to safer and more efficient transportation systems.

2.1.4 Sustainability and Resource Efficiency

Environmental sustainability is a cornerstone of smart city initiatives. These cities focus on minimizing their environmental impact through the adoption of energy-efficient technologies, smart grids, and renewable energy sources. Waste management is optimized, with sensors providing real-time data on fill levels in bins, enabling more efficient collection routes and reducing unnecessary resource consumption.

2.1.5 Citizen Engagement and Participation

Smart cities prioritize citizen-centric approaches, actively involving residents in the decision-making process. Digital platforms and mobile applications provide avenues for citizens to voice their opinions, report issues, and participate in community initiatives. This engagement fosters a sense of belonging, encourages civic responsibility, and ensures that urban development aligns with the needs and preferences of the diverse population.

2.1.6 Infrastructure Optimization

Smart cities optimize the management of critical infrastructure through advanced technologies. Sensors monitor the condition of utilities, public spaces, and buildings in real-time, allowing for predictive maintenance and efficient resource allocation. Smart grids enhance energy distribution, and intelligent infrastructure management ensures that city assets are utilized to their full potential.

2.1.7 Safety and Security

Advanced technologies enhance public safety and security in smart cities. Surveillance systems equipped with AI-driven analytics can identify and respond to potential security threats in real-time. Predictive policing models use historical and real-time data to allocate resources more effectively, ultimately creating safer urban environments.

2.1.8 Digital Connectivity and Accessibility

Smart cities prioritize digital connectivity as a fundamental utility. High-speed internet access is considered essential for all residents, ensuring that the benefits of digital services are accessible to everyone. This connectivity supports initiatives such as smart education, telemedicine, and e-governance, contributing to a more inclusive and connected society.

2.1.9 Innovation Ecosystem

Smart cities actively cultivate innovation hubs and ecosystems. These environments support the growth of technology-driven industries, startups, and research institutions. By fostering a culture of innovation, smart cities attract talent, encourage entrepreneurship, and position themselves as leaders in emerging technologies.

2.1.10 Inclusive and Equitable Development

Smart cities prioritize inclusivity, aiming to bridge digital divides and ensure that technological advancements benefit all residents. Initiatives focus on providing equal access to services, addressing socio-economic disparities, and considering the diverse needs of the population. This commitment to inclusivity underpins the vision of smart cities as environments that cater to the well-being of everyone.

Smart cities embody a holistic and interconnected approach to urban development, where technology serves as an enabler to create more efficient, sustainable, and inclusive urban environments. The key characteristics work in harmony to transform cities into adaptive, responsive, and livable spaces that meet the evolving needs of their residents.

2.2 Challenges Faced by Modern Urban Environments

Modern urban environments navigate a complex tapestry of challenges that stem from the intricate interplay of demographic shifts, technological advancements, and the imperative for sustainable development. The phenomenon of overpopulation and urban sprawl stands out as a formidable challenge, with cities strained by the influx of people seeking better economic opportunities and improved living conditions [10]. The resultant surge in housing demands often outpaces urban planning efforts, leading to insufficient infrastructure and public services, creating a breeding ground for social and economic disparities.

In tandem, traffic congestion and transportation inefficiencies present formidable hurdles. The burgeoning number of vehicles, coupled with inadequate public transportation infrastructure, results in snarled traffic patterns, extended commute times, and environmental pollution. The need for comprehensive urban mobility solutions that integrate smart technologies and sustainable practices becomes increasingly urgent to alleviate these issues and enhance the overall quality of life for residents [14].

The aging and strained urban infrastructure add a layer of complexity to these challenges. Many cities grapple with the upkeep and modernization of aging facilities, including water supply networks, sewage systems, bridges, and roads. Striking a delicate balance between preserving historical structures and embracing modernization is a pivotal consideration for urban planners seeking to create resilient and efficient urban landscapes.

Environmental sustainability takes center stage as urbanization unfolds. The rapid expansion of cities contributes to air and water pollution, noise disturbances, and the diminution of green spaces. Addressing these environmental concerns necessitates a paradigm shift in urban planning towards eco-friendly practices, renewable energy integration, and the creation of green urban spaces that enhance the well-being of residents.

Housing affordability emerges as a critical socio-economic challenge. Escalating property prices and housing shortages intensify issues of homelessness and social inequality. Bridging the gap between housing demand and supply requires innovative housing solutions, inclusive policies, and community engagement to ensure that urban development benefits all segments of the population [12].

Amidst the digitization of urban landscapes, the digital divide, cybersecurity, and privacy concerns emerge as contemporary challenges. Unequal access to technology and the potential for data breaches underscore the importance of equitable technology integration and robust cybersecurity measures. The responsible deployment of smart technologies requires careful consideration of privacy implications and the establishment of ethical frameworks to safeguard citizen rights.

Addressing these multifaceted challenges demands a holistic and collaborative approach. Urban planners, policymakers, community stakeholders, and the private sector must collaborate to design and implement innovative solutions. Smart urban development, incorporating sustainable practices, resilient infrastructure, and inclusive policies, is essential to forge cities that not only withstand the challenges of the present but also thrive in the face of the dynamic forces shaping the urban landscapes of the future.

3 Role of AI in Smart City

Creating a smart city involves the integration of artificial intelligence (AI) into various aspects of urban life, presenting transformative opportunities and solutions to complex challenges. One of the primary domains where AI plays a pivotal role is in the management of smart infrastructure. Equipped with sensors and IoT devices, urban infrastructure becomes sentient, continuously monitored and analyzed by AI algorithms [16]. This real-time data collection allows for predictive maintenance, ensuring that critical assets such as bridges and roads are proactively addressed, ultimately enhancing their longevity and reliability. The intersection of AI and smart infrastructure management marks a paradigm shift, empowering cities to move from reactive to proactive approaches in maintaining their critical assets.

Traffic management and optimization stand out as another critical arena where AI reshapes the urban landscape. The proliferation of vehicles, coupled with outdated transportation systems, often results in traffic congestion, lengthy commute times, and environmental pollution. AI-driven solutions, however, transform urban mobility. Machine learning algorithms analyze data from sensors, cameras, and other sources to predict traffic patterns, optimize signal timings, and offer dynamic route planning. These interventions not only enhance the efficiency of transportation systems but also contribute to reduced congestion, lower emissions, and improved overall urban mobility [17].

Predictive analytics, powered by AI, serves as a cornerstone in urban planning for smart cities. By analyzing historical and real-time data, machine learning models can forecast population growth, identify areas suitable for development, and optimize land use [18]. This predictive capability empowers city planners to make informed decisions, ensuring that urban development is not only sustainable but also aligned with the evolving needs of the population. The integration of AI into the urban planning process represents a significant leap forward, allowing for adaptive and responsive strategies that can effectively address the dynamic nature of urban environments.

AI's impact extends to public safety and surveillance, enhancing security measures in smart cities. Advanced surveillance systems, supported by video analytics and facial recognition technologies, can identify potential security threats, monitor crowded areas, and aid law enforcement agencies in preventing and responding to incidents. Moreover, predictive policing models utilize AI to analyze crime data, enabling authorities to allocate resources more effectively and proactively address emerging security challenges. The fusion of AI and public safety not only strengthens security measures but also contributes to the overall resilience of smart cities in the face of evolving threats [19, 20].

In the realm of sustainability, AI emerges as a potent tool for optimizing energy management. Smart grids, driven by AI algorithms, can predict energy demand patterns, integrate renewable energy sources, and optimize energy distribution. This not only enhances the efficiency of energy systems but also contributes to environmental sustainability by reducing the reliance on non-renewable resources.

Furthermore, AI plays a vital role in waste management optimization. Sensors in waste bins monitor fill levels, and AI algorithms analyze this data to optimize waste collection routes, reducing operational costs and minimizing the environmental impact of waste disposal. Citizen services and engagement are also transformed by AI in smart cities. Chatbots and virtual assistants, powered by AI technologies, provide instant responses to citizen inquiries and improve the efficiency of public service delivery. This not only streamlines communication between residents and city authorities but also contributes to a more responsive and citizen-centric urban environment. The implementation of AI in citizen services fosters a dynamic and interactive relationship between the city and its residents, enhancing overall satisfaction and engagement.

Water management and conservation benefit significantly from AI applications. Smart water systems utilize sensors and AI algorithms to monitor water quality, detect leaks, and optimize water distribution. This proactive approach supports water conservation efforts and ensures the sustainable use of this critical resource. The integration of AI into water management not only enhances the efficiency of water systems but also contributes to environmental conservation and resilience in the face of water-related challenges.

Healthcare and emergency response represent crucial areas where AI can save lives and improve public health outcomes in smart cities. AI-driven systems can analyze health data to identify potential disease outbreaks, enabling early intervention and prevention measures. In emergency response management, AI contributes to optimizing resource allocation and response times during crises, enhancing the overall effectiveness of emergency services. The synergy between AI and healthcare in smart cities reflects a commitment to leveraging technology for the well-being of residents and ensuring a robust response to health-related challenges.

The inclusive nature of services is further bolstered by Natural Language Processing (NLP) powered by AI. This technology enables smart cities to offer services that are accessible to diverse linguistic communities. The ability of AI-powered language processing to facilitate multilingual communication aligns with the overarching goal of creating inclusive and equitable smart cities that cater to the needs of all residents, regardless of linguistic background.

In the role of AI in smart cities is multifaceted, encompassing infrastructure management, traffic optimization, urban planning, public safety, sustainability, citizen services, water management, healthcare, and linguistic inclusivity. As cities increasingly embrace the possibilities offered by AI, they position themselves to address current and future challenges with unprecedented efficiency and innovation. The transformative impact of AI in smart cities extends beyond technological advancements; it shapes the very fabric of urban living, fostering resilience, sustainability, and inclusivity in the face of dynamic urban environments.

3.1 Key AI Techniques for Smart City

AI techniques play a crucial role in transforming traditional urban environments into smart cities. These techniques leverage advanced algorithms, data analytics, and machine learning to optimize various aspects of city life. Here are key AI techniques that contribute to the development and enhancement of smart cities:

3.1.1 Machine Learning Applications

Machine learning (ML) is a cornerstone of AI in smart cities, enabling systems to learn from data and make predictions or decisions. ML applications include predictive analytics for traffic management, where algorithms analyze historical and real-time data to predict traffic patterns and optimize signal timings. ML is also employed for demand forecasting in public services, helping cities allocate resources efficiently based on anticipated demand.

3.1.2 Internet of Things (IoT) Integration

The integration of IoT devices is fundamental to smart cities. These devices, equipped with sensors and actuators, collect and exchange data in real-time. AI techniques process and analyze this data to enable smart functionalities, such as smart traffic lights that respond to real-time traffic conditions, or environmental sensors that monitor air quality. The synergy between AI and IoT creates dynamic and responsive urban ecosystems.

3.1.3 Data Analytics

Data analytics is a key AI technique used in smart cities to derive actionable insights from vast amounts of data. Big data applications in urban planning, transportation, and public services provide valuable information for decision-making. By analyzing patterns and trends, cities can optimize resource allocation, enhance services, and make informed, data-driven decisions for sustainable urban development.

3.1.4 Automation and Robotics

Automation and robotics, powered by AI, contribute to various aspects of smart city infrastructure. Autonomous vehicles are a notable example, revolutionizing urban transportation by reducing traffic congestion and improving safety. Robotics is also employed in maintenance tasks, such as automated systems for cleaning streets or inspecting infrastructure, enhancing efficiency and reducing operational costs.

Natural Language Processing (NLP)

NLP enables machines to understand, interpret, and generate human language, facilitating communication between residents and smart city systems. Smart city chatbots and virtual assistants leverage NLP to provide information, answer queries, and assist residents. Multilingual communication capabilities enhance inclusivity, ensuring that language is not a barrier to accessing city services.

3.1.5 Edge Computing

Edge computing is gaining prominence in smart cities, especially for real-time and latency-sensitive applications. By processing data closer to the source (at the edge of the network), AI algorithms can provide rapid responses, crucial for applications like autonomous vehicles, smart grids, and public safety systems.

3.1.6 Computer Vision

Computer vision, a subset of AI, enables machines to interpret and make decisions based on visual data. In smart cities, computer vision is used for various applications, including surveillance, traffic monitoring, and public safety. Automated video analytics can detect anomalies, monitor crowd behavior, and enhance security through facial recognition technologies.

3.1.7 Blockchain Technology

While not traditionally considered an AI technique, blockchain technology is increasingly integrated into smart city initiatives. Blockchain ensures secure and transparent transactions, enhancing trust in data sharing and reducing the risk of tampering. In smart cities, blockchain can be applied to secure transactions in energy trading, identity verification, and data sharing among various stakeholders.

3.1.8 Predictive Analytics for Maintenance

Predictive analytics is applied to predict the maintenance needs of critical infrastructure. By analyzing data on the condition of assets such as bridges, roads, and utilities, AI algorithms can predict when maintenance is required, allowing for proactive and cost-effective maintenance strategies.

3.1.9 Simulation and Modeling

Simulation and modeling, facilitated by AI, are used in urban planning and development. These techniques help city planners simulate various scenarios, such as the impact of new infrastructure projects or changes in land use. This allows for informed decision-making, optimizing city development plans for sustainability and efficiency.

Incorporating these AI techniques into the fabric of smart cities enables municipalities to create dynamic, responsive, and efficient urban environments. As technology continues to advance, the synergy between AI and smart city initiatives will play a pivotal role in addressing urban challenges and shaping the future of urban living.

3.2 Automation and Robotics in Smart City

Automation and robotics play a transformative role in shaping the landscape of smart cities, contributing to increased efficiency, sustainability, and improved quality of life. As urban areas face growing challenges related to population density, resource management, and environmental impact, the integration of automation and robotics becomes essential. Here's an exploration of the key aspects of automation and robotics in smart cities:

3.2.1 Autonomous Vehicles

Automation in smart cities is prominently manifested through autonomous vehicles, such as self-driving cars, buses, and drones. These vehicles leverage advanced sensors, artificial intelligence (AI), and connectivity to navigate urban environments efficiently. Their deployment aims to reduce traffic congestion, enhance mobility, and contribute to a safer and more sustainable transportation system.

3.2.2 Smart Traffic Management

The integration of automation in traffic management is a key strategy for optimizing urban transportation. Intelligent systems, including automated traffic lights and adaptive signal control, utilize real-time data analytics to improve traffic flow. This not only reduces congestion but also enhances commuting times and overall transportation efficiency, making cities more livable.

3.2.3 Automated Waste Management

Robotics and automation technologies are revolutionizing waste management in smart cities. Automated waste collection systems, often employing robotics, enhance efficiency by optimizing waste collection routes. Smart bins equipped with sensors signal when they require emptying, reducing operational costs and contributing to a more sustainable waste management process.

3.2.4 Robotic Process Automation (RPA) in Governance

Robotic Process Automation (RPA) is applied in administrative tasks within smart cities, automating routine, rule-based processes. This includes permit processing, document verification, and citizen service interactions, resulting in increased efficiency and a more streamlined governance structure.

3.2.5 Infrastructure Maintenance and Inspection

Drones and robotic systems are employed for the inspection and maintenance of critical infrastructure in smart cities. Automated drones equipped with cameras and sensors can survey bridges, roads, and buildings, detecting potential issues proactively. Robotic systems contribute to tasks such as cleaning and repairing infrastructure, ensuring optimal functionality.

3.2.6 Automated Surveillance and Public Safety

Automation in surveillance using AI-powered cameras and sensors enhances public safety. Video analytics and facial recognition technologies automate the monitoring of public spaces, assisting law enforcement in identifying and responding to security threats more effectively. This contributes to overall urban safety and resilience.

3.2.7 Automated Energy Management

Automation is employed to optimize energy consumption in smart cities. Smart grids, automated lighting systems, and energy-efficient buildings leverage automation to adapt to fluctuating energy demands. This contributes to energy conservation and supports the development of sustainable urban environments.

3.2.8 Delivery and Logistics Automation

Autonomous delivery robots and drones are transforming last-mile logistics in smart cities. These automated systems navigate urban environments to deliver packages, groceries, and other goods, reducing delivery times, traffic congestion, and carbon emissions. This automation enhances efficiency in urban logistics (Neirotti et al. 2014).

3.2.9 Smart Agriculture and Green Spaces

Automation technologies extend to urban agriculture and green spaces. Automated systems for precision farming and smart irrigation contribute to sustainable agricultural practices within city limits. In parks and green areas, robotic lawnmowers and automated maintenance systems help keep public spaces well-maintained, fostering a green and vibrant urban environment.

3.2.10 Automated Building Management Systems

Automation is integral to the management of smart buildings. Automated climate control, lighting, and security systems contribute to energy efficiency and occupant comfort. These systems can be controlled and monitored remotely, optimizing resource usage based on real-time data.

3.2.11 Telepresence Robots for Public Services

Telepresence robots find applications in public services, providing remote assistance and communication. In scenarios such as public information kiosks or healthcare services, telepresence robots enable virtual interactions, extending services to a broader audience and enhancing accessibility.

As smart cities continue to evolve, the integration of automation and robotics stands as a cornerstone for building resilient, efficient, and sustainable urban environments. These technologies not only address current urban challenges but also pave the way for innovative solutions to shape the future of city living [12].

3.3 Natural Language Processing (NLP)

Natural Language Processing (NLP) is a transformative technology that holds immense potential for enhancing various aspects of smart cities. NLP enables machines to understand, interpret, and generate human language, facilitating communication between residents and smart city systems. Here's an exploration of how Natural Language Processing contributes to the development of smart cities:

Smart City Chatbots and Virtual Assistants:

NLP is integral to the development of smart city chatbots and virtual assistants. These conversational interfaces leverage natural language understanding to provide information, answer queries, and assist residents. By understanding and responding to diverse linguistic inputs, these AI-driven interfaces enhance user experience and accessibility, making city services more user-friendly.

Multilingual Communication:

Smart cities are often characterized by diverse populations with various linguistic backgrounds. NLP technologies enable multilingual communication in city services. Translation services and multilingual chatbots ensure that language is not a barrier to accessing information or interacting with smart city systems. This inclusivity aligns with the goal of creating smart cities that cater to the needs of all residents.

Voice-Activated Services:

Voice-activated services powered by NLP are becoming increasingly prevalent in smart cities. Virtual assistants and smart speakers equipped with NLP capabilities allow residents to interact with city services using voice commands. This hands-free interaction enhances convenience, especially in scenarios where manual input may be impractical, such as when driving or navigating public spaces.

Citizen Feedback and Sentiment Analysis:

NLP plays a crucial role in analyzing citizen feedback and sentiments expressed in various channels. Sentiment analysis powered by NLP helps city authorities gauge public opinion on different initiatives, services, or policies. This valuable feedback loop enables cities to make data-driven decisions and tailor services to better meet the needs of residents.

Emergency Response and Public Safety:

NLP technologies contribute to improved emergency response and public safety in smart cities. Analyzing natural language data from emergency calls, social media, or other communication channels helps authorities understand the context of incidents. This information aids in deploying resources more effectively during emergencies and enhancing overall public safety.

Smart Governance and Civic Engagement:

NLP facilitates smart governance by automating and streamlining communication between citizens and government entities. Automated processing of citizen inquiries, complaints, and feedback using NLP enhances responsiveness. Civic engagement is also fostered through interactive platforms that utilize NLP to facilitate meaningful two-way communication between residents and local authorities.

Smart Parking Solutions:

NLP is employed in smart parking solutions to simplify the process of finding parking spaces. By analyzing natural language queries from users, NLP-powered systems can provide real-time information about parking availability, locations, and regulations. This contributes to reducing traffic congestion and optimizing urban mobility.

Natural Language Processing in Planning and Zoning:

NLP is utilized in urban planning and zoning processes. By analyzing documents, public comments, and planning proposals, NLP helps city planners extract valuable insights. Automated processing of natural language data streamlines the analysis of large volumes of information, aiding in more informed decision-making for sustainable urban development.

Accessibility Services:

NLP contributes to making smart city services more accessible to individuals with disabilities. Voice-controlled interfaces, text-to-speech, and speech-to-text functionalities powered by NLP enhance accessibility for residents with visual or auditory impairments, ensuring that smart city services are inclusive and equitable.

Public Information Kiosks and Interactive Displays:

NLP is applied in public information kiosks and interactive displays throughout the city. These interfaces, equipped with NLP capabilities, enable residents to ask questions, seek information, and interact with city services in a natural and intuitive manner. This enhances the overall user experience in public spaces.

NLP is a versatile technology that plays a pivotal role in shaping smart cities by improving communication, accessibility, and civic engagement. As smart city initiatives continue to evolve, NLP will likely remain at the forefront, contributing to the creation of more responsive, inclusive, and citizen-centric urban environments.

4 Application of AI for Green Transportation

In an era where environmental sustainability is a paramount concern, the transportation sector stands as one of the most significant contributors to carbon emissions. As the world grapples with the pressing need to mitigate climate change, the application of Artificial Intelligence (AI) emerges as a powerful ally in the pursuit of green transportation. AI's potential to revolutionize how we move people and goods is not just a technological advancement but a vital step towards a more sustainable future.

4.1 Optimizing Traffic Flow

One of the most immediate and impactful applications of AI in green transportation is optimizing traffic flow. Traffic congestion is a major source of carbon emissions in urban areas. Traditional traffic management systems, which rely on static signals and human intervention, are often inefficient. AI, however, can analyze real-time traffic data from various sources, such as cameras, sensors, and GPS devices, to dynamically adjust traffic signals. This real-time optimization reduces idle times, decreases fuel consumption, and minimizes emissions.

AI-driven traffic management systems can also predict traffic patterns and provide alternative routes to drivers, thus distributing traffic more evenly across the road network. This not only enhances fuel efficiency but also reduces the overall time vehicles spend on the road, contributing to lower emissions.

4.2 Enhancing Public Transportation

Public transportation is inherently more environmentally friendly than individual car use, but its efficiency can be significantly improved with AI. AI can optimize bus and train schedules based on passenger demand, reducing the number of empty or underutilized vehicles on the road. Predictive maintenance powered by AI ensures that public transportation vehicles are always in optimal condition, preventing breakdowns that can disrupt services and lead to higher emissions as shown in Fig. 2.

Moreover, AI can enhance the user experience by providing real-time updates on arrival times and crowd levels, encouraging more people to use public transport instead of personal vehicles. By making public transportation more reliable and

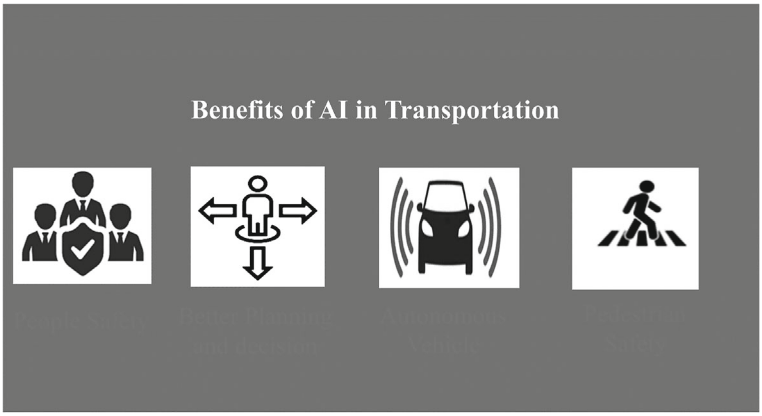

Fig. 2 Benefits of artificial intelligence in green transportation

convenient, AI can play a crucial role in shifting public behavior towards greener modes of travel.

4.3 Electric and Autonomous Vehicles

Electric vehicles (EVs) are a cornerstone of green transportation, and AI is integral to their efficiency and adoption. AI algorithms optimize battery usage and charging, ensuring that EVs operate at peak efficiency and have a longer lifespan. Additionally, AI can manage the smart grid to balance the load and integrate renewable energy sources, making EVs even more sustainable.

Autonomous vehicles (AVs), powered by AI, promise to transform transportation. These vehicles can drive more efficiently than humans, reducing unnecessary acceleration and braking, which saves fuel and cuts emissions. When combined with electric powertrains, AVs represent a significant leap towards zero-emission transportation. Furthermore, AVs can be coordinated to form dynamic ride-sharing networks, reducing the total number of vehicles needed and thereby cutting down on overall emissions.

4.4 Freight and Logistics

The logistics sector is another area where AI can significantly reduce emissions. AI can optimize delivery routes for freight trucks, minimizing travel distances and fuel consumption. By predicting maintenance needs and avoiding breakdowns, AI also ensures that trucks run efficiently.

AI can improve warehouse operations by automating processes and optimizing inventory management, which reduces energy consumption. Additionally, AI-powered supply chain management can enhance the efficiency of goods movement from production to end-users, minimizing waste and energy use across the entire logistics network [9].

4.5 Urban Planning and Smart City

AI's role in urban planning is pivotal for developing green transportation infrastructures. AI can analyze vast amounts of data to provide insights into urban mobility patterns, helping city planners design more efficient public transportation networks and pedestrian-friendly spaces. Smart cities, equipped with AI technologies, can dynamically adjust to changing conditions, such as modifying traffic light patterns based on real-time traffic data or reallocating public transport resources during peak times [14].

4.6 Promoting Behavioral Change

AI can also drive behavioral change towards greener transportation habits. Personalized travel recommendations, incentives for using public transport, and real-time feedback on one's carbon footprint are ways AI can encourage individuals to make more sustainable choices. By gamifying green transportation habits or providing social incentives, AI can make sustainability an integral part of daily life [9].

The integration of AI in transportation is not just about enhancing efficiency but about fundamentally transforming how we move towards a greener future. By optimizing traffic flow, enhancing public transport, supporting electric and autonomous vehicles, improving logistics, aiding urban planning, and promoting behavioral change, AI is pivotal in the transition to sustainable transportation systems. As we look to the future, embracing AI's capabilities will be crucial in our quest to create a cleaner, greener, and more sustainable world for generations to come.

5 Role of Green Transportation in Smart City

As urbanization continues to accelerate, the concept of smart cities has emerged as a solution to manage the complexities of modern urban life while promoting sustainability and improving quality of life. Central to this vision is the role of green transportation, which encompasses various modes of transport designed to reduce environmental impact. Green transportation is not only essential for reducing carbon emissions but also for enhancing the overall functionality and livability of smart cities.

5.1 Reducing Carbon Footprint

One of the primary roles of green transportation in smart cities is to reduce the carbon footprint of urban mobility. Traditional transportation systems heavily reliant on fossil fuels are major contributors to greenhouse gas emissions. Green transportation, including electric vehicles (EVs), public transit, cycling, and walking, significantly reduces these emissions. Electric buses and trains, for example, provide mass transit options that can move large numbers of people efficiently without the associated pollution of diesel-powered vehicles.

5.2 Improving Air Quality

Improved air quality is a direct benefit of reduced emissions from green transportation. Air pollution is a critical health issue in many urban areas, contributing to respiratory problems, cardiovascular diseases, and premature deaths. By transitioning to electric buses, trams, and other low-emission vehicles, smart cities can reduce pollutants such as nitrogen oxides and particulate matter, leading to cleaner air and healthier residents [11].

5.3 Enhancing Energy Efficiency

Green transportation is also about enhancing energy efficiency. Smart cities leverage advanced technologies to optimize energy use in transportation. For instance, EVs can be integrated into smart grids, allowing for efficient energy distribution and use. Renewable energy sources such as solar and wind can power these vehicles, further reducing reliance on non-renewable energy. Additionally, smart traffic management systems use AI to reduce congestion, which in turn minimizes idle times and improves fuel efficiency.

5.4 Promoting Multimodal Transport

Smart cities promote multimodal transport systems that integrate various forms of green transportation. This approach ensures that residents have access to diverse, efficient, and sustainable mobility options. For example, a commuter might use a combination of biking, public transit, and walking to reach their destination. Smart city infrastructure supports this by providing seamless connections between different modes of transport, such as bike-sharing stations near train stations and well-designed pedestrian pathways.

5.5 Encouraging Sustainable Urban Planning

Green transportation influences urban planning and development in smart cities. Sustainable transportation systems require the creation of infrastructure that supports EV charging, dedicated bike lanes, pedestrian-friendly streets, and robust public transit networks. These elements encourage higher-density, mixed-use developments that reduce the need for long commutes, making cities more compact and walkable. This planning not only reduces the environmental impact but also enhances the quality of urban life by reducing traffic congestion and promoting active lifestyles [13].

Green transportation enhances mobility and accessibility in smart cities. By providing efficient and affordable public transit options, cities can ensure that all residents, including those in underserved communities, have access to reliable transportation. This inclusivity promotes social equity, enabling people to access jobs, education, healthcare, and other essential services without the financial burden of owning a private vehicle.

6 Cities Successfully Implementing AI Techniques

Several cities around the world have successfully implemented AI techniques to enhance urban living, address challenges, and improve the overall efficiency of public services. Here are examples of cities that have made notable strides in leveraging AI:

6.1 Singapore, Singapore

Singapore is a global leader in smart city initiatives, utilizing AI to enhance various aspects of urban life. The city-state employs AI for traffic management, predictive maintenance of public infrastructure, and urban planning. The "Smart Nation" initiative incorporates AI to analyze data from sensors, cameras, and other sources to optimize city services and improve the quality of life for residents.

6.2 Barcelona, Spain

Barcelona has embraced AI for smart urban planning and sustainability. The city utilizes IoT devices and AI algorithms to monitor and manage services such as waste management, parking, and street lighting. The integration of AI in these areas contributes to improved efficiency, reduced environmental impact, and better resource allocation.

6.3 Toronto, Canada

Toronto has implemented AI in various domains, including traffic management and healthcare. The city uses AI to analyze traffic patterns and optimize transportation routes, reducing congestion. Additionally, Toronto has incorporated AI in healthcare services, utilizing predictive analytics to identify potential disease outbreaks and optimize resource allocation in hospitals.

6.4 Seoul, South Korea

Seoul has employed AI for public safety and city management. The city utilizes AI-powered surveillance cameras to monitor public spaces and detect potential security threats. Additionally, Seoul has implemented AI in public transportation, using predictive analytics to optimize bus routes and reduce waiting times.

6.5 Dubai, United Arab Emirates

Dubai is at the forefront of incorporating AI into various aspects of city governance. The city has introduced the "Dubai Paperless Strategy," which aims to digitize government services using AI and blockchain. Additionally, Dubai has implemented AI in transportation, healthcare, and energy management to create a seamless and efficient urban experience.

7 Conclusion

The integration of green transportation within smart cities marks a significant step towards sustainable urban development. By leveraging advanced technologies like AI and IoT, cities can enhance transportation systems, reducing environmental impacts and improving residents' quality of life. Key initiatives include electric vehicles (EVs), optimized public transit, and shared mobility services, all of which decrease pollution and fossil fuel dependence while fostering efficient urban infrastructure. AI-driven traffic management ensures smoother traffic flows and minimizes congestion, leading to lower emissions and better air quality. Predictive maintenance and infrastructure management, powered by real-time data and machine learning, address maintenance needs proactively, enhancing the reliability and lifespan of urban transportation networks.

Incorporating renewable energy into transportation, such as solar-powered EV charging stations, demonstrates a commitment to environmental stewardship. Public engagement through digital platforms empowers residents to make informed decisions and fosters community ownership of sustainability efforts. Enhanced safety measures supported by AI-driven technologies further improve the attractiveness and functionality of green transportation systems.

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Analysis of Wireless Sensor Networks Applications in Intelligent Transportation System

Alex Khang, Vugar Abdullayev, and Yitong Niu

Abstract In this chapter, we analyze the application of wireless sensor networks (WSNs) in intelligent transportation systems (ITS). Intelligent transport leverages information technology and intelligent means such as computers, sensors, and self-control technologies to achieve real-time automatic collection of traffic information. The integration of traffic signal control, traffic guidance, and intervention systems ensures orderly traffic operation through real-time supervision. As conventional detection technologies like microwave, video, and ultrasonic fail to meet modern ITS development needs, WSNs emerge as a critical solution. We explore the use of giant magnetoresistive sensors for magnetic-sensitive detection, which enhances the efficiency and intelligence level of ITS. WSNs enable real-time data collection and traffic monitoring, providing traffic managers with essential information to address road conditions promptly, optimize traffic signal control, and improve traffic flow. Additionally, WSNs facilitate intelligent traffic management and emergency responses, increasing safety and emergency handling efficiency. Intelligent navigation systems, based on WSN data, offer accurate road condition information, enabling better route planning and reducing traffic congestion and accidents. This paper highlights the potential of WSNs in transforming ITS and outlines the future research directions necessary for overcoming current challenges.

Keywords Wireless sensor · Intelligent transportation system · Berkeley · Traffic management · Traffic flow monitoring · Traffic signal control · MITuAMPs · InteliMote · TinyOS · YOLO · Radio frequency identification

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1 Introduction

Intelligent transport is the use of information technology and intelligent technical means, including computers, sensors, self-control, and other technologies, to achieve real-time automatic collection of traffic information, organic integration of traffic signal control, traffic guidance, traffic intervention, and other systems, the use of computer network technology real-time supervision, to ensure that the traffic system operates in an orderly manner. In the intelligent transport system construction process, the first step to solving the information collection problem is to build a wireless sensor network, which uses sensors to collect information from various regions. At present, China's research in this area is relatively small; traffic information collection generally uses more conventional detection technology, including microwave, video, ultrasonic, etc., and these detection technologies have been gradually unable to meet the needs of the development of intelligent transport systems, the need for in-depth study of wireless sensor networks, wireless sensor networks to enhance the operational efficiency of the intelligent transport system and the level of intelligence. In this chapter, according to the application characteristics of wireless sensor networks in intelligent transportation, the magnetic sensitive detection technology of giant magnetoresistive sensors is used, and the application scheme of wireless sensor networks in intelligent transportation is analyzed.

Nowadays, the application of intelligent technology is more and more extensive, which not only improves operational efficiency but also reduces the input of human costs. In intelligent transport construction, the role of wireless sensor networks should be given full play. The so-called wireless sensor network arranges a large number of small or microsensors in the monitoring area, uses the sensors for real-time monitoring and sensing of the environment, targets object information, uses embedded systems to achieve intelligent processing of data and information, and at the same time, use the random self-organizing wireless communication network, use the multi-hop relay mode to transfer sensing information to the user terminal, to achieve intelligent management and real-time monitoring [1].

Wireless sensor networks use various technologies, including sensing technology, network technology, distributed intelligent information processing technology, etc. In this network system research, it is necessary to continuously integrate various advanced technological means, including nanomaterials, microfabrication, System-on-Chip (SOC) design, etc., to achieve the design requirements such as integration, networking, and systemization [16]. Wireless sensor networks can achieve long-term unattended in various industries and fields and have a wide range of application prospects,in addition to the application in intelligent transportation, the biomedical, anti-terrorism prevention and control, national defense and military, and other fields also play a substantial advantageous role.

China's research in wireless sensor networks is still in its infancy due to the high application value of this technology, so China is very supportive of the research of this technology; various research institutions, experts, and scholars are actively involved in the research and analysis of this technology. Specific research includes wireless sensor node hardware design, network routing technology, and communication protocols [46]. In the research of sensor networks at the University of California, Berkeley, the sensor position research uses network connectivity technology for position reconstruction as the basis for developing the sensor operating system TinyOS.

Other research institutions have also carried out related research, including the analysis of wireless sensor network environment simulation, sensor network simple structure, etc.; in the research of the sensor node hardware platform, it has already been developed Berkeley, MITuAMPs, InteliMote, and other platforms. Different applications require different sensor node design schemes, which can generally be applied in TinyOS system, although the hardware size and design cost are different; in the research of protocols, routing algorithms based on negotiation-type protocols, multipath-type protocols, and directional release-type protocols have been proposed [6].

In the process of national economic development, the traffic problem has been aggravated. To solve the traffic problem, each country has invested heavily in its workforce and material resources to study the intelligent transport system.

In the process of system research, according to the needs of transport development, information, measurement, computer networks, and other technical means are applied in the transport field to build an intelligent human–computer interaction system that can monitor and manage transport in real time and accurately [35]. Intelligent transport system (ITS) consists of several systems, including vehicle positioning, traffic information distribution, traffic video surveillance, etc. Among them, traffic condition detection, dynamic control, information dissemination, and operation status evaluation are the four primary functions of ITS.

Traffic data collection is taken as the core detection function to provide honest, accurate, and real-time data information, which provides accurate data and information support for signal control, driver driving behavior supervision, and traffic accident on-scene response, and guarantees that traffic planning and decision-making are more scientific and reasonable [29].

2 Intelligent Transport System

An intelligent transport system (ITS) is a future mode of transport that uses advanced technology to comprehensively optimize land-based traffic management systems to achieve real-time, precise, and efficient traffic operation control. Intelligent vehicles are an essential part of the future ITS, which have the ability of autonomous planning and control, as well as the function of working with human drivers. Intelligent transport is essential to constructing smart cities and plays a vital role in speed monitoring, vehicle positioning, and electronic police. In the application scenario of traffic monitoring, vehicle matching technology is critical.

Vehicle matching techniques are mainly classified into three categories: sensor-based methods, methods based on artificially designed features, and methods based

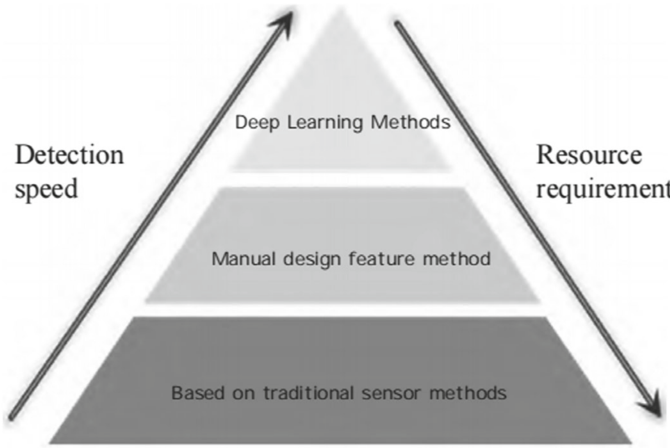

Fig. 1 The difference between traditional sensor-based methods, manually designed feature methods, and deep learning methods

on deep learning. They differ in detection speed and resource consumption, as shown in Fig. 1.

2.1 Sensor-Based Approach

Vehicles detected using sensors usually require specific methods to extract the vehicle's characteristics, and different types of sensors can provide information about the characteristics of different vehicles, such as infrared, ultrasonic, and linear magnetic. Traffic detectors can use these sensors to detect the passage or presence of vehicles and various road flow parameters to provide the control system with the information needed for optimal control. As technology advances, novel sensors and technologies have emerged to provide new solutions for vehicle matching. For example, radio frequency identification (RFID) technology can enable a new vehicle-matching algorithm [30].

2.2 Methods Based on Artificial Design Features

In the past, research in target detection has relied heavily on traditional computer vision methods that emphasize feature engineering of images and rule-based target recognition. These methods use expert-designed handcrafted features such as Haar cascade, Histrogram of oriented gradient (HoG), and Scale Invariant Feature Transform (SIFT) method. These features have the advantages of rotational invariance, scale invariance, and illumination invariance and perform well in many tasks. However, these methods also have drawbacks, requiring much human involvement, difficulty adapting to complex scenes, and multi-category problems. Therefore, traditional methods have been replaced by deep learning methods in target detection. The history of traditional detection algorithms is shown in Fig. 2.

In progressive research, some scholars have found attribute information of the vehicle itself in the vehicle image, and the vehicle attribute information includes color, texture, etc., which can be used to distinguish the exact vehicle in different scenes or vehicles in the same scene. Wang, Huang et al. [39] proposed a large feature pool consisting of multiple feature descriptors to represent the vehicle image, and based on this, they constructed a feature pool dependent on this feature pool for the vehicle type search.

The advantage of this method is that it is relatively simple, intuitive, and can effectively distinguish different types and colors of vehicles; the disadvantage is that it is not robust to scale changes, rotational transformations, lighting changes, etc., and it requires manual design and selection of appropriate features. It cannot automatically adapt to different scenes and tasks. Liu, Liu, Mei et al. [20] proposed methods based on the binary classification problem, such as calculating the probability of similarity in the identity of the vehicles, which can use the probabilistic model to measure the similarity between vehicles instead of simply using the distance between features. However, it requires a large amount of training data.

Liu, Liu, Mei, et al. [20] proposed methods based on bag-of-words (BOW) models, such as BOW-SIFT and BOW-CN, which combine bag-of-words methods with SIFT [24], and BOW-CN uses Color Name (CN), which can transform the vehicle image into a fixed-length feature vector, to perform feature matching and comparison. This method can resist the scale change and the rotational transformations to a certain extent. The disadvantage of this method is that it ignores the spatial relationship between the features in the image and needs to be more robust to lighting changes, occlusion, etc. Jeng and Chu [9] borrowed some well-established algorithms in pedestrian matching, such as HOG, LBP, etc., to extract the local texture features in the vehicle image and combine them with information such as the global color histogram to perform vehicle matching [9].

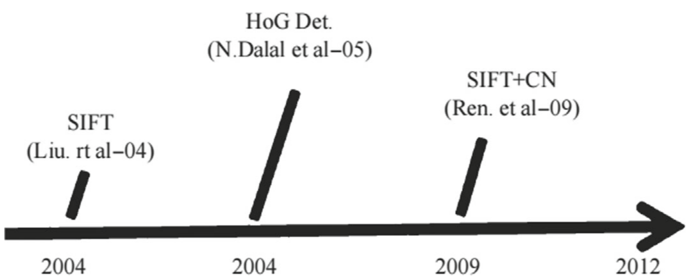

Fig. 2 History of traditional detection algorithms

2.3 Deep Learning-Based Approach

The history of deep learning algorithms is shown in Fig. 3. The rise of deep learning after 2010 has revolutionized the target detection landscape. The successful application of convolutional neural networks to image classification tasks paved the way for target detection. The initial emergence of Region Based Convolutional Neural Networks (R-CNN) scaled the image to a fixed size for training.

Finally, it used Support Vector Machine (SVM) to predict categories, improving detection and recognition accuracy, but it was prolonged. The proposed Fast R-CNN solves this problem, but the detection speed is still affected by how many targets are in the image. Faster R-CNN breaks through the speed bottleneck of Fast R-CNN. However, there was still computational redundancy in the subsequent detection stage until the emergence of the YOLO network in 2016, which pioneered single-stage detectors and greatly improved vehicle matching speed. Some subsequent single-stages have borrowed the idea of the YOLO network.

Convolutional neural networks are suitable for target re-identification. Target re-identification methods can be divided into global feature-based and local feature-based. Methods based on global features suffer from accuracy bottlenecks, while methods based on local features can better capture the differences of similar vehicles. The standard methods for extracting local features are critical point localization and region segmentation, but some limitations exist.

Earlier vehicle matching methods mainly used global features, i.e., the entire image was used to retrieve feature vectors. This approach needs more accuracy bottlenecks, so some studies have begun to focus on local features because the differences between similar vehicles are mainly in local regions. Vehicle matching methods based on local features mainly include the following methods: LIU et al. used a critical point localization method to extract features based on location and edge information, and based on this, vehicle matching is performed by comparison [18]. Liu et al. used

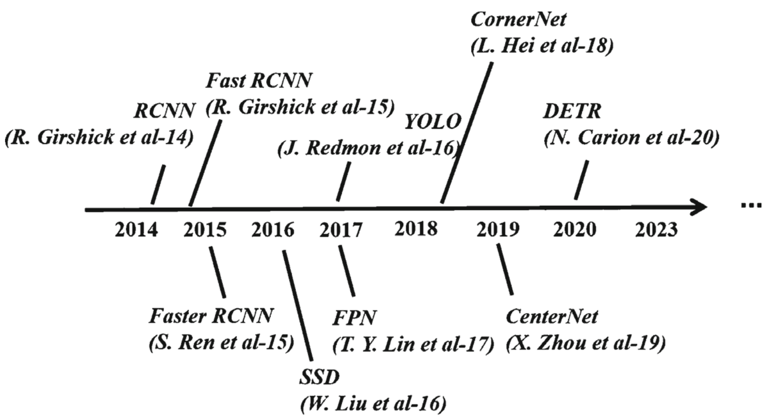

Fig. 3 History of deep learning algorithm development [19]

reinforcement learning to match vehicles at a fine-grained level [21]. Deng et al. [5] proposed Point Pair Feature NETwork (PPFNet), which is described by using a three-bit feature descriptor to improve the global sensing ability of the network [5].

Based on the method of crucial point localization and region segmentation, WANG et al. used a convolutional neural network to extract feature vectors of multiple regions. They fused them with global feature vectors for vehicle matching, which can solve the problem of multi-angle recognition, but the pre-labeling workload is significant. The quality of the dataset is required to be high [37]. The model's accuracy is easily affected by multiple conditions, so the specific implementability of this method is low.

Vehicles of the same style have a very high degree of similarity in appearance; Liu, Zhang et al. [23] proposed to use a Region-Aware deep Model Modelegion-aware deep model to extract features from a local region and train them in combination with information such as vehicle identification, type, and color as a means of generating more discriminative global and regional features [23]. This method can distinguish between vehicles sharing the same model manufacturer but requires additional vehicle information, such as vehicle identification type and regional features, using a priori conditions to some extent.

HE et al. introduced a new detection branch by adding vehicle detail part features such as front and rear lights, windows, etc., combined with the overall features for vehicle matching [8]. This method adjusts the global recognition by local features and enhances the detection and recognition of subtle differences. Qian et al. [32] proposed a segmentation and recombination network-based method that uses segmentation in multiple dimensions (e.g., height, width, and channel) in a natural map to extract more local features from each image dimension. The method also employs a two-branch network structure to prevent certain spatial features from being double-counted [32].

Peng et al. [31] used a method based on spatial transform networks and contextual reordering, which extracts features from a series of localized regions using a multiregional model and introduces a localization model based on a spatial transform network to locate the localized regions that contain more unique visual cues [31]. The method also proposes a context-based reordering method to improve the accuracy of vehicle matching by combining before and after-time data features and detection features to calculate feature distances.

Zhao et al. [45] propose a region of interest-based vehicle matching method based on single-stage detector (SSD). This method continues to extract the return on investment (ROI) region based on the target frame by extracting deep features. Ma et al. [25] use a grid space transformation network embedded network for learning, local feature extraction based on detecting the vehicle, a combination of coarse-grained and fine-grained recognition, and a fusion of the overall vehicle features and fine-grained features in order to reach the accurate vehicle matching results [25].

All of the above-proposed methods utilize local information to enhance the performance of vehicle re-identification, but there are some things that could be improved. Therefore, some researchers have proposed to reach vehicle matching through metric learning, which can improve the accuracy of vehicle matching by learning key features. Some scholars have combined twin networks to achieve vehicle matching.

Zakria et al. [42] screened similar vehicles in sequential images and then identified the vehicle license plate number to match whether it was the exact vehicle or not [42]. They also added fine-grained features such as vehicle color and annual inspection marks to improve the accuracy of the matching results. Some other scholars have added other methods based on twin networks to improve the accuracy of vehicle matching. Zhai and Min [43] applied twin networks to extract deep learning features from the input vehicle image pairs and verify the license plate numbers for accurate vehicle searches [43]. The schematic diagram of the twin network is shown in Fig. 4. To improve the similarity matching accuracy, a linear combination of softmax function and hybrid similarity learning function is used to obtain the vehicle detection results and feature extraction results, laying the foundation for accurate vehicle matching.

Liu, Liu et al. [22] on the other hand, proposed a new vehicle matching framework, which combines contextually relevant information in the temporal information and the current image features while combining the fine-grained features in order to match the vehicles accurately. Zhu et al. [47] used a concatenated structure network

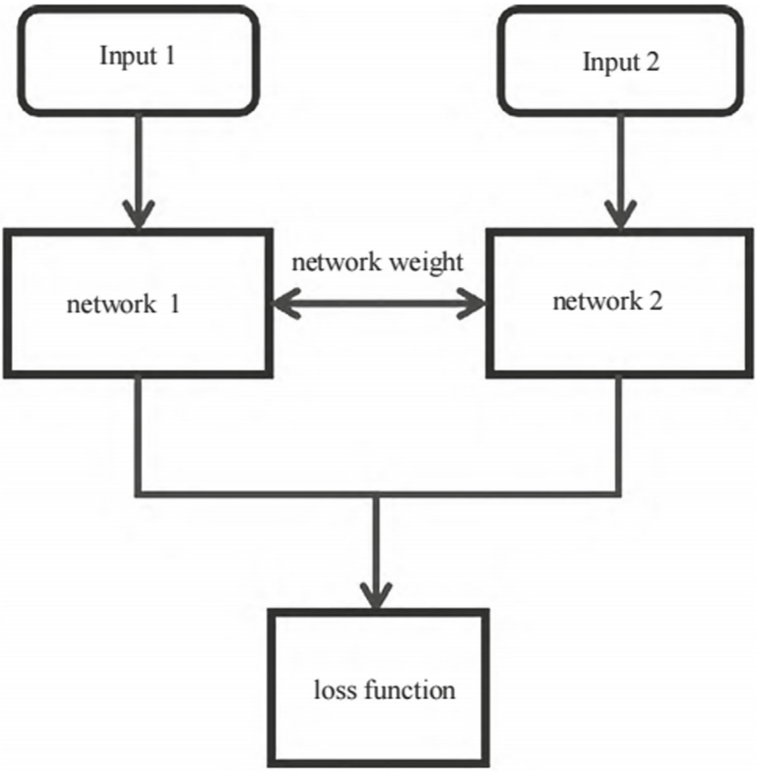

Fig. 4 Schematic diagram of a twin network

to share parameters for feature learning in the deep network to improve the feature learning capability of the network.

The similarity between different kinds of vehicles and the difference between vehicles of the same class are two significant difficulties in vehicle matching. Some scholars proposed some methods to increase the interclass feature distance in convolutional neural networks and, at the same time, reduce the intraclass feature distance to improve the model-matching ability. Schroff et al. [33] proposed intraclass loss to solve the problem of the intraclass features being too close to each other.

Weinberger and Saul [40] used the modified triple loss to improve the intraclass loss. Chen et al. [3] improved based on the proposed method and proposed the quadruple network to improve feature generalization representation. Zhang et al. [44] eliminated the undesirable effects of intra-class feature differences by adding a priori conditions such as increasing feature types and target labels. Cui et al. [4] designed a knowledge graph to represent the relationships between features to optimize training and image features for deep learning. Li et al. added image labels to the annotation and used the labels to reflect semantic information to improve the accuracy of vehicle matching [17].

In addition, existing networks have also derived a detection-feature integration model, which merges the traditional vehicle detection stage with the feature distance computation stage and integrates them into the same network to complete the process. Xiao et al. were the first to propose a detection-feature integration model based on Faster R-CNN, which replaces the original classification stage with a feature extraction network and integrates the feature distance computation process in a single network; the matching efficiency is improved. However, the matching speed decreases with the increase in the number of vehicle targets in the image due to the use of the RPN structure [41].

Voigtlander et al. used 3D convolution based on Mask R-CNN, combining temporal information for improvement and enhancement [36]. Han et al., on the other hand, proposed the ROI transform layer concept, which directly connects the detector with the feature extraction part [7]. Wang et al. proposed an embedded learning model that directly adds the feature extraction task through the original FPN network and directly uses classification supervision to reach the feature extraction effect, which improves the efficiency of the target matching, sacrificing some of the accuracy, but dramatically improves the detection speed [38]. The detection feature integration model is shown in Fig. 5.

The field of vehicle matching still needs some challenges, such as small target detection, occlusion, unbalanced data, and generalizability. The model output will also be affected if the data is complete, accurate, consistent, balanced, and representative. Therefore, there is a need for effective pre-processing, cleaning, enhancement, and selection of data in order to improve the quality and quantity of data. Future research directions include cross-domain target matching, weakly supervised learning, self-supervised learning, multimodal detection, and broader target detection applications in edge computing and autonomous driving areas.

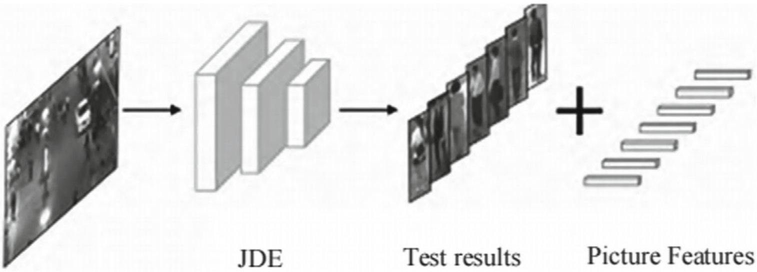

Fig. 5 Detecting feature integration models

3 Wireless Sensor Network Technology

Firstly, wireless sensor networks have real-time data collection and traffic monitoring capabilities. Wireless sensor networks can be deployed in roads, intersections, and other critical locations through the sensor to accurately collect traffic flow, speed, road conditions, and other data. These data are then transmitted to a central control system in real-time, allowing for comprehensive monitoring of traffic conditions. With the help of this data, traffic managers can accurately grasp road conditions, identify and solve traffic problems promptly, and effectively improve the efficiency of traffic operations. In addition, the data can be used to optimize traffic signal control, achieve intelligent traffic scheduling, relieve congestion, and improve traffic efficiency.

Secondly, wireless sensor networks can achieve intelligent traffic management and emergency response, which helps to improve the safety of the whole traffic system and emergency handling efficiency. Through the wireless sensor network, traffic managers can quickly obtain traffic information, congestion, accidents, and other abnormal conditions for a timely response. For example, when a traffic accident occurs, the traffic management system based on a wireless sensor network can alarm in real-time and provide detailed information such as the location of the incident, the severity of the accident, etc., which can help the emergency rescue personnel to handle the accident faster and more accurately. Moreover, the wireless sensor network can achieve real-time adjustment of traffic signals to make intersection traffic smoother.

Finally, based on real-time data from wireless sensor networks, intelligent navigation systems can provide more accurate information about road conditions, providing drivers with more intelligent and reasonable driving routes. At the same time, through the information interaction between vehicles and traffic infrastructure, the driver assistance system can provide real-time traffic warnings to help drivers avoid congested road sections, which not only improves driving safety but also helps reduce the incidence of traffic accidents.

3.1 Routing Technology

In wireless sensor networks, the routing technique is crucial to ensure data transmission from sensor nodes to the target location. Since sensor nodes are usually widely distributed and must communicate through multi-hop transmission, and traditional network routing algorithms do not apply to wireless sensing networks (nodes have limited computational power and energy), routing techniques must be optimally designed to improve network performance [26].

Routing techniques for wireless sensor networks must consider energy consumption, dynamic topology changes, and data transmission reliability. A typical routing technique is based on event-driven routing, where an event occurs, and only the nodes related to that event participate in data transmission, which can reduce unnecessary communication overhead. In addition, hierarchical routing protocols can divide the network into different levels and reduce the communication complexity between nodes. Meanwhile, there are some energy-aware routing algorithms based on optimizing the routing paths by considering the energy status of the nodes, which can effectively solve the problem of energy imbalance of the nodes in the network and prolong the network lifetime [15].

3.2 Data Fusion Technology

Data fusion technology combines similar or related data collected from multiple sensor nodes into a more comprehensive and accurate data set. In wireless sensor networks, data fusion technology can reduce data redundancy and reduce the amount of data transmission, thereby reducing energy consumption and improving network operation efficiency. The core of data fusion technology lies in the optimal design of fusion algorithms, which include algorithms such as weighted averaging, decision-level fusion, and model fusion. By fusing data from neighboring nodes, the ITS can generate more accurate and comprehensive information about the environmental state, such as temperature and humidity, which not only helps improve the data's accuracy but also reduces energy consumption during data transmission and extends the network lifetime.

3.3 Energy Management Technology

Energy management techniques are an essential aspect of wireless sensor network design. Since the energy drive of sensor nodes is limited, effective energy management techniques can prolong the lifetime and improve the network's reliability. In energy management, optimizing the energy consumption of the nodes is crucial, e.g., designing low-power hardware, adopting energy-efficient communication protocols, and developing intelligent energy scheduling strategies. Some protocols and algorithms, such as LEACH (Low Energy Adaptive Clustering Hierarchy), can effectively reduce nodes' communication and computation energy consumption by clustering nodes and dynamically adjusting the node's working state.

4 Application of Wireless Sensor Networks in Intelligent Transportation

4.1 Application in Traffic Environment Monitoring

The wireless sensor network can monitor urban vehicles and traffic, the use of sensors to monitor each vehicle, master vehicle traveling speed, flow, and other parameters, and then real-time transmission of the monitoring results for each management department to provide data and information basis for the various departments to facilitate the management of the traffic environment, effective control of traffic violations, to alleviate the problems of urban traffic congestion and other issues have a certain degree of help [10]. For example, sensors can be installed on utility poles, which can detect information such as vehicle traveling speed, license plate, etc. Other node routing uses the multi-hop self-assembled network to transmit data to the gateway nodes. Then, Ethernet is used to transmit data to the traffic management department to facilitate the monitoring of illegal driving and other behaviors.

Wireless sensor network has the function of wireless transmission and at the same time, have the characteristics of real-time monitoring, so you can signal lights, street lights, traffic signs, and other traffic facilities organized together to form an intelligent transport network, real-time monitoring, and control of each traffic facility. For example, wireless sensors can be installed at intersections to detect the intersection traffic flow, provide feedback monitoring data to the traffic signal, and then calculate the signal switching frequency through algorithms to reasonably regulate the vehicle waiting time to avoid prolonged and extensive congestion. The sensor also has an alarm function; if a safety accident or violation occurs, the sensor will transmit the information and alarm in time to ensure traffic safety and make the vehicle traveling more standardized. MICA2, MICAz (wireless sensor device), and other products can be used to meet the needs of such applications.

Wireless sensors can be installed on both sides of the road to monitor the natural environment of traffic through wireless sensor networks, including road conditions, water accumulation, dust, noise, etc., which can ensure traffic safety and meet environmental protection requirements. For example, sensors can be installed on both sides of the road to monitor changes in the surrounding noise, dust, CO2, and other parameters in real time and transmit the data through the wireless sensing network to provide an accurate basis for the work of environmental monitoring, traffic management, and other departments [2].

In addition, in public transport environments such as subways, stations, airports, etc., wireless sensor networks also play an essential monitoring role, which can monitor and manage the flow of people and prevent terrorist activities. For example, a wireless sensing network is set up in a public transport hub with many people. The environmental parameters are monitored by sensors so that if accidents such as fires, gas releases, or explosions occur, the sensors will alert the police for the first time and transmit data information to the control room, providing a basis for the duty officer to implement treatment measures.

Wireless sensor networks play a crucial role in traffic flow monitoring. By deploying sensor nodes at critical locations such as roads and intersections, they can collect traffic flow data in real-time, thus providing comprehensive traffic monitoring data.

Firstly, wireless sensor networks have high accuracy and real-time performance. In traffic flow monitoring, the sensor nodes can be improved to sense the passage of vehicles and transmit these data to the central control system in real-time to monitor traffic flow continuously. Compared with traditional means of traffic monitoring, such as cameras and ground sensing coils, wireless sensor networks can more comprehensively obtain real-time traffic conditions on the road, including traffic density, speed, and other information, providing more accurate data support for traffic managers.

Secondly, wireless sensor networks are flexible and can deliver distributed traffic flow monitoring deployment. Sensor nodes can be flexibly deployed in different locations without relying on fixed infrastructure, and this flexibility allows the system to adjust the node locations in real-time according to the changes in traffic conditions, thus better adapting to the dynamics of traffic on highways, national and provincial roads, and county and township roads [34].

Finally, wireless sensor networks can support intelligent analysis and optimization of traffic flow. With the help of wireless sensor networks to collect data for in-depth analysis, traffic managers can more accurately identify the causes of traffic congestion and then optimize the signal light control strategy, traffic management planning, etc., which helps to improve the operational efficiency of the traffic system, reduce congestion, and improve the overall quality of road traffic.

4.2 Application in Traffic Accident Early Warning

By deploying sensor nodes on roads, intersections, and other traffic-critical areas, it is possible to monitor traffic conditions in real time and provide real-time early warning of traffic accidents.

Firstly, through real-time data interaction between sensor nodes, the system can efficiently monitor vehicle behavior on the road, including crucial information such as speed, the direction of travel, and acceleration. Detection of abnormal traveling patterns or speed changes, such as sharp deceleration or sudden lane changes of vehicles, indicates the existence of certain traffic dangers, and the sensor nodes can quickly transmit these data to the central control system through the wireless sensor network, triggering a traffic accident warning.

Secondly, with the help of a wireless sensor network, the system can realize all-round and multi-angle monitoring, with broader coverage and more comprehensive monitoring, which can detect the signs of potential accidents at an earlier stage, provide more rapid warning services, and provide more reaction time for traffic management personnel and drivers.

Finally, wireless sensor networks can also integrate other information, such as weather and road conditions, to improve the accuracy of traffic accident warning systems. For example, in rainy and snowy weather, sensor nodes can sense road conditions in real-time and combine vehicle speed and braking information to predict potential traffic accident risks. The combined use of relevant information enables the system to comprehensively understand the traffic environment, thus providing more accurate accident warnings [11].

4.3 Applications in the Motorway System

In the process of intelligent transport system construction, the highway is a significant construction content that can be applied in the highway system wireless sensor network for vehicle and road condition monitoring and management to provide technical support. For example, RFID technology can be combined with applying a highway toll collection system in the vehicle close to the alarm and accurately identifying the vehicle information and the data real-time feedback to the management system [28].

Under the wireless sensor network application, RFID technology is optimized to break through spatial limitations and realize automatic parking charges, which can save labor costs. In the process of road condition monitoring, sensors can be used to obtain road surface information, including temperature, humidity, flatness, etc., and at the same time, monitor the speed of vehicle traveling and transmit the data to the management department to ensure that the management department can timely find violations, safety hazards in the highway, and then take effective management or preventive measures.

4.4 Applications in Traffic Signal Control

First, applying wireless sensor networks in traffic signal control can achieve intelligent, real-time signal adjustment. By deploying sensor nodes on the road, the system can sense real-time intersection vehicle flow, speed and queue length, and other vital data, and these real-time data are transmitted to the central control system, which then adjusts the traffic signal in real time according to the actual traffic conditions. Compared with the traditional signal control method with fixed time intervals, the traffic signal control based on a wireless sensor network is more flexible. It can be intelligently adjusted according to different periods and changes in traffic flow, which further improves the efficiency of intersection access [14].

Secondly, a wireless sensor network supports traffic signal cooperative control; sensor nodes near the intersection can work together, share traffic information near the intersection, jointly optimize signal control strategy, avoid cross-impact, and effectively avoid traffic congestion. For example, adjacent intersections can achieve signal optimization through cooperative control to reduce congestion when congestion occurs at an intersection.

Finally, wireless sensor networks can also be used to control priority vehicles. For example, public transport or emergency vehicles can carry wireless communication devices to achieve priority access signal control through communication with sensor nodes near the intersection, and this mode helps to improve the efficiency of emergency rescue and the level of public transport services [27].

4.5 Application in Intelligent Car Park

In the intelligent management mode of car parks, wireless sensor networks can enhance intelligent management and truly achieve unmanaged and intelligent services. Sensors can be installed inside the car park, not only can sense the vehicle in and out of the situation, but also can confirm whether the vehicle is in the parking space, and to the central system feedback information, automatic statistics in the car park in the free parking space, for the vehicle to find a parking space to provide convenience but also to avoid the lack of parking space after the vehicle is still entering the car park, thus causing internal blockage. It can also be combined with RFID technology, the use of sensors on the field of vehicles staying in the state, and the time to monitor the perception of the exit position to set up a charge point can be realized without stopping to charge.

4.6 Applications in Vehicle Tracking and Logistics Management

First of all, wireless sensor networks can be used for vehicle tracking. Deploying sensors on significant traffic routes can monitor the location and speed of vehicles, and this real-time vehicle tracking can provide logistics companies with accurate information to help them better monitor the progress of cargo transport, optimize transport routes, and improve transport efficiency. Especially for long-distance trucking on national and provincial highways and motorways, due to the overall long transport distance, wireless sensor networks can provide reliable real-time monitoring, which can significantly improve the level of transport services [13].

Secondly, the application of wireless sensor networks can further ensure the safety of goods transport. Installing sensors in logistics vehicles allows real-time monitoring of cargo status, such as temperature, humidity, vibration, etc., which is particularly important for transporting sensitive goods (e.g., food, pharmaceuticals, chemicals, etc.). Suppose there is any abnormality in the status of the cargo. In that case, the system can immediately issue an alarm so that emergency measures can be taken in time to ensure the quality and safety of the cargo.

Finally, wireless sensor networks also play an important role in fleet management. Logistics companies can use wireless sensor networks to track and manage the location and operation of their entire fleet, which can help optimize vehicle allocation, reduce operating costs, reduce empty driving, and improve vehicle utilization. At the same time, monitoring driving behavior can help reduce the risk of traffic accidents and improve the safety of the transportation process.

5 Conclusion

In summary, in the process of intelligent transport development, wireless sensor networks can be used to enhance the level of system intelligence. Wireless sensor networks have a broad application prospect and far-reaching influence in intelligent transport. Specifically, it is the use of sensor nodes, real-time monitoring of the traffic environment, vehicle conditions, timely mastery of the information data, and transmission of feedback to the various user ends to provide more data and information support for traffic management, planning, and decision-making, and to solve traffic congestion and other problems.

In the future, continuous innovation and collaborative cooperation will become the key to promoting this field's development in constructing intelligent transport. The government, enterprises, and academic institutions should make joint efforts to strengthen the research and application of wireless sensor network technology and promote the formulation and improvement of related policies to promote the popularization of ITS and the enhancement of service level [12].

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Declarations

Conflict of Interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this chapter.

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Integrating Industrial Robotics and Internet of Things (IoT) in Smart Transportation System

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Abstract Smart transportation systems represent a transformative approach to managing urban mobility, leveraging advanced technologies to enhance efficiency, safety, and sustainability. Central to these systems are various types of sensors, which gather real-time data critical for informed decision-making. This chapter explores the diverse applications of sensors within smart transportation, categorizing them into traffic, environmental, vehicle, and infrastructure sensors. It delves into how these sensors are utilized for traffic management and control, public transportation optimization, autonomous and connected vehicle functionality, environmental monitoring, and smart infrastructure management. The integration of Internet of Things (IoT) technology and sophisticated communication protocols such as 5G and Dedicated Short-Range Communications (DSRC) underpins the seamless operation of these systems. Despite the promising advancements, challenges such as sensor accuracy, data security, and privacy concerns persist, necessitating ongoing research and development. Future trends point towards further integration of artificial intelligence and machine learning to enhance predictive capabilities and decision-making processes. Through detailed case studies and real-world implementations, this chapter illustrates the practical benefits and lessons learned from deploying sensor technologies in various urban settings. By synthesizing current research and technological innovations, it provides a comprehensive overview of the critical role

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sensors play in realizing the vision of smart transportation. The chapter concludes with an outlook on future developments, emphasizing the continuous evolution and potential of sensor applications to revolutionize urban mobility.

Keywords Cybersecurity · Smart transportation systems · Critical infrastructure · Threats and vulnerabilities · Security measures

1 Introduction

1.1 Smart Transportation Systems Overview

Smart Transportation Systems (STS) use cutting-edge technology to boost efficiency, safety, and sustainability in transportation infrastructure [2]. These systems employ a number of technologies, including wireless communication, sensors, data analytics, and artificial intelligence, to optimize the flow of people and products. STS essentials include:

- Intelligent Transportation Systems (ITS): These employ information and communication technology to improve traffic management, alleviate congestion, and enhance the overall travel experience. Intelligent traffic lights, real-time traffic monitoring, and dynamic toll pricing are examples.
- Connected Vehicles: Vehicles that interact with one another, infrastructure, and other entities over the internet. This connectivity assists in exchanging real-time data for increased safety and efficiency.
- Public Transportation Enhancements: Real-time tracking, automated fare collection, and smart ticketing increase public transit dependability and convenience.
- Smart Logistics: Uses IoT and data analytics to manage fleet operations, track shipments, and forecast repair requirements [1].

1.2 Value of Industrial Robotics and IoT

Industrial Robotics and the IoT are essential to smart transportation systems for various reasons:

- Automation and Efficiency: Industrial robots can automate production, loading, and unloading, saving time and decreasing error. In transportation, robots can be employed for automated warehouses, autonomous cars, and traffic management systems [3–5]
- Real-time Monitoring and Data Collection: IoT devices can capture large volumes of data from cars, infrastructure, and the environment. This data is crucial for real-time monitoring, predictive maintenance, and informed decision-making, which promotes the efficiency and safety of transportation networks.

- Enhanced Safety: Both robots and IoT contribute greatly to safety. Autonomous cars and drones, outfitted with sensors and AI, can decrease accidents caused by human error. IoT-enabled infrastructure can monitor and regulate traffic conditions to prevent accidents.
- Sustainability: IoT can aid in optimizing routes and lowering fuel use, leading to fewer emissions. Smart grids and energy-efficient technologies may be connected with transportation infrastructure to improve sustainability [3–5].

1.3 Objectives of Integration

The key aims of integrating industrial robots and IoT into smart transportation systems are:

- Efficiency Optimization: To boost the efficiency of transportation operations by automating procedures and leveraging real-time data for decision-making. This involves optimizing traffic flow, decreasing congestion, and enhancing the reliability of public transit.
- Safety Improvement: To enhance safety for all road users by utilizing robots for autonomous driving and IoT for real-time monitoring and notifications. This attempts to prevent accidents, improve emergency response times, and ensure safer movement of products and people.
- Cost Reduction: To minimize operational costs by lowering the need for human labor, minimizing maintenance expenses using predictive analytics, and improving fuel economy. Automation and data-driven decision-making may drastically reduce expenditures in logistics and transportation management.
- Sustainability: To build a more sustainable transportation ecosystem by lowering carbon emissions, boosting the use of electric and autonomous cars, and optimizing resource utilization. IoT can monitor environmental effects and assist in adopting green practices throughout transportation networks.
- Enhanced User Experience: To improve the overall travel experience for users by delivering real-time information, assuring timely and dependable services, and boosting convenience through technologies like smart ticketing and route optimization.
- Innovation and Growth: To stimulate innovation in the transportation industry by integrating cutting-edge technology, stimulating the creation of new applications and services, and supporting economic growth through enhanced logistics and supply chain management.

In summary, the integration of industrial robots and IoT into smart transportation systems is vital for establishing a more efficient, safe, cost-effective, sustainable, and user-friendly transportation network. By utilizing these technologies, we can address many of the issues encountered by contemporary transportation systems and pave the path for future advancements.

2 Fundamentals of Industrial Robotics

2.1 Definition and Types of Industrial Robots

Definition: Industrial robots are programmable mechanical devices designed to execute a range of activities in industrial environments. They are capable of carrying out difficult and repeated activities with high precision, speed, and efficiency. These robots are primarily employed in manufacturing, assembling, packing, and material handling procedures [3–5].

2.2 Types of Industrial Robots

2.2.1 Articulated Robots

- Description: Robots having rotary joints that can range from two to ten or more interacting segments.
- Applications: Welding, material handling, packing, and assembly.

2.2.2 SCARA Robots (Selective Compliance Assembly Robot Arm)

- Description: Robots having a horizontal motion plane and minimal vertical motion, suited for applications demanding accurate lateral motions.
- Applications: Pick-and-place jobs, assembly procedures, and packaging.

2.2.3 Cartesian Robots (Gantry Robots)

- Description: Robots with three linear axes of control that move in straight lines along the X, Y, and Z axes.
- Applications: CNC machines, 3D printing, and heavy-load assembly.

2.2.4 Delta Robots

- Description: Parallel robots with three arms attached to a common base, recognized for their exceptional speed and precision.
- Applications: High-speed pick-and-place activities, packing, and sorting.

2.2.5 Collaborative Robots (Cobots)

- Description: Robots intended to operate alongside human workers safely without the need for fences or other safety obstacles.
- Applications: Assembly, machine tending, and quality inspection.

2.3 Key Components and Functions

2.3.1 Key Components

- Manipulator/Arm: The primary body of the robot, comprised of joints and connections that give movement and flexibility.
- End Effector: The tool connected to the robot's arm, designed to interact with the environment (e.g., grippers, welding torches, painting nozzles).
- Actuators: Devices that drive the robot's joints, providing movement. They might be electric, hydraulic, or pneumatic.
- Sensors: Devices that offer feedback to the robot, allowing it to sense its surroundings and change its actions accordingly. Common sensors include vision systems, force sensors, and proximity sensors.
- Controller: The brain of the robot, which interprets input from sensors and orders from software to drive the actuators and end effectors.
- Power Supply: Provides the required electrical, hydraulic, or pneumatic power to the robot's components.

2.3.2 Functions

- Movement and Positioning: Achieving exact control over the robot's movements and position.
- Sensing and Feedback: Gathering and processing input from the environment to make educated judgments.
- Task Execution: Performing specialized activities such as welding, painting, assembling, or material handling.
- Communication: Interacting with other machines, systems, and human operators using various communication protocols.

2.4 Current Trends and Innovations

- Collaborative Robotics: Development of Cobots that securely operate alongside people without major safety procedures. These robots are equipped with powerful sensors and control algorithms to recognize and respond to human presence.

- Artificial Intelligence and Machine Learning: Integration of AI and machine learning to enable robots to learn from their surroundings, improve their performance over time, and tackle difficult, unstructured jobs.
- Advanced Sensing and Vision Systems: Use of modern sensors, including 3D vision systems and LiDAR, to boost the robot's capacity to detect and interact with its surroundings with high precision.
- Enhanced Connectivity and IoT Integration: Implementation of IoT technology to connect robots with other devices and systems, allowing for real-time data sharing, predictive maintenance, and optimal operations.
- Modular and Reconfigurable Robots: Development of robots with modular designs that can be quickly modified or updated to perform multiple jobs, boosting flexibility and lowering downtime.
- Energy Efficiency: Focus on producing energy-efficient robots that decrease power consumption and environmental effect through enhanced design and control tactics.

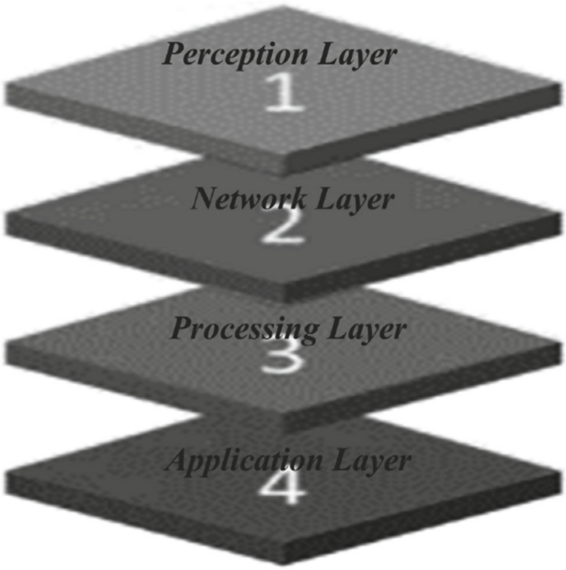
3 Basics of IoT in Transportation

3.1 IoT Architecture and Components

(See Fig. 1).

IoT Architecture are described as below:

Fig. 1 IoT architecture layers



3.1.1 Perception Layer

- Components: Sensors and actuators.
- Function: Collects data from the physical environment. Sensors measure various parameters like temperature, speed, location, and pressure, while actuators perform actions based on the data received.

3.1.2 Network Layer

- Components: Gateways and data acquisition systems.
- Function: Transfers data from the perception layer to the processing layer. This layer uses various communication technologies such as Wi-Fi, Bluetooth, cellular networks, and LPWAN (Low Power Wide Area Network).

3.1.3 Processing Layer

- Components: Cloud computing platforms, data storage systems, and analytics engines.
- Function: Processes and analyzes the data collected. This layer utilizes big data analytics, machine learning, and artificial intelligence to derive insights and make decisions.

3.1.4 Application Layer

- Components: Application software and user interfaces.
- Function: Provides specific services to users based on the processed data. Examples include traffic management systems, fleet management applications, and smart parking solutions.

3.1.5 Business Layer

- Components: Business models, regulations, and standards.
- Function: Manages the overall business logic and operations, ensuring that the IoT system aligns with organizational goals and regulatory requirements.

IoT Components:

- Sensors and Actuators: Devices that detect and respond to environmental inputs.
- Connectivity Modules: Wi-Fi, Bluetooth, cellular modules, and other networking hardware.
- Data Processors: Edge computing devices and cloud servers that analyze and store data.

- Software: Platforms and applications for data management, analytics, and visualization.
- User Interfaces: Dashboards, mobile apps, and web interfaces for users to interact with the system.

3.2 Role of IoT in Transportation Systems

(See Fig. 2).

Here is description of each component.

- Traffic Management: Function: IoT-enabled traffic lights and cameras monitor and control traffic flow, reducing congestion and improving road safety. Real-time data is used to optimize traffic signal timings and manage traffic incidents [6].

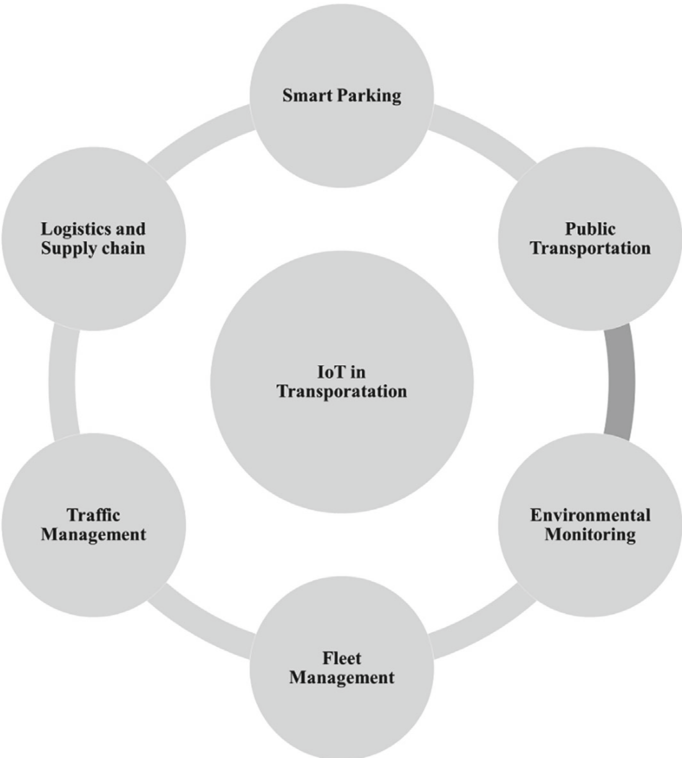


Fig. 2 Representation of IoT in intelligent transportation

- Fleet Management: Function: IoT devices track vehicle location, fuel consumption, and driver behavior. This helps in route optimization, maintenance scheduling, and enhancing driver safety.
- Public Transportation: Function: IoT solutions provide real-time information on bus and train schedules, delays, and occupancy levels. This improves the efficiency and reliability of public transport services.
- Smart Parking: Function: IoT sensors detect available parking spaces and direct drivers to them via mobile apps, reducing the time spent searching for parking and easing urban congestion.
- Logistics and Supply Chain: Function: IoT systems monitor the condition of goods during transit, track shipment locations, and predict delivery times. This enhances the transparency and efficiency of supply chains.
- Safety and Maintenance: Function: IoT-enabled predictive maintenance systems monitor the health of vehicles and infrastructure, predicting failures before they occur and reducing downtime.
- Environmental Monitoring: Function: IoT sensors monitor air quality and noise levels in urban areas, helping to implement measures to reduce pollution and improve public health.

3.3 IoT Standards and Protocols

3.3.1 MQTT (Message Queuing Telemetry Transport)

- Description: A lightweight messaging protocol designed for small sensors and mobile devices, optimized for high-latency or unreliable networks.
- Use: Widely used in IoT for real-time communication, particularly in constrained environments.

3.3.2 CoAP (Constrained Application Protocol)

- Description: A protocol designed for use with constrained nodes and networks in IoT. It allows devices to communicate over the Internet with minimal overhead.
- Use: Suitable for low-power, lossy networks such as 6LoWPAN and other wireless sensor networks.

3.3.3 HTTP/HTTPS (Hypertext Transfer Protocol/Secure)

- Description: The foundation of data communication for the World Wide Web, used for transmitting hypertext. HTTPS is the secure version, encrypting data for security.
- Use: Commonly used for web-based IoT applications where security and reliable data transmission are crucial.

3.3.4 AMQP (Advanced Message Queuing Protocol)

- Description: An open standard application layer protocol for message-oriented middleware.
- Use: Provides reliable communication and ensures message delivery, often used in enterprise environments.

3.3.5 Zigbee

- Description: A specification for a suite of high-level communication protocols using low-power digital radios.
- Use: Suitable for low-power, low-data rate applications such as home automation and industrial control systems.

3.3.6 LoRaWAN (Long Range Wide Area Network)

- Description: A protocol for wide-area networks, designed to allow low-powered devices to communicate with Internet-connected applications over long-range wireless connections.
- Use: Ideal for large-scale IoT deployments in smart cities, agriculture, and environmental monitoring.

3.3.7 BLE (Bluetooth Low Energy)

- Description: A wireless personal area network technology designed for short-range communication with low power consumption.
- Use: Commonly used in wearable devices, smart home products, and health monitoring systems.

These standards and protocols ensure interoperability, security, and efficient communication within IoT ecosystems, enabling a wide range of applications in transportation and beyond.

4 Integration of Industrial Robotics and IoT

The integration of industrial robotics and the Internet of Things (IoT) in smart transportation systems is a major step towards constructing more efficient, safe, and intelligent transportation networks. This integration utilizes the strengths of both technologies, combining the precise, high-speed operations of industrial robots with the real-time data collection and processing capabilities of IoT. The conceptual framework for this integration contains numerous major components and layers. At the core, industrial robots outfitted with numerous sensors operate as the major data generators. These sensors monitor multiple characteristics such as position, speed, temperature, and force, enabling the robots to perform tasks with high precision and adaptability.

IoT devices and sensors are placed throughout transportation infrastructure, vehicles, and logistics systems to capture real-time data on traffic conditions, vehicle performance, and environmental factors. The data collected is transported via resilient communication networks to centralized or cloud-based processing units where advanced analytics, machine learning, and artificial intelligence algorithms process the information to create actionable insights. This processed data is then put back into the system to optimize robot operations, traffic control, and overall transportation efficiency [15].

Integration techniques and methodologies for combining industrial robotics with IoT comprise numerous ways. One major strategy is edge computing, where data processing occurs locally to the source of data generation rather than depending entirely on central cloud servers. This minimizes latency and bandwidth utilization, allowing for speedier decision-making and real-time answers. In this setting, industrial robots and IoT devices can interface directly with local edge nodes to process crucial data fast.

Another way involves deploying digital twins, which are virtual representations of physical assets like robots and transportation networks. These digital twins imitate and analyze real-world situations, enabling predictive maintenance, optimization of operations, and testing of new tactics without affecting actual operations. Integration also demands robust interoperability standards and protocols such as MQTT, CoAP, and OPC-UA, which permit smooth communication between varied devices and systems. Middleware systems play a critical role in handling data interchange, device control, and application integration. These platforms provide a uniform interface for monitoring, controlling, and analyzing the integrated system [14].

However, integrating industrial robotics and IoT with transportation systems raises various problems. One important difficulty is guaranteeing the security and privacy of the large amounts of data generated and transmitted across the network. Cybersecurity techniques like as encryption, secure communication protocols, and authentication procedures are vital to safeguard sensitive information from breaches and cyber-attacks. Another key problem is the compatibility across multiple devices, systems, and standards.

The vast spectrum of sensors, robotics, and IoT devices generally come from many vendors with distinct communication protocols and data formats. Developing global standards and leveraging middleware technologies can assist address this issue, assuring easy integration and operation? Scalability is also a challenge, as the number of linked devices and the volume of data expand exponentially. Efficient data management strategies, scalable infrastructure, and powerful data analytics tools are vital to handle this expansion without compromising performance [13].

Furthermore, there are technical problems connected to the dependability and robustness of the integrated system. Industrial robots and IoT devices operate in diverse and sometimes severe settings, needing durable hardware and resilient software solutions. Real-time processing and low latency are crucial for applications like autonomous vehicles and traffic control, necessitating high-performance computing resources and efficient network setups. Another problem is the integration of historical systems with new IoT and robotic technology.

Many existing transportation infrastructures and industrial settings are not meant to be compatible with IoT and robotics, requiring extensive retrofitting and adaption. This procedure can be costly and time-consuming, but it is necessary for exploiting the full potential of the integration. Additionally, worker skills and training are vital for the successful deployment and operation of integrated systems. Personnel need to be adept in both robots and IoT technologies, needing thorough training programs and continuing education to stay up with the rapid improvements in both domains.

Solutions to these difficulties entail a combination of technology improvements, standardization efforts, and strategic planning. Enhancing cybersecurity measures is vital, with continual research and development in secure communication protocols, intrusion detection systems, and encryption technologies. Establishing and adopting global standards and protocols will promote interoperability and seamless integration of varied devices and systems.

Collaborative efforts among industry stakeholders, regulatory authorities, and standardization organizations are crucial to drive these projects. Scalability can be addressed with cloud computing and edge computing technologies, which offer flexible and scalable infrastructure to meet the increasing data volumes and processing demands. Leveraging modern data analytics, machine learning, and artificial intelligence can boost the system's ability to manage and utilize the huge amounts of data created, enabling more efficient and intelligent decision-making. Developing strong and reliable hardware and software solutions is vital for maintaining the endurance and performance of the integrated system. This includes adopting high-quality materials, thorough testing, and integrating redundancy and failover methods to sustain ongoing operation in case of breakdowns [11].

To allow the integration of legacy systems, strategic planning and investment are required. This may involve phased implementation, where components of the system are changed sequentially, and interoperability solutions that enable old and new technologies to coexist and interact efficiently. Training and education programs are required to equip the workforce with the necessary skills and knowledge to operate and maintain integrated systems.

Continuous professional development and hands-on training may ensure that people stay informed with the latest technologies and best practices. Finally, cultivating a culture of innovation and collaboration is crucial for the effective integration of industrial robotics and IoT in transportation systems. Encouraging research and development, establishing partnerships between academia, business, and government, and supporting pilot projects and testbeds can stimulate innovation and speed the adoption of integrated solutions.

In conclusion, the integration of industrial robotics and IoT in smart transportation systems offers substantial benefits, including greater efficiency, safety, and sustainability. The conceptual framework incorporates a multi-layered architecture with crucial components and advanced data processing capabilities. Integration approaches such as edge computing, digital twins, and middleware platforms promote seamless operation and real-time decision-making. However, difficulties relating to security, interoperability, scalability, reliability, legacy systems, and workforce skills must be addressed by a combination of technology developments, standardization efforts, strategic planning, and continual education. By addressing these hurdles, the integration of industrial robotics and IoT can alter transportation systems, leading to smarter, more connected, and more efficient networks.

5 Applications in Smart Transportation Systems

5.1 Automated Traffic Management

Automated traffic management systems leverage the power of IoT and industrial robotics to enhance the efficiency and safety of urban transportation networks. These systems use a network of sensors, cameras, and IoT devices strategically placed throughout the city to monitor real-time traffic conditions. Data collected from these devices, such as vehicle speed, traffic density, and incident reports, is transmitted to a central control system. Advanced algorithms and artificial intelligence analyze this data to optimize traffic light timings, predict congestion, and suggest alternative routes.

Industrial robots can be deployed for tasks such as automated road maintenance and dynamic traffic signage adjustments. By integrating these technologies, traffic management becomes more responsive and adaptive, reducing traffic jams and improving the flow of vehicles. The system can also prioritize emergency vehicles, providing them with a clear path and reducing response times. Furthermore, automated traffic management systems can communicate with connected vehicles, providing drivers with real-time updates on traffic conditions and potential hazards, enhancing overall road safety. The ultimate goal of these systems is to create a seamless and efficient transportation environment that reduces travel time, fuel consumption, and greenhouse gas emissions, contributing to a smarter and more sustainable urban infrastructure.

5.2 Intelligent Transportation Systems (ITS)

Intelligent Transportation Systems (ITS) integrate advanced information and communication technologies into the transportation infrastructure to improve safety, mobility, and efficiency. ITS encompasses a broad range of applications including traffic management, public transportation systems, and traveler information services. By employing IoT devices, sensors, and data analytics, ITS can monitor and manage transportation networks in real-time. For instance, ITS can manage traffic flow by adjusting traffic signal timings based on real-time traffic conditions, thus reducing congestion and improving travel times.

Public transportation systems benefit from ITS through real-time tracking of buses and trains, allowing passengers to receive up-to-date information on arrival times and service disruptions. This enhances the reliability and convenience of public transit, encouraging its use and reducing the number of private vehicles on the road. Additionally, ITS can provide drivers with real-time information on road conditions, weather, and accidents, helping them make informed travel decisions. The integration of ITS with connected vehicle technology further enhances safety by enabling vehicles to communicate with each other and with infrastructure to avoid collisions and improve traffic flow. Overall, ITS aims to create a more efficient, safe, and user-friendly transportation system by leveraging the capabilities of modern technology to address the challenges of urban mobility.

5.3 Smart Logistics and Supply Chain Management

Smart logistics and supply chain management utilize IoT and industrial robotics to streamline operations, improve efficiency, and reduce costs. IoT devices such as RFID tags, GPS trackers, and environmental sensors provide real-time visibility into the location and condition of goods throughout the supply chain. This enables precise tracking of shipments, inventory management, and environmental monitoring to ensure products are stored and transported under optimal conditions. Industrial robots are used in warehouses and distribution centers for tasks such as picking, packing, sorting, and palletizing, significantly reducing human error and increasing operational efficiency.

Automated guided vehicles (AGVs) and drones can transport goods within warehouses and between distribution points, further enhancing the speed and accuracy of logistics operations. Predictive analytics, powered by data collected from IoT devices, can forecast demand, optimize inventory levels, and predict maintenance needs for logistics equipment, minimizing downtime and ensuring the smooth operation of supply chains. Furthermore, smart logistics solutions can improve sustainability by optimizing routes for delivery trucks to reduce fuel consumption and emissions. By integrating IoT and robotics into logistics and supply chain management, companies can achieve greater visibility, efficiency, and responsiveness, ultimately leading to better service for customers and a more resilient supply chain.

5.4 Autonomous Vehicles and Drones

Autonomous vehicles and drones represent a significant advancement in smart transportation systems, offering potential improvements in safety, efficiency, and convenience. Autonomous vehicles, equipped with a combination of sensors, cameras, radar, and artificial intelligence, can navigate and operate without human intervention. These vehicles can communicate with each other and with traffic management systems to optimize routes, reduce traffic congestion, and enhance road safety by eliminating human error. Autonomous vehicles also have the potential to provide mobility solutions for individuals who are unable to drive, such as the elderly or disabled, thereby improving accessibility and independence.

Drones, on the other hand, are increasingly being used for various transportation-related tasks, including aerial surveillance, traffic monitoring, and delivery services. Equipped with advanced navigation systems and cameras, drones can provide real-time data on traffic conditions, accidents, and road infrastructure, assisting traffic management systems in making informed decisions. In logistics, drones can be used for last-mile delivery, quickly and efficiently transporting small packages to remote or congested urban areas. The use of drones for delivery can reduce the reliance on traditional delivery vehicles, lowering traffic congestion and emissions. The integration of autonomous vehicles and drones into transportation systems promises to transform urban mobility, making it safer, more efficient, and more adaptable to the needs of modern society.

6 Conclusion

The integration of industrial robotics and IoT in smart transportation systems marks a transformative shift towards more efficient, safe, and sustainable urban mobility solutions. This comprehensive approach leverages the strengths of both technologies, creating a synergistic effect that optimizes transportation networks at multiple levels. Industrial robots, with their precision, speed, and reliability, coupled with the real-time data collection and processing capabilities of IoT, form the backbone of this integrated system. By implementing these advanced technologies, cities can significantly enhance their traffic management, logistics operations, and overall transportation infrastructure.

Automated traffic management systems exemplify the practical benefits of this integration. By using sensors and IoT devices to monitor real-time traffic conditions, these systems can dynamically adjust traffic signal timings, reduce congestion, and prioritize emergency vehicles, leading to smoother and safer urban transportation. Intelligent Transportation Systems (ITS) further extend these capabilities by providing real-time information to drivers and public transportation users, enhancing the reliability and convenience of travel. The ability to make informed travel decisions based on up-to-date information significantly improves the overall travel experience and reduces the environmental impact of transportation.

In the realm of logistics and supply chain management, the integration of IoT and robotics has revolutionized operations. Real-time tracking of goods, predictive maintenance of equipment, and automated warehousing processes have resulted in greater efficiency, reduced costs, and enhanced service quality. The use of autonomous vehicles and drones in logistics and delivery services further demonstrates the potential of these technologies to reduce traffic congestion and lower emissions, contributing to more sustainable urban environments.

However, this integration is not without its challenges. Ensuring the security and privacy of data, achieving interoperability among diverse systems and devices, and maintaining scalability and reliability are critical issues that need to be addressed. Robust cybersecurity measures, standardization efforts, and strategic planning are essential to overcoming these obstacles. Additionally, the integration of legacy systems with new technologies and the need for continuous workforce training highlight the complexity of implementing such advanced systems on a large scale.

Despite these challenges, the potential benefits of integrating industrial robotics and IoT in smart transportation systems are immense. Enhanced efficiency, improved safety, cost savings, sustainability, and a better user experience are just a few of the advantages that can be realized. The continuous advancements in technology and collaborative efforts among industry stakeholders, regulatory authorities, and researchers are paving the way for more innovative and effective transportation solutions.

In conclusion, the integration of industrial robotics and IoT into smart transportation systems represents a significant step towards smarter, more connected, and more efficient urban mobility. By harnessing the power of these technologies, cities can address the growing challenges of urbanization, improve the quality of life for their inhabitants, and create a more sustainable future. As technology continues to evolve, the possibilities for further enhancing transportation systems are limitless, promising an exciting and transformative journey ahead.

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Beyond the Horizon: Exploring the Future of Artificial Intelligence (AI) Powered Sustainable Mobility in Public Transportation System

Babasaheb Jadhav, Ashish Kulkarni, Alex Khang, Pooja Kulkarni, and Sagar Kulkarni

Abstract Recent news highlights the severe impact of traffic congestion, such as in a major Information Technology (IT) city in India where 37 IT companies are relocating due to continual traffic issues. This not only disrupts the daily lives of workers and related businesses but also significantly harms the environment. High temperatures, such as the record 54 degrees Celsius in the capital city, are partly due to pollution, despite efforts to improve mobility with metros, public transport, CNG, and electric vehicles. Imagine driving a quiet vehicle on an empty street. While this may seem like a distant dream now, it can become a reality with Artificial Intelligence (AI)-based automation. Beyond the Horizon: Exploring the Future of AI-powered sustainable mobility aims to discover revolutionary ways to achieve hassle-free travel. By leveraging data science and sophisticated algorithms, AI can identify traffic-free routes, pinpoint the causes of traffic jams, and notify authorities for quick action. This chapter delves into how AI can guide us toward a more sustainable and efficient way to move around the world, envisioning a future where seamless and eco-friendly transportation is within our grasp.

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Keywords Artificial intelligence · Sustainable mobility solutions · Smart transportation · Traffic management · Green technology · AI in logistics and SCM · Intelligent transportation system · Smart city mobility

1 Introduction

Everyone talks about transportation these days. It can be tough to get around, what with traffic jams, expensive gas, and pollution. People are looking for ways to make travel better for the environment, so there's a lot of talk about new fuels like CNG, electric batteries, and even ethanol. The current transportation system faces many problems, such as traffic jams, high fuel prices, and sustainability issues. Stakeholders are always trying to solve these problems and find new solutions. Artificial Intelligence (AI) can help address some of these issues.

1.1 Purpose

This chapter delves into the transformative potential of artificial intelligence (AI) in shaping the future of sustainable transportation. We will examine the myriad benefits, challenges, and practical applications of AI in creating a more seamless and environmentally friendly mobility landscape. Through this exploration, we aim to highlight how AI can revolutionize transportation systems, making them more efficient, reliable, and sustainable.

1.2 Methodology

The analysis incorporates a comprehensive review of recent studies and detailed case examples of AI-powered transportation solutions. Additionally, we have conducted interviews with leading experts in AI and sustainable mobility to provide deeper insights and diverse perspectives.

1.3 Outcomes

AI has the potential to significantly reduce the environmental impact of transportation through various means. By optimizing traffic management, AI can reduce congestion and lower emissions. The integration of self-driving cars can enhance fuel efficiency and reduce the number of vehicles on the road. Additionally, AI can improve the efficiency and appeal of public transit systems, encouraging more people to use them instead of personal vehicles. However, there are critical challenges that need to be addressed to fully realize these benefits. Ensuring the protection of data privacy is paramount, as the vast amounts of data required for AI systems must be securely managed. Updating infrastructure to support advanced AI technologies is essential, requiring significant investment and planning. Furthermore, ethical concerns must be carefully considered, including the implications of AI decision-making and the potential for job displacement. Addressing these challenges is crucial to leveraging AI for a more sustainable and efficient transportation future.

Nowadays, AI can help manage traffic and reduce congestion. For example, maps can show traffic conditions and suggest the best routes to reach destinations. For public transport, AI can provide exact times and routes to individuals on their cell phones. This helps reduce carbon emissions and supports sustainability efforts. AI might not tackle sustainability directly, but it can help in ways that make a big difference. By finding ways to use less energy, AI can lead to fewer emissions and a more sustainable world. Small changes, like public transport that runs on time and smart traffic lights that reduce congestion, can make life easier and support sustainability efforts.

AI can help reduce traffic problems and support sustainability, but putting AI in existing vehicles is hard. Old cars can't easily be updated with advanced AI technology. Current solutions, like using maps and GPS for navigation, depend on the GPS settings of all passengers in a vehicle, which can sometimes be inaccurate and not very helpful. However, there are easier solutions we can use right now. For example, AI can manage traffic lights better. Smart traffic lights can change their timings based on real-time traffic, helping reduce congestion and improve traffic flow. AI can also help enforce traffic rules by identifying and acting against people who break the law, using AI-powered cameras and monitoring systems.

In our effort to be more sustainable, even small steps can make a big difference. While a fully AI-integrated transportation system is the goal, starting with simple changes can lead to significant improvements. Better traffic light management and stricter rule enforcement are practical steps that can make our transportation systems smarter and more sustainable. By taking these small steps, we can move towards a future where AI helps make travel easier and better for the environment as shown in Fig. 1.

2 Literature Review

Rizvi, Xin, and Masood published an article in the 11th International Conference on Power and Energy Systems (ICPES) titled "Optimal Scheduling of Virtual Power Plants Utilizing Wind Power and Electric Vehicles." They found that the expanding share of wind power, despite its environmental benefits, is hindered by its unpredictability and the need for precise forecasting. Virtual power plants (VPPs) are crucial in addressing the scattered nature of distributed energy resources. This study proposes integrating wind farms and electric vehicles (EVs) as a VPP. Researchers

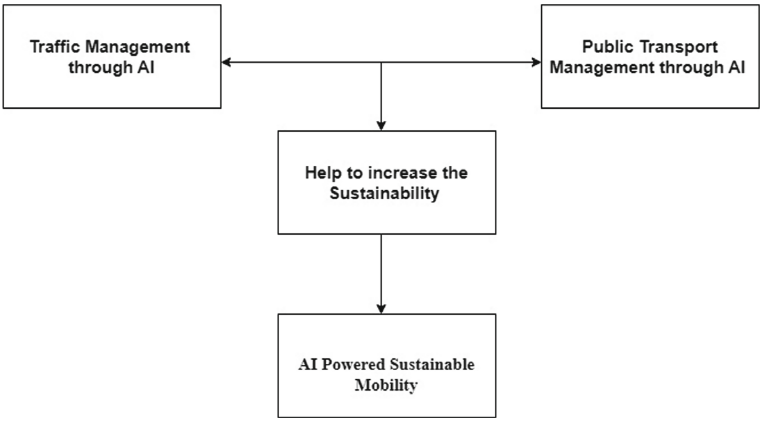

Fig. 1 Role of AI in sustainability for mobility

found that EVs can serve as the storage system for VPPs, mitigating the intermittent of wind power and saving the initial investment cost of setting up a specified storage system. Additionally, the mobility and frequent grid connectivity of EVs are advantageous. They proposed a linear programming optimization model for optimal VPP scheduling in the day-ahead market and introduced an innovative payment procedure for participating EVs.

Swarnkar, Chopra, Dhote, Nigam, Upadhyaya, and Prajapati [10] published an article in the 2023 IEEE Renewable Energy and Sustainable E-Mobility Conference (RESEM) titled "Use of AI for Development and Generation of Renewable Energy." They explored the potential of artificial intelligence (AI) to transform renewable energy production and generation. AI can optimize efficiency and output at various stages, including site selection, design, operation, and maintenance, leading to greater energy production and cost savings. It can also predict and reduce equipment failures, enhance energy storage systems, and improve renewable energy grid integration. Despite challenges like data availability, technical expertise, and regulatory barriers, AI integration in renewable energy is expected to increase, resulting in a more sustainable and efficient energy future [6].

Singh and Singhal's article in the 2023 IEEE Renewable Energy and Sustainable E-Mobility Conference (RESEM) titled "Artificial Intelligence-based Technique for Solar Irradiance Prediction Model with Improved Performance" found that solar energy is a frequently used renewable energy source due to its benefits such as lower emissions, reduced power losses and costs, direct DC load charging, and improved power quality. AI-based approaches produce accurate solar energy projections, enabling photovoltaic power plants to participate in energy auctions early, resulting in more cost-effective resource planning. The study describes effective machines and deep learning strategies for improving forecasting performance with datasets from the base article or public sources. Simulations were carried out using Python Spyder IDE 3.7, showing performance improvements in terms of root mean square error and mean absolute error.

Ben Yahia's [1] article in the 2023 International Conference on Networking and Advanced Systems (ICNAS) titled "Data-Driven Approaches for Resilient and Sustainable Urban Mobility" highlights that the transport industry accounts for 23% of all energy-related CO_2 emissions, with 92% currently relying on nonrenewable resources. Current transport decarbonization measures are insufficient to decrease CO_2 emissions to required levels. Strategies for lowering emissions from urban transport are crucial. This study proposes a framework for novel data-driven traffic signal methods to minimize CO_2 emissions in urban transportation for Connected and Autonomous Cars.

The platform uses next-generation Edge-AI to provide composable, distributed, and federated intelligence designed to be secure. Multimodal data fusion feeds AI models, allowing for more accurate CO_2 and urban noise projections and improving dashboards for awareness. Advanced reinforcement learning uses these predictions to optimize traffic lights in real time. The paper also addresses issues in attaining resilience through the detection of misbehaving entities in Vehicle-to-Everything environments.

Melethil, Mohammed et al. [9] published an article in the 2024 International Conference on E-mobility, Power Control and Smart Systems (ICEMPS) titled "AI-Enhanced Precision Crop Rotation Management for Sustainable Agriculture." They presented a revolutionary approach to crop rotation management by combining cutting-edge AI tools to modernize agricultural procedures. The study uses supervised learning techniques to revolutionize traditional crop rotation practices.

AI-powered technology uses real-time weather forecasts and previous crop performance data to provide farmers with specific advice on maximizing crop rotations, resulting in improved agricultural outcomes. The process includes planning, data collection, AI model construction, and system implementation, emphasizing setting specific goals, analyzing soil data, developing AI-driven suggestions, and ensuring continuous monitoring and improvement. The system utilizes various tools and technologies to achieve a rigorous, data-driven approach, advancing the fast-emerging area of AI in agriculture by enhancing farming processes, boosting crop yields, and encouraging sustainable farming.

Guo, Vallati, Wang, Zhang, Chen, and Wang's article in IEEE Transactions on Intelligent Vehicles titled "Sustainability Opportunities and Ethical Challenges of AI-Enabled Connected Autonomous Vehicles Routing in Urban Areas" discusses the introduction of Connected Autonomous Vehicles (CAVs), which ushers in a new era of urban traffic control and management powered by AI-enabled techniques. This improvement optimizes infrastructure utilization, reduces traffic delays, and enhances overall sustainability.

CAVs' autonomous driving capabilities and communication technologies enable them to serve as accurate moving sensors for traffic authorities, executing specific orders. However, these capabilities pose risks for cyber exploitation and the potential for increased social and economic inequality. The article explores how AI-enabled routing might improve urban transportation sustainability while addressing ethical concerns and challenges [8].

Ueda and Ogishi's [14] article in the 6th International Conference 2021 on Smart and Sustainable Technologies (SpliTech) titled "Sustainable Platform for Environmental Changes in Smart City" offers a future smart city concept based on species' survival by adapting to their surroundings. The proposed platform includes a massive archive of AI models, continual trials, and upgrades distributed over three hierarchies: cloud stratum (wider, longer-term), MEC stratum (medium-term), and fog stratum (narrower, shorter-term). The cloud stratum regularly updates models based on historical data, current models, and newly completed modules. Federated learning combines AI, human expertise, and societal trends to generate new models for adapting to significant changes, effectively responding to changing trends and building future smart cities [4].

Sridharan, Aakash, Karthik, Naleem, and Vignesh's [11] article in the 2021 Second International Conference on Electronics and Sustainable Communication Systems (ICESC) titled "A Smart AIS Based Portable Wireless Electric Charging Vehicles" addresses the growing demand for petrol and diesel due to increased automotive use, prompting the development of electric vehicles.

Public EV charging is limited to designated areas, making it financially unfeasible to provide separate charging stations for each parking spot. Researchers developed an autonomous, robot-like mobile charger that is portable and can charge EVs in various parking locations. Wireless car charging eliminates the need for cables, and inductive charging technology ensures batteries charge comfortably and autonomously. Companies are working to commercialize this non-contact technology due to its benefits.

Shetty et al.'s [12] article in the 2024 12th International Conference on Smart Grid (icSmartGrid) titled "AI-Driven Energy Forecasting for Electric Vehicle Charging Stations Powered by Solar and Wind Energy" explores the need for reliable energy forecasts for renewable-powered EV charging stations due to rising EV demand. The study investigates an AI-driven forecasting model for EV charging stations using solar and wind energy. Validated with metrics such as Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and R-squared (R2), the model outperforms traditional approaches like ARIMA and Naive forecasting, with an R-squared score of 0.92. It efficiently reduces grid power dependency during peak hours, improving grid stability and aligning with environmental goals. The model's scalability and versatility make it suitable for various locations and energy capacities, highlighting its transformational potential for sustainable and efficient transportation networks. Future research may focus on real-time adaptability and integration with smart grid technology.

Shah, Natraj, Hallur, and Aslekar's [13] article in the 2023 International Conference on Sustainable Computing and Data Communication Systems (ICSCDS) titled "Artificial Intelligence (AI) in the Automotive Industry and the Use of Exoskeletons in the Manufacturing Sector of the Automotive Industry" discusses the substantial impact of integrating AI into the automotive industry and developing associated technologies. Autonomous driving, a key technical advance employing AI, represents the future of transportation, altering the concept of driving. New mobility firms will emerge, while existing ones must adapt. AI and security algorithms are crucial in vehicle security. The study emphasizes the importance and impact of AI in the automotive sector, focusing on the feasibility of autonomous production, and examines the benefits and requirements for automating manufacturing operations, as well as their long-term implications.

Gajanan, Kirar, Paliwal, and Rajak's [2] article in the 2023 IEEE Renewable Energy and Sustainable E-Mobility Conference (RESEM) titled "A State-of-the-Art Review on Modern Artificial Intelligence Based Techniques for Economic Load Dispatch" presents an overview of newly discovered AI strategies used to tackle the economic load and emission dispatch problem. Economic load dispatch is a complex and nonlinear optimization task in power systems that requires effective dispatch solutions. The article discusses several optimization strategies recently discovered and not previously widely used to solve this problem. It covers descriptions of problem formulation and limitations, as well as in-depth reviews of optimization techniques, their advantages and disadvantages, and important analysis results.

Despite advancements, there are still gaps in AI and renewable energy research. We need a unified system that integrates various renewable sources and AI models, as current studies are often small-scale and not fully scalable. Additionally, ethical and security concerns with AI in transportation need more attention, and there is a need for better data quality and availability for accurate AI predictions. Finally, the economic feasibility of these AI solutions needs further exploration to ensure they are cost-effective on a large scale.

The role of AI in transportation system were start from 1970 where AI algorithms were used to optimize the traffic signal whereas in 1990 the mathematical calculation added made some application which can help to dynamic traffic management.

3 Proposed Work

Today, AI is deeply integrated into the transportation sector. Autonomous vehicles, capable of navigating complex environments with minimal human intervention, are a testament to the progress made. AI-driven traffic management systems now use real-time data to optimize traffic flow and reduce congestion. Additionally, predictive maintenance powered by AI helps in preempting vehicle and infrastructure failures, thereby enhancing safety and efficiency. Case studies from cities like Singapore and Helsinki highlight the successful implementation of AI in creating smarter and more sustainable urban mobility systems [5].

Although there are some developments is happing in AI and mobility sector more applications can be generated which can help in mobility as well as traffic control one of the proposed applications which can be used is as follows.

Imagine AI learning your travel habits. It notices that you typically leave for work at 9:00 am on weekdays. By the time you start your car, AI can predict that your destination is most likely your workplace based on your past routines.

- Real-time traffic and estimated travel time: The AI can instantly display traffic conditions and estimated travel time to your workplace on your car's dashboard.
- Suggested routes: The AI can recommend the least congested route based on current traffic patterns. If your usual route is jammed, AI can suggest an alternate path to get you there faster.
- Reduced stress and smoother navigation: With all this information at your fingertips, you can make informed decisions, avoiding last-minute route changes and stressful traffic situations. This leads to a smoother journey for you and everyone else on the road.
- Sustainability boost: By optimizing traffic flow and reducing congestion, AI can play a significant role in lowering car emissions. Less traffic means cleaner air for everyone. AI can also be a big help for traffic cops. Imagine smart sensors at zebra crossings. When a car stops at the crossing while the light is red, the sensor triggers an alert.
- Traffic cameras catch the culprit: Cameras mounted on the traffic light snap a picture of the vehicle's license plate, catching red-light runners in the act. This helps in enforcing traffic rules more effectively and deters people from breaking the law.
- Accident and breakdown detection: If a car stops on the road for more than 2 min, sensors can detect it and send an alert to the nearest police station. This rapid detection system helps address accidents and breakdowns faster, ensuring that traffic keeps flowing smoothly and safely.

This AI-powered system can make our roads safer and less congested. It not only helps in catching traffic violators but also quickly identifies and responds to road incidents, reducing the chances of traffic jams and secondary accidents. Moreover, this technology frees up police officers' time from monitoring traffic violations, allowing them to focus on more complex and critical issues. This means better resource allocation and more efficient law enforcement overall.

Incorporating AI into traffic management systems can significantly improve road safety and efficiency, making every commute smoother and safer every day. This is just a glimpse of what AI-powered transportation can offer. In the future, AI might even help you schedule carpool rides with colleagues or seamlessly integrate with public transport options for the most efficient commute possible as shown in Fig. 2.

Sustainable transportation means using different types of transport that are kind to the environment and people. This includes reducing vehicle emissions and ensuring that everyone, young or old, has access to reliable transportation. The big goal is to be kind to our planet. To achieve this, people are exploring different fuels for vehicles, like switching from petrol to CNG or electric cars. These alternative fuels produce fewer emissions, which is better for the environment and public health.

However, there are challenges. One major challenge is finding enough of these new fuels to meet demand. For example, while electric cars are great for reducing

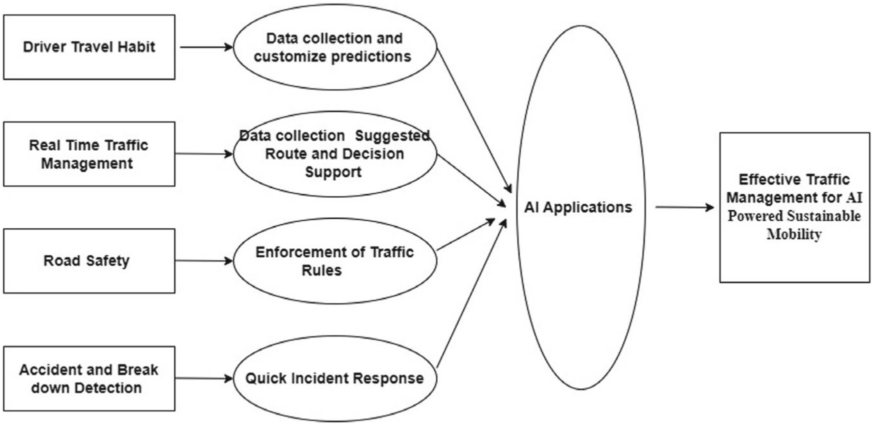

Fig. 2 Role of AI in traffic management

emissions, they require a lot of electricity, which must come from sustainable sources to be truly effective. Another challenge is making these new technologies affordable for everyone. Electric cars and CNG vehicles can be expensive, and not everyone can afford to switch from petrol vehicles. Additionally, building the infrastructure needed to support these new fuels, like charging stations for electric cars or CNG refueling stations, is a big task. It requires significant investment and coordination.

3.1 *Self-Driving Cars*

Self-Driving Cars use a combination of sensors, cameras, and AI algorithms to navigate roads, interpret traffic signals, and avoid obstacles. The impact on sustainability is profound, as Self-Driving Cars can improve fuel efficiency through optimal driving patterns, reduce traffic congestion by maintaining steady speeds, and lower emissions by using electric powertrains. Companies like Tesla, Waymo, and Uber are at the forefront of this technology.

3.2 *Predictive Maintenance*

Predictive maintenance uses AI to monitor the condition of vehicles and infrastructure, predicting potential failures before they occur. By analyzing data from sensors and historical records, AI can identify patterns and anomalies that indicate imminent issues. This proactive approach extends the lifespan of transportation assets, reduces maintenance costs, and enhances safety. For example, airlines use AI to predict engine failures, while public transit systems apply it to monitor the health of buses and trains.

3.3 Mobility-As-A-Service (MaaS)

Mobility-as-a-Service (MaaS) integrates various transportation services into a single, accessible platform. AI plays a crucial role in this integration by coordinating different modes of transport, providing real-time information, and optimizing routes. MaaS platforms like Whim and Moovit offer users the convenience of planning and paying for multi-modal trips through a single app. The benefits of MaaS include increased efficiency, reduced dependence on private vehicles, and enhanced sustainability through better resource utilization.

3.4 Optimizing Public Transit Systems

AI optimizes public transit systems by improving route planning and scheduling. By analyzing passenger data and traffic conditions, AI can develop optimal routes and schedules that minimize waiting times and enhance service reliability. Cities like London and Tokyo have implemented AI-driven systems to manage their extensive public transit networks, resulting in improved efficiency and reduced operational costs.

3.5 Enhancing Passenger Experience

AI enhances the passenger experience by providing personalized services and real-time information [3]. AI-powered apps offer features like real-time bus and train tracking, personalized journey planning, and notifications about service disruptions. These improvements increase the convenience of using public transport, encouraging more people to choose it over private cars. For instance, the New York City Metropolitan Transportation Authority (MTA) uses AI to provide real-time updates and improve passenger satisfaction.

3.6 Case Studies

Imagine a future where traffic jams are a thing of the past. This is the goal of a project in the Netherlands that uses artificial intelligence (AI) to make traffic flow smoother and cleaner. The Dutch Traffic Management Authority (DTMA) teamed up with Siemens to create a smart system. Here's how it works: Sensors on roads, traffic lights, and buses constantly feed data on traffic flow, trouble spots, and accidents into a special computer program. This program uses AI, like a super-smart brain, to analyze all this information.

The AI can then predict jams and adjust traffic light timings in real-time to keep traffic moving. It can also share this information with drivers through navigation apps, suggesting alternative routes to avoid congestion. The results are promising. In some cities, this system has reduced traffic jams by up to 10%! This means shorter commutes, less gas wasted, and cleaner air for everyone. There are challenges, like data security and making sure everyone trusts the system, but this project shows how AI can revolutionize traffic management and create a more sustainable future for our cities.

3.7 Environmental Impact of AI-Powered Mobility

Emission Reductions: AI contributes to lowering vehicle emissions by optimizing driving patterns, reducing congestion, and promoting the use of electric vehicles. AI algorithms can optimize routes to minimize fuel consumption and emissions. Additionally, AI-driven traffic management systems reduce idling and stop-and-go traffic, further cutting emissions. A comparative analysis shows that AI-driven mobility solutions are more efficient and environmentally friendly than traditional approaches.

Energy Efficiency: AI plays a crucial role in optimizing energy usage in transportation. Electric and hybrid vehicles equipped with AI can manage battery usage more efficiently, extending their range and reducing the need for frequent charging. AI also helps in managing energy distribution in smart grids, ensuring that renewable energy sources are utilized effectively. This contributes to a more sustainable and energy-efficient transportation ecosystem.

4 Conclusion

This chapter explores the transformative potential of AI in achieving sustainable mobility. It has covered the historical evolution of AI in transportation, current technologies, and their applications in various aspects of mobility. The discussion included autonomous vehicles, smart traffic management, predictive maintenance, public transportation, and non-motorized transport. The environmental impact, ethical considerations, and prospects of AI-powered mobility were also addressed.

5 Future of Work

Emerging Technologies: The future of AI-powered mobility is filled with potential advancements and innovations. Emerging technologies such as quantum computing [8], advanced machine learning algorithms, and enhanced sensor technologies will further enhance AI capabilities in transportation. These advancements will enable more accurate predictions, better decision-making, and improved system efficiency.

Long-term Vision: Speculatively, the long-term future of AI-powered sustainable transportation envisions a world where mobility is seamless, efficient, and environmentally friendly. Autonomous vehicles integrated into public transit systems, and smart infrastructure will work together to create a connected and sustainable transportation network. This future will have a profound impact on urban development, reducing the need for extensive parking spaces, and promoting green spaces and pedestrian-friendly areas [7].

Authors Contribution Babasaheb Jadhav and Alex Khang: Contributed experiments, conceptualization and methodology. Babasaheb Jadhav, Ashish Kulkarni, Pooja Kulkarni, and Sagar Kulkarni: Contributed Writing and Editing. Alex Khang: Contributed Writing – Review & Editing, and Supervision.

Declarations

Conflict of Interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this chapter.

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3D Modelling and Printing in Smart Transportation System

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Abstract Smart transportation systems that include 3D printing and modeling technology are a game-changer in terms of design and production. In this chapter, we look at how these technologies may be used to make today's transportation systems more efficient, personalized, and useful. With the use of 3D modeling, transportation systems and components may be accurately shown and simulated, leading to better analysis of performance and new ideas for design. Coupled with 3D printing, which enables rapid prototyping and the production of complex, bespoke parts, this combination offers significant advantages in terms of cost reduction, time efficiency, and adaptability. The study examines various case studies where 3D modeling and printing have been implemented in smart transportation projects, including the development of lightweight vehicle components, customizable infrastructure elements, and advanced traffic management tools. Additionally, it addresses the challenges and limitations of these technologies, such as material constraints and scalability issues, and proposes potential solutions for overcoming these hurdles. Overall, this chapter highlights the transformative potential of 3D modeling and printing in creating more responsive, efficient, and adaptable transportation systems. It offers insights into future directions for research and development in this field, emphasizing the role of these technologies in shaping the future of smart transportation.

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1 Introduction

A lot of new developments are happening in the car sector because of the Internet of Things (IoT) and 3D printing. In this chapter, we will explore how the intersection of IoT and 3D printing is revolutionizing automotive manufacturing, creating connected factories, and paving the way for a new era of smart transportation.

Major automotive OEMs such as Daimler, BMW, Schaeffler AG, and Ford are embracing Industry 4.0 and incorporating additive manufacturing systems and IoT devices into their production processes. This integration is transforming traditional cars into connected IoT ecosystems, unleashing a wave of opportunities for enhanced customization, efficiency, and functionality.

With additive manufacturing, automotive OEMs can leverage 3D printing for new product introductions, prototyping, and supply chain management. The customizability and connectivity of 3D printing systems enable the creation of complex and unique parts, reducing part complexity and streamlining manufacturing operations.

IoT devices play a vital role in the automotive manufacturing process, connecting vehicles, infrastructure, and people. These devices enable equipment monitoring, communication, and data analysis in connected factories. From monitoring equipment health to ensuring worker safety and product quality, IoT devices form the backbone of smart transportation.

But the integration of IoT and 3D printing doesn't stop at mechanical parts—it extends to the fabrication of complex printed circuit boards (PCBs) and other electronic devices, including IoT products. This opens up new possibilities for creating smarter cars and seamlessly integrating IoT devices into manufacturing operations [14].

2 3D Printing's New Beginnings

A collection of tools known as "3D printing" (3DP) enables users to build physical objects from digital blueprints by using an additive, layer-by-layer production technique. This new manufacturing process represents a radical departure from traditional approaches like subtractive manufacturing—that is, building things by removing material from a solid block of material—and from the traditional manner of molding raw materials into finished goods. If 3DP is really the catalyst for the next industrial revolution, trend analysts have long predicted [15].

Disappointment ensued since the first growth estimates (2014–2016) fell short of these forecasts [6]. More varied 3D printed materials (e.g., metals), faster printing speeds, and increased printing volumes have all contributed to the industry's recent upswing in growth. The global 3D business is expected to see rapid growth in the next years, with estimates ranging from $7.3 billion in 2017 to $15.8 billion in 2020 and $35.6 billion in 2024. Rather than desktop printers, more industrial 3DP devices are predicted to drive expansion. 3DP has been available for a while in the form of printed dental items, and it has since found its way into industries that place a premium on small-batch manufacturing, such as those dealing with hearing aids, custom jewelry, and clothing [22].

The aerospace and automotive sectors have made use of additive manufacturing for "rapid prototyping," or the relatively quick production of prototypes, in the context of product development. The landscape of 3D printing is being transformed by two new innovations. To start, additive manufacturing is quickly becoming better. Conventional wisdom held that 3DP generated inferior results in areas such as geometric repeatability (the reproducibility of digital images), surface quality, and fatigue resistance [11]. Modern scientific and technical developments are resolving these problems.

Secondly, with the advent of affordable desktop 3D printers like RepRap, MakerBot, or Ultimaker, anyone can now create unique home goods like jewelry and bike components. The shift from fast prototyping in factories to home manufacturing is being facilitated by 3DP [21]. Thus, 3DP is linked to a dispersed, more customized manufacturing approach that, if implemented, would undoubtedly impact logistics, supply chains, and transportation. But first, what exactly is 3DP? How will it change the way people shop, the places they choose to live, and their attitudes toward public transportation? When this happens, how will the logistics and transportation industry feel? In light of 3DP's advent, what is the current level of understanding and what obstacles are on the horizon? This article seeks to address these topics, while acknowledging that there is a great deal of ambiguity surrounding the rise of 3DP and its potential repercussions.

3 The Use of 3D Printing

In 1984, Chuck Hull constructed the prototype of the first 3D printer that could print objects. 3D printing machines nowadays use a laser scan or computer-aided 3D design to build up layers of material (current materials include liquids, organic materials, plastics, glass, ceramics, cement, bituminous concrete, or metal powders) to produce a three-dimensional object. The thing is faithfully reproduced, and in many cases even strengthened, by stacking and gluing the components.

It is now possible to print products anywhere, and with to technological advancements, a customer's place of business may produce a large number of tiny components much more quickly than a distant parts shop. Scanning and developing obsolete machinery or one-of-a-kind components that would otherwise need expensive new molding or production takes less than a day.

Companies like General Electric (GE) are increasing their usage of 3D printers, which is speeding up the pace of producing bigger printers. Current printers can only utilize a narrow variety of materials. Massive adoption of the technology and reasonable prices is still at least five to ten years off. Adaptation timescales may vary greatly, depending on criticality and available funds, but they often fall within the range of three to five years.

Instead of working with raw materials and shaping them by processes like forging, casting, stamping, or molding, or cutting away at blocks of material, 3DP involves creating objects layer by layer. The three parts that make up 3D printing, as shown in Fig. 1, are the additive process method, the design and/or scanning software, and the materials. New discoveries on all three of these components, as well as combinations of them, are driving the rise of 3DP, which may be seen as an innovation route.

In 1986, Charles Hull created the first functional 3D printer using stereolithography. Several additive process approaches have been invented since then, as shown in Fig. 1. Computer aided design (CAD) and other 3D modeling programs govern the printer motions and the shape and size of the successive layers needed to print the 3D item.

3D printing has the potential to produce a wide range of goods. To construct organs from patient cells in a lab, bioengineers are 3D printing networks of blood vessels in [2], a variety of prosthetic limbs and anatomical aids to movement are also in the works as medical devices.

Adopt 3D printing in an effort to speed up repairs and cut manufacturing costs, said GE and Siemens in December 2013. It projects that during the next two decades, over half of its production will include the new technology. 3D printing will help the German electronics and engineering company Siemens to reduce service times and costs. Repair times for turbine burners will be reduced from 44 weeks to only four weeks in some instances. What a remarkable decrease in time it has taken.

The new 3D-printed concrete slab structure hints to the potential for manufacturing concrete roadway slabs. Printing new barriers and signage using metal powders and particles is a possibility. 3D CAD models can be made from repair parts using a 3D laser scanner. Then, reinforcement can be added where needed to make the replacement part even better than the original.

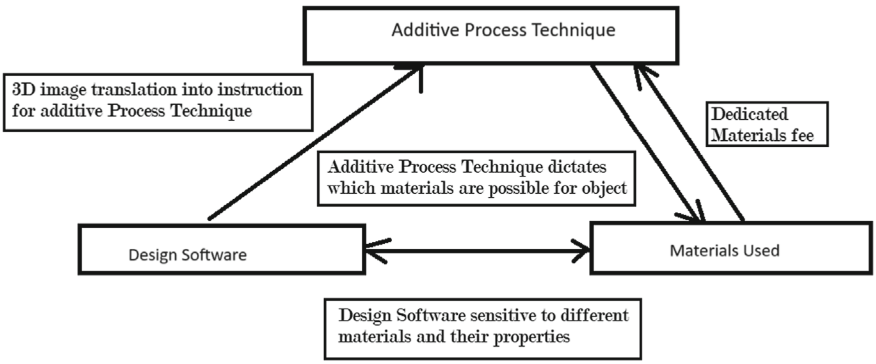

Fig. 1 The fundamentals of three-dimensional printing

4 Transportation Problem

One of the many potential benefits of 3D printing is the creation of more efficient methods of work and project development, as well as novel approaches to and solutions for current transportation problems. However, transportation agencies will certainly face several issues as a result of this technology in terms of both planning and running their operations. An example of this is the shortening of decision-making and planning horizons. Because of the predicted changes in mobility patterns, transportation plans with a horizon of 20–30 years may become significantly out of date very soon.

Major port and multimodal capital projects reliant on an increase in traffic and commodities from abroad supply chains may also find it difficult to get funding in light of recent changes in transportation logistics. Transportation decision-makers must demonstrate agility and decisiveness in the face of these challenges. Possible effects on transportation include:

4.1 Planning the Transportation of Goods

The service parts sector is probably going to be the first large-scale firm to be impacted by logistics of the supply chain. This will be followed by the distribution of most construction and manufacturing products [17], which will reduce distribution costs and the existing practice of far-off manufacture. Consequently, there will be a shift away from large-scale manufacturing facilities in Asia or Latin America and toward smaller production centers closer to the consumers or companies who need to print their own products. Possible ancillary effects may comprise:

- Smaller trucks and vans are only one example of how truck traffic patterns are changing.
- Since more materials can be made in this nation for 3D printing, port traffic and long distance distribution are projected to decrease, leading to a fall in the cargo business. Congestion management strategies may need to be adjusted, and long-term strategic plans for ports to finance new or expanded facilities and intermodal connections to fulfill U.S. demand will be put to the test.
- As 3D printing becomes more accessible to consumers, manufacturing business models that have been around for 15–20 years will be replaced by more flexible strategies that can adapt their locations and products to meet the changing needs. Because of this, transportation planners will need to be flexible in order to meet the evolving mobility demands of their communities, rather than relying only on conventional methods that take into account the proximity of job hubs to housing.
- Because components may be made on demand, there will likely be less air freight overall, which will have an impact on levels of both high-value and urgent cargo.

4.2 Architecture and Components

With the help of 3D printing, transportation decision-makers will have more freedom to imagine and build buildings and facilities that were previously either too expensive or impossible. A simple example would be noise barriers; with 3D printing, the designs and materials for these walls could be customized to represent the community's identity, allowing for an interesting presentation at public meetings, and they wouldn't have to be confined to pre-existing molds.

- Bus shelters and small bridges might be built on-site or in close proximity, seamlessly blending into their surroundings without sacrificing safety or structural integrity.
- On-site manufacturing of composite wraps that reinforce bridge piers and decrease the need to rebuild bridges may greatly cut costs and expedite the restoration of bridge operation.

4.3 Change Management in Transportation Organizations

Due to the availability of new approaches and tools via 3D applications, new technology will impact transportation planning. With this new technology, transportation authorities may collaborate more effectively with community and regulatory groups, which might make public outreach and environmental compliance simpler.

- New options to enhance asset management and achieve longer life cycles will free up capital equipment needs and reduce prices, creating a genuine possibility for cost savings.
- Transportation agencies will need to acquire new knowledge and undergo training.
- One benefit of 3D printing is that it will make it easier to fix or replace broken equipment without keeping a huge supply on hand. There is no longer any requirement for special orders for even obsolete components; they may be produced.
- Procurement contracts and proposals will need to evolve to accommodate 3D printing, which also brings about changes to copyright and patent regulations.
- As both demand and income for these expenditures are expected to decline, it will become more challenging to fund large-scale intermodal and highway projects.
- Several IoT devices are essential to the optimization, data analysis, and real-time monitoring of connected automobile plants. Factory responsiveness, efficiency, and ability to fulfill the needs of the current automobile industry are all enhanced by the seamless integration of additive manufacturing technologies into this IoT environment.
- Automotive: Buses and trains, among other forms of public transportation, may have their parts and components manufactured using 3D printing technology. Lighter, more efficient cars with individualized features may be the result of this.

- Elements of the Infrastructure: Using additive printing, intricate parts of the transportation infrastructure, such as bus shelters, bike racks, and traffic signs, may be made to suit particular metropolitan settings.

5 Resistance to Transport

The kind and magnitude of transport flows are determined by the placement of 3DP. There is less distance between producers and consumers when 3DP happens locally [24]. The amount of goods transported by ship or plane can fall as well. Raw material shipments will play an increasingly crucial role as inputs to decentralized 3DP. The distribution model would change from manufacturer-consumer to manufacturer-supplier of raw materials [10].

Bulk delivery reduces packing and urgency, which in turn reduces the number of ton-kms and cubic meter-kms of freight movements, allowing for more effective transport of raw materials [18]. More nodes and more adaptability will make distribution networks more efficient. As manufacturing moves closer to home and feedstock is delivered more effectively in cartridges, resulting in less air being transported on the outbound-shipping section of the chain, transport and logistics costs might go down.

Additionally, 3DP influences the field of warehousing. A decrease in inventory could be the outcome of less input material diversity, fewer safety stock, and more customer devotion to their demands. The fact remains, nevertheless, that transportation costs might go up, according to some experts. 3D printers situated in "mini-factories" or hubs will need the shipment of raw materials. Then, distribution between hubs and customers' houses might prompt shorter "last mile" rapid delivery, which is linked to more distribution flexibility but also more expensive. However, various prices might cancel each other out. For instance, although 3DP-related design expenses are greater, the savings from lower after-sales logistics costs and lead times more than make up for it.

6 Transportation Amounts and Methods

More raw materials may need to be transported as a result of 3DP, for instance, powders and gels packed in cartridges. As a result, there will likely be less need for containers and greater emphasis on transporting raw inputs for 3D printers, rather than ready-made consumer items. However, according to experts, other new technologies, including electric vehicles and driverless cars, will have a much greater impact on the future of transportation.

Possessing 3DP production aboard a driving vehicle is a fascinating, out-of-the-box concept that might lead to the creation of things just-in-time for delivery. With a longer product life in use, less air to carry, and fewer kilometers in the final mile, it is reasonable to expect a drop in transported volume. A rise in the amount of material that has to be taken out and then returned is one reason why transport volumes are going up. Customers may see changes in the timing of their delivery. There are two possible outcomes: first, an increase in deliveries made outside of normal business hours; and second, the introduction of innovative dispatching methods, including smart letterboxes.

7 Effects on Society: Ease of Access, Security, and the Natural World

No research has examined how 3DP would influence passenger transportation in a roundabout way, or how it will affect infrastructure requirements, accessibility, or safety on the road. The global transport industry may be impacted by 3DP in a way that disrupts welfare, income, and employment [3]. Because transportation and labor expenses are two communication vessels, the overall cost of the system could not decrease [4]. For instance, as 3D printer hubs are supposed to be situated closer to consumers, 3DP could cause production to be "reshored" to nations with higher incomes [9]. Also, these centers would have to provide high-skilled employment opportunities [19].

According to analysts, traditional outsourcing nations are also rapidly improving their capabilities to become 3DP industry leaders, therefore reshoring may not hurt them [10]. Some model-based research have focused on 3DP's material utilization and waste as potential environmental implications. The environmental effect of logistics and transportation is under-discussed. Emissions and oil consumption are expected to decrease, according to certain publications' initial projections [1, 8]. Production closer to home, according to the proposed assumptions, might lead to more efficient distribution of raw resources and less need for long-distance transport.

Even if last-mile deliveries rise, they won't contribute to pollution levels if they're made by cars with low emissions [5, 20]. Reduced inventory waste and increased recycling potential could be outcomes of 3DP's production-on-demand strategy [7, 8]. Conversely, logistics network efficiency might decline: The transition from mass-produced logistics services to customize ones will result in less sustainable logistics systems [12, 23].

8 Discussion

The interplay between end-user desires and requirements, geographical considerations, and transportation barriers will determine the shape of 3DP's future. Integration with trends like mass customization is possible with 3DP, which is linked to product customization. Naturally, not every product type lends itself well to customization, and there are instances when working in small quantities isn't the most (cost) effective option. However, small batch 3DP has found widespread use in industries like as aerospace and medical, and other areas may follow suit. Therefore, decentralization is a predicted outcome of 3DP, while the specifics of this decentralization are up for debate.

From centralized manufacturing to home-based printing, 3DP might be seen as a point on a continuum (Fig. 2). There are a lot of variables that affect the final result, such as the nature of the product, the materials used, etc. A hybrid situation, with various kinds of 3DP coexisting in different regions, is expected to emerge because to the great range of customer wants and product types.

The transportation and logistics industry will be affected in several ways by the rise of 3DP and the decentralization of production that comes with it:

- While we don't guarantee a drop in transport quantities, we do predict a decrease in delivery times and transportation costs.
- Distribution networks are anticipated to be more effectively arranged with regard to transport flows and movements. The transportation of raw materials to several dispersed sites is an ongoing need of distributed production. But since raw materials are often transported in bulk in containers like cartridges, resulting in fewer empty cars, this mode of transportation is anticipated to be more efficient.
- Goods are now built to order and safety-stock is no longer required, among other reasons, therefore the quantity of inventories could shrink, altering the manner inventories are handled. The potential for the rapid manufacture of replacement components is expanding, particularly in the service parts sector. Along with this, suppliers don't have to worry as much about holding onto unsold inventory.

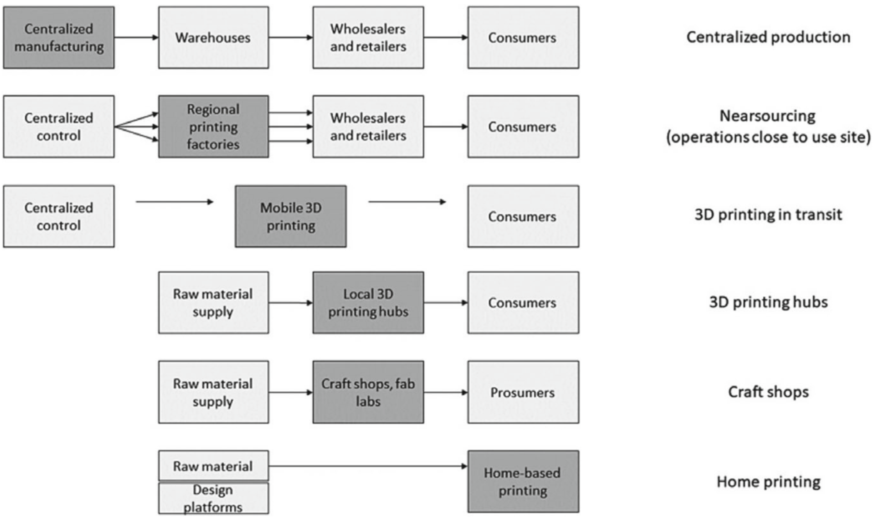

Fig. 2 Distribution of potential sites for 3D printing

- Organizations' functions and standings in the value chain will change. Wholesalers and retailers are examples of middlemen that might become unnecessary in certain situations. Some stores may transform into product showcases or perhaps close their doors permanently. Simultaneously, businesses may strategically shift upstream or downstream. The establishment of 3DP hubs may be a step toward decentralized manufacturing for logistics businesses. When it comes to last-mile delivery, for instance, postal services might use their distribution networks and transform their post offices into print shops (United States Postal Service Office of Inspector General, 2014). Another illustration of this trend is the growing emphasis of wholesalers to provide the raw materials required for home-based printing.
- The flow of data will alter regardless of whether the organizations' functions in the value chain stay the same. Customers are increasingly submitting customized designs, whether they're generated independently or based on drawings seen on the internet, thanks to 3DP's emphasis on agile development, on-demand manufacturing, and customization [16]. The 3D printer has to have the design files supplied to it and then reviewed before production can start. Because design platforms include proprietary designs and because there was uproar over the development of a 3D-printed gun design template, it is difficult to maintain control over intellectual property rights and undesirable items.
- Consequently, digitization is gaining prominence as product design might shift from consumers to printing centers or even from centralized corporations to centers that are near shores (Fig. 2). Decentralized manufacturing must nevertheless follow quality standards set by the corporation and/or the government, therefore quality control plays a significant part in this process.

9 Conclusion

3D printing is a powerful tool for Smart transportation, offering innovative solutions across various domains, from construction and urban planning to transportation, healthcare, and environmental management. By integrating 3D printing technology, transportation can become more efficient, sustainable, and responsive to the needs of their inhabitants. The ability to rapidly prototype, customize, and produce complex structures and devices makes 3D printing an essential component of the Smart transportation [13].

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Future-Proofing Green Transportation: Fusing Technology for Safer Roads

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Abstract At present, the automobile industry is experiencing substantial transformations in the areas of in-vehicle communication and information technologies. This transition is significantly affected by the advancement of advanced driver assistance systems. Nevertheless, this development poses a risk to both vehicles and pedestrians by introducing the potential for information overload. Driver Assistance Systems are critical to guaranteeing vehicle safety in today's world, and they are likely to become even more significant in the future as autonomous vehicles become more common. This technical paper discusses various technologies that can improve the functionality of the Driver Assistance System. These technologies include methods for detecting driver fatigue, precisely defining lanes, tracking vehicles in real time, and correctly recognizing traffic signs. The components were easily merged and synchronized into a web-based platform using the Django framework, resulting in a user-friendly interface. Combining Hyper Text Markup Language and Graphical User Interface components together makes things much easier to access and use. The article also suggests a loT of different ways that the model could be improved in the future. These possible improvements could make it easier and more flexible to make sure the safety and comfort of both pedestrians and cars. The addition of driver-focused technologies to the constantly changing field of Driver Assistance Systems is a big step towards safer and more efficient transportation options.

Keywords Driver assistance system · Drowsiness detection · Django · Graphical user interface · Hyper text markup language · Lane detection traffic sign guide · Vehicle detection · MATLAB

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1 Introduction

According to current World Health Organization (WHO) studies and surveys, roughly 1.3 million people die each year as a result of traffic accidents. Pedestrians, cyclists, and motorcyclists account for more than half of all road traffic fatalities. The majority of traffic accidents are caused by human error. Improving safety [3] and decreasing road accidents [5], hence saving lives, are important goals for driver assistance systems.

Road lane detection, or road boundary detection, is one of the hard and difficult problems for future road vehicles. Obstacle detection, particularly for moving objects, may be a critical component of collision avoidance in driving assistance systems. Driver assistance systems (DAS) [4] are innovative technologies that live within the vehicle and support the primary driver in a variety of ways. These methods can be utilized to deliver basic traffic information, street closures and blockages ahead, congestion levels, and alternative routes to avoid congestion. Similar methodologies can also be utilized to detect the human driver's exhaustion and distraction and provide cautious alerts, and to assess driving execution and provide indications based on it.

The linked technologies are also applied in the development of self-driving cars. Utilizing image processing techniques, our research aims to develop a vehicle driver assistant system that will provide drivers with trustworthy traffic information, along with lane and object Vishwanth [17] detection, and will assist the driver in identifying the car ahead. DAS can also measure the driver's overall performance, measuring features such as speed, following distance, and stopping patterns. Based on this assessment, recommendations can be made that will help drivers improve safety and ultimately reduce the risk of accidents.

To conclude, DAS represent a solution to the global safety challenges faced. This technology uses processed images to provide drivers with important traffic information, accurate road and object detection, and important alerts to prevent accidents. Because of the intricate relationships between the key elements (vehicle, surroundings, and driver) and the dynamic nature of these elements, driving is a complex decision-making process.

The driver is a critical component in the driver–vehicle–road closed-loop system, with distinct driving characteristics that vary from driver to driver or even for the same driver under different situations or on different days. In addition, DAS combines with Vehicle to everything (V2X) communication, safety and traffic control will boost up in roadways. The V2X technology lets vehicles and objects to exchange information with other vehicles, with traffic lights, road signs, etc., about the current situation on the road, about the traffic intensity, or about the possible risks. The interlinkage between the vehicle and a road or environment can give a driver early alert of an object on the roadway, a changing signal light or an incident up ahead hence aiding the driver in decision making.

However, integrating it with DAS and state-of-the-art driver monitoring systems, one can achieve optimization of road safety. Through the monitoring of driver's critical condition, such as fatigue, distraction, or inadequate sobriety, the system can warn the driver or take the necessary actions, applying the brakes, for instance, to prevent an accident. For instance, if a driver is seen to be dozing off, the system can alert the driver to take a rest or in extreme conditions where the driver cannot be relied upon to safely pull over, then the system can steer the car—come to a safe correct stop. It also means that there are opportunities in improving the formulation and organization of large cities and traffic pattern systems. Information gathered from DAS and V2X will enable the identification of traffic flow, risky areas, and efficiency of infrastructure in roads. There is a possibility to use such information for improving road network design, applying necessary safety measures, and enhancing traffic organization in cities.

In addition, issues such as knowledge and understanding of the population to these technologies is paramount for their application. Awareness activities and planned demonstrations and pilots projects will prepare the driver with the purpose and functioning of the DAS and V2X systems. The goal of developing and sustaining such trust and understanding is that more people would adapt to the proposed forms and means of transport and communication, subsequently decreasing the number of road accidents and fatalities.

Therefore, one can conclude that the introduction of Advanced Driver Assistance Systems (ADAS), V2X, and driver monitoring systems is a major prerequisite to overcoming the challenges of global road safety. Thus, utilizing these innovations, it is possible to turn the sphere of transportation into a much safer and efficient environment not only for saving human lives but also for the benefit of driving experiences. The future of road safety is going towards the integrating of intelligent systems capable of sensing and handling the unsteady characteristics of the modern roadway environment.

2 Literature Review

Pathan and Patil [11] provided a review of the proposed techniques to implement Connected Advanced Driver Assistance Systems (C-ADAS) and intelligent traffic management systems, comparing advantages and disadvantages and also looking at the practically feasible features. [1] present an overview of information and communication technology-based support and assistance services for future connected vehicle safety, with emphasis on vehicle identification, road detection, lane detection, pedestrian detection, sleepiness detection, and accident avoidance.

Xing et al. [18] give an overview of driver intention inference, with a focus on highway lane change intention. Marina Martinez, Heucke, Wang, Gao and Cao [9] explores driving-style characterization and recognition, rewriting many algorithms with an emphasis on machine learning approaches.

The literature reviewed did not adequately address a holistic approach to the system in the interactions between vehicle-environment, vehicle-driver, and driver-environment, which are critical for enhancing road safety. In this regard, the current

ADAS design faces a number of potential challenges, including reflecting the effects of various traffic factors on driving safety, describing the interactions between the characteristics of the driver's behavior, the state of the vehicle, and the road environment, thereby providing an accurate basis for vehicle control.

Existing systems that assess driving safety may not work properly if they consider only a limited number of factors and their interactions. Notwithstanding the latent demands and challenges of the integration and bidirectional interactions of the three subsystems studied, these features have not been addressed in the scholarly literature to the best of our knowledge. This study zeroes in on these core technologies to emphasize their indispensable function in building effective and inclusive web content. Its implications also extend to cybersecurity and web fortitude [7], shining a spotlight on the necessity of adaptable design in ensuring user-friendly access across a vast array of devices by focusing on Hyper Text Markup Language (HTML) and Cascading Style Sheets (CSS), the authors provide a practical approach to creating accessible and user-friendly web pages on a variety of devices. This is consistent with the critical importance of responsive design in today's digital environment. Ongoing research in this area is essential to keep up with evolving web development practices and technologies.

The suggestion put forth by the authors enhances the well-established You Only Look Once (YOLO) V3 and Nithya, Narmadha et al. [10] algorithm, which is famed for its accurate and efficient object detection capabilities. However, the authors have implemented a personalized version for identifying lane lines. Using this method, the accuracy of identifying and tracking lane markings has increased, which is a critical requirement for reliable and safe autonomous vehicle operations.

3 Objective

The project goal is to keep an eye on the driver and guide him/her to follow proper lanes and traffic rules, and to inform the driver anytime the rules are breached or the lanes are altered. It will also monitor the driver's facial expressions to determine whether the driver is asleep, using his or her phone while driving, or not paying full attention to the windscreen, and warn the driver of the situation.

The primary function of the driving aid system is to detect potential hazards to the vehicle and driver, also to warn drivers of sleepiness or other road distractions, and to serve as a traffic guide, identifying and indicating any sign symbol and not allowing the driver to violate any traffic rules.

Facial expressions are continuously monitored [12]. So that the system keeps the watch of driving distractions and signaling fatigue. It is also perfect at assessing how alert the driver is through top notch algorithms which incorporate most of the facial part and even the expressions. Once signs of over fatigue, or lack of focus on the road is sensed, the system gives out notifications to the driver that he or she should stay focused on driving. This feature is very essential to ensure that the driver is extremely attentive and there is no likelihood of a road accident through fatigue or distraction.

In the same regard, it functions as a solid traffic navigator that can effectively identify and analyze virtually any form of sign/signal on the road. It faithfully analyzes and relays this information to the driver as it happens; the car is a strict protector of traffic laws. Through consistent availing of the current traffic information and timely frequency advice/reminders, the system assists the driver to manage the traffic strictly in accordance with the provisions of the law. This has the added benefits of increasing the driver's alertness of their environment, and promoting a more responsible form of driving. By way of all these functions, the system contributes to the aims of decreasing traffic violations, the possibilities as regards the occurrence of accidents and enhancement of road security.

4 Block Diagram and Methodology

This block diagram as shown in Fig. 1 is mainly highlighting the features that are developed in our web page for improving the safety of drivers and traffic. It begins with a facial recognition camera located in a way that it will be able to track the face of the driver. This camera is vital in monitoring the level of drowsiness and attentive nature of the driver along with the ability to handle and respond to conditions on the road. Subsystems include the facial recognition system that uses the best algorithm, which helps detect times when the driver is tired or distracted.

The authors proposed [13] to develop a Traffic Sign Guide which can be used as a signboard classifier that will help the driver to understand different signs on the road. The project has a goal of creating a vigilant system that ensures both driver and traffic safety by promoting adherence to lanes and traffic rules. It utilizes real-time monitoring to notify drivers about rule violations promptly.

Moreover, it monitors facial expressions to identify signs of drowsiness or distractions, issuing timely warnings. This multifunctional system acts as a hazard detector,

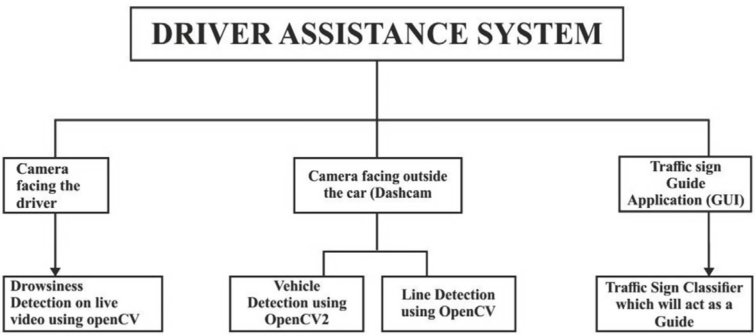

Fig. 1 Block diagram of the driver assistance system

minimizing risks, while also functioning as a reliable traffic guide by interpreting signs and enforcing rules. (F3: The Complete Advanced Driver-Assistance System (ADAS) Sensing Network [3]) Apart from constantly identifying the lane positions and traffic signs that the car occupies, it also checks on the facial expressions of the driver to determine if he or she is sleepy or distracted in any way. In case such signs are recognized, some signals are given with an intention of calling the attention of the driver. In particular, the centralized system serves as a hazard detection system and an intelligent traffic management system all in one.

4.1 For Front End Part

In the frontend part of the webpage, HTML and CSS languages have been used, which act as the backbone of the entire framework of the page. The HTML language was used to build the complete basic outline structure of our webpage. After creating the entire structure of the webpage, the CSS language is used. This CSS language is used for styling the webpage. Along with styling, CSS is used to enhance the User Interface (UI) design of the page and also provide a better experience to the users.

CSS also helped us create a unique design and make the page more accessible and responsive. To add and develop in interactivity to the webpage, JavaScript was also used besides the conventional HTML and CSS languages. JavaScript enables the dynamic or changing of content which enhances the users experience since new content could be updated without refreshing the entire page. For example, JavaScript was applied to build such forms as interactive ones and dynamic content blocks that change according to the users' actions.

In addition, for the webpage to be responsive on several devices ranging from laptops to mobile phones, the use of CSS frameworks such as bootstrap was also incorporated. Also, the appearance of the webpage is pleasing, but also, with the help of using the grid, the page is viewable properly on different devices, orientations, and resolutions. The methodology to integrate the HTML, CSS and JavaScript skills to engineer a streamlined functional front end that is more efficient and expressive was given by the team.

4.2 For Back End Part

Django was used by us for providing the backend since it is a powerful backend framework that makes a use of Python's native strength file, making it easy to use and reuse the code. It is compatible with any client-side framework and can deliver content in any format, like HTML, Extensible Markup Language (XML) [16]. Along with this, many packages and libraries in the backend development of the webpage have been used. So, Django optimizes these aspects relying on Python and allowing to development of applications with better scalability and maintainability.

On the other hand, Keras acts as a connection for the TensorFlow library. Keras has also been used to facilitate a faster neural network experience and to create a user-friendly interface that can be handled with ease. The model for traffic classifications was trained using Keras, encompassing vehicle and lane detection, and the identification of various signs like animal crossing, total speed of the vehicle by adding the passing limits, landslide area, and steep curve ahead.

Further, Open Computer Vision Library (OpenCV) was used to work on different images and videos, which helped us analyse and process the visual data. The Ipywidgets package was implemented to analyse data in real time. It allowed us to create Graphical User Interface (GUIs) for Jupyter notebooks. The well-known open-source Cv2 (cv2 module is the main module in OpenCV) library was used for facial recognition of the web camera and image segmentation of traffic sign identifiers.

Numerical Python (NumPy) is a powerful tool that was used for working on multidimensional matrices. Python has many such modules for converting images into NumPy arrays. For interactive visualizations in Python, Matplotlib was used because it is a plotting library in the Python programming language and a numerical mathematics extension of NumPy. The OS (Miscellaneous operating system interfaces) library contains routines for interfacing the webpage with the operating system of the device.

Furthermore, Scientific Python (SciPy) was used, which is built on the top of the NumPy extension of Python. SciPy is used for more utility functions because it provides some added functions that are frequently used in NumPy. At last, Django is used again to connect all the above libraries and packages to our webpage. Using all the above technologies, a webpage was developed that comprises the below-mentioned four parts. As widely known, OpenCV contains the Cv2 library which has been used in the current work for facial recognition issues and the image segmentation of traffic signs. Some of the key features that have enabled this library to be very rich include the new algorithms that have made it easier for the library to track and analyze facial expressions to determine the level of alertness and distraction of the drivers.

While dealing with data having more than one dimension and doing operations in the form of numbers, NumPy has advantage in this implementation. This powerful library is intended for operations on the arrays and mathematical calculations, which are the core components for converting images into NumPy arrays and more data manipulations. Matrix laboratory (MATLAB) conversion tool has also been used to generate, interactive visualization and plots and the plotting library used in this paper is Matplotlib which is widely integrated into python.

The main focus of Matplotlib is that as an extension of NumPy, it offers an extensive capacity in creating an array of figures such as graphs and plots: from the most fundamental to the most complicated; these features make it easy to disseminate and understand data outputs. The Operating system (OS) library has been employed to set up communication between the webpage invoked and the operating system of the gadget to facilitate file handling among other system procedures.

Also, SciPy, which is another popular library developed based on NumPy for Python programming language, has been used for high-level computation functionality and convenient functions. Several libraries are built on top of NumPy or are NumPy derived, one of which is SciPy which adds on to the functionalities of NumPy by providing more commonly used functions in scientific and numerical computations. In addition to the above Django acts as the framework to our project [15] essentially linking all these libraries and packages together to enable the creation and functional operation of our webpage. By leveraging the strengths of these technologies, a comprehensive webpage was developed by us that encompasses the following four core components: By leveraging the strengths of these technologies, we have developed a comprehensive webpage that encompasses the following four core components:

4.3 Face Camera (Drowsiness Detection)

In order to accurately determine the status of the driver's eyes, the Eye Aspect Ratio (EAR) measurement was utilised. The Euclidean formula was used to calculate the distance between the main locations on the eyes in order to determine EAR. The equation for this relationship, which is commonly referred to as the EAR, is as follows it's of a driver's face as shown in Fig. 2.

Particularly the size of the eyes, differ noticeably. To detect drowsiness as shown in Fig. 3. First determine whether the eyes are closed or open during the period. EAR $= \|p2 - p6\| + \|p3 - p5\|\ 2\|p1 - p4\|$

The numerator of this equation calculates the vertical distance between eye landmarks, while the denominator calculates the horizontal distance between them. In this proposed model, the threshold value is set to 0.25. If EAR is below 0.25 then the driver is detected as drowsy. EAR is used to assess the driver's state of wakefulness for it is an important determinant. Cutoff value for EAR has been kept equal to 0 in the model explained in this chapter, the next section provides the summary of the study.

To advance our drowsiness detection system more profoundly, feature learning was used to fine-tune the EAR threshold according to the driver's characteristics. A lot of information was collected about different facial layouts and eyes shapes to train a model that would allow applying the threshold value depending on the given user and increase the stability of the system. Also, timely alarms were incorporated like audial alarm and vibration seat for the driver as soon as drowsiness is identified. It measures the total time which eyes are closed, and the frequency of blinking which takes into account factors such as environment brightness. This ensures that the drowsiness detection system to be developed approaches the problem self-sufficiently and will be effective in different driving conditions, thus improving road safety conditions.

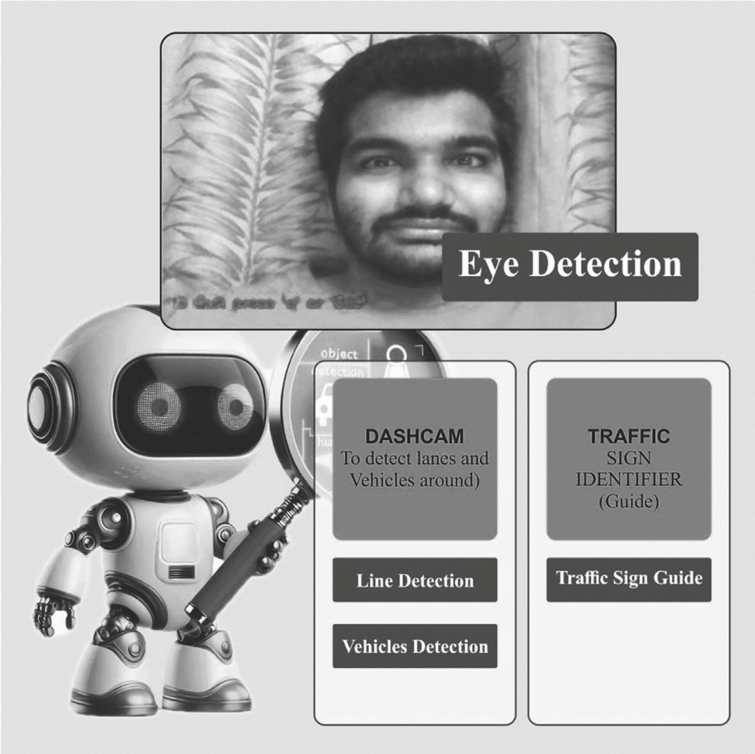

Fig. 2 Drowsiness detection-while driver is awake

4.4 Dashcam (Lane Detection)

First, all the required modules and packages are imported. Then, a movie as a sample is imported to thoroughly test its functionality and accuracy. The video is divided into multiple frames, which are saved as training data. From this data, a single frame is chosen and a mask is created for it by defining the region of interest in the shape of a polygon. These frames were obtained from videos. By providing the polygon coordinates, everything may be concealed except few areas.

Using the masked picture, next an image thresholding is done using two methods. When image thresholding is utilized, only the lane markings are obtained in the output picture since they are all white patches surrounding the black road. Then, using the Hough Line Transformation, the geometry of these patterns can be easily determined. Then after creating the masked image is complete, the next thing that is needed to be done is to threshold the image in other to treat the frame. This step involves two distinct approaches: In this work, a method known as image thresholding was applied for the segmentation of images and so also the well-recognized Hough Line

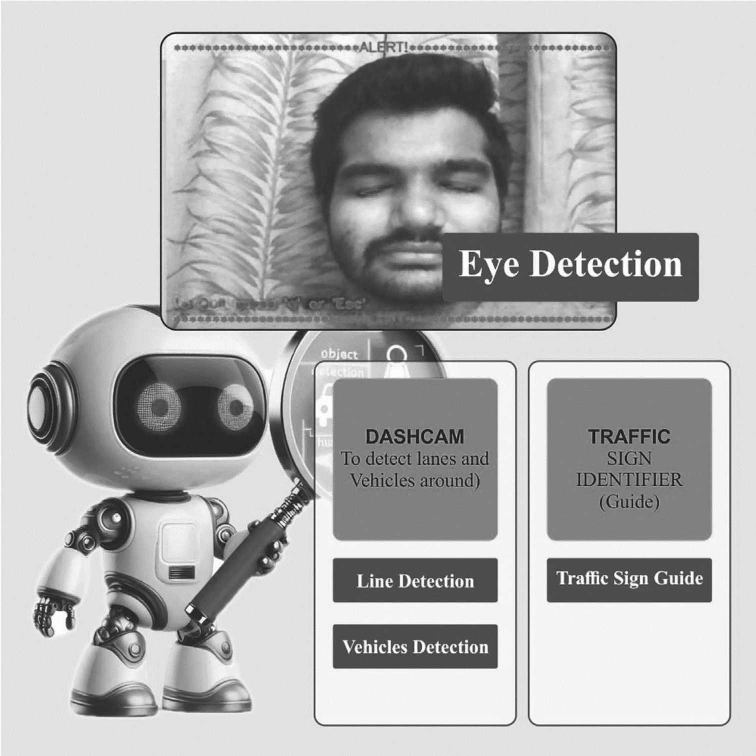

Fig. 3 Drowsiness detection-while driver is asleep

transformation. It is also quantized to binary in image thresholding which makes the lane marking to be a clear white object on a black background.

Whereas the second one, Hough Line Transformation is used to eliminate and to find out the pattern and the lane's shapes from the binary image. It makes it possible to obtain a good view of the lane markings and consequently correctly paint the lane lines. Such output screens are drawn out as shown in Figs. 4 and 5, and all actions are conducted on each and every frame, and the resulting output frames are saved in a new directory, where they will be concatenated to create a complete video as an output.

4.5 *Dashcam (Vehicle Detection)*

In our study, the Vehicle Detection algorithm was proposed, which may be utilised to develop an intelligent driver assistance system capable of identifying automobiles, trucks, or any other vehicle in order to maintain road safety.

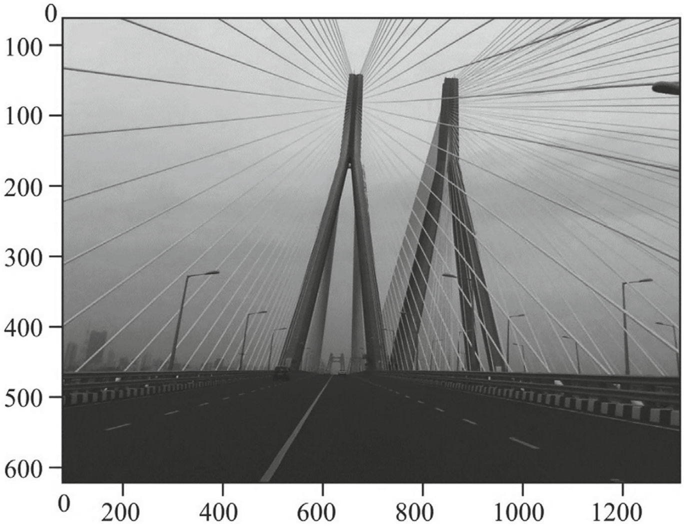

Fig. 4 Lane detection frame

Fig. 5 Next lane detection frame

This paper schedules the process by including essential modules and packages; initially, a video is imported to verify its functionality and accuracy before converting it to frames and specifying certain features of the item that needs to be focus. Following that, the frames are read and converted to grayscale for simple viewing.

Then, in the input picture, they identify items (cars) of various sizes and draw a rectangle around them.

Followed by the frames back into the video to help the driver identify any cars surrounding or near it. To enhance the results of vehicle detection algorithm the authors incorporated deep learning models like YOLO for real time object detection. These models were fine-tuned on large datasets to identify, classify and reduce considerable variations of type of vehicle along with the driving conditions. Also, contextual information like the speed and direction of the car was also incorporated through Global Positioning System (GPS) and accelerometers which improves the detection rate.

In applying real-time processing on the dashcam, the system can be able to issue instantaneous feedback to the driver about the possibly dangerous situation. This greatly proves helpful in avoiding accident risks and also ensures the driver keeps a safe distance from other vehicles. Therefore, due to its high efficiency and accuracy of operation using algorithms and real-time data as shown in Fig. 6, the Vehicle Detection system is an essential subsystem of an intelligent driver assistance system.

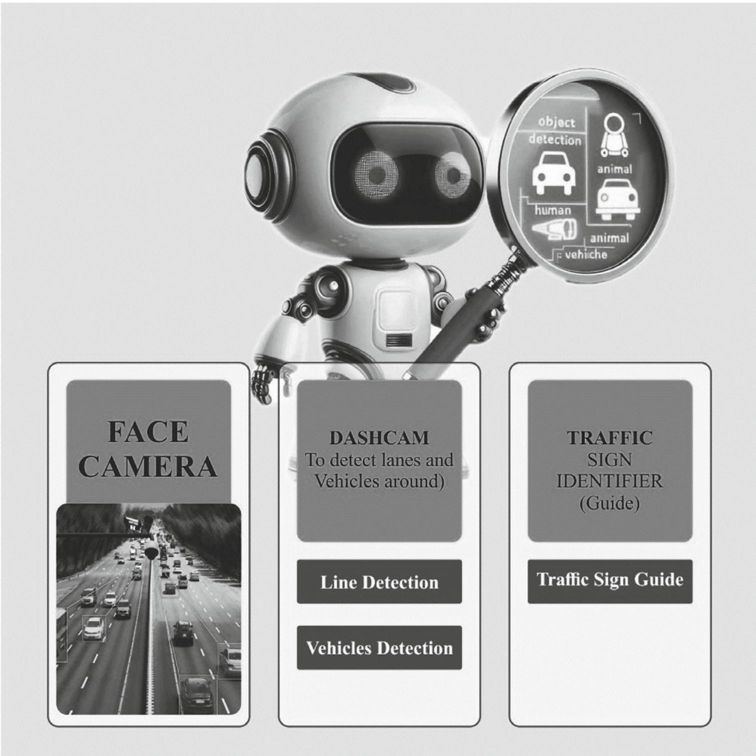

Fig. 6 Vehicle detection system

4.6 Signboard Classifier (Guide)

To begin, a trained model was imported to categorize signs, creating a dictionary to label all traffic sign classes. The photos and labels are then retrieved. Turning lists to NumPy arrays, and separating training [14] and testing datasets. It is mostly used as a guide because there are many traffic signs on the road and sometimes people do not understand the meaning of each and every sign. In order to make it easier for the driver, this traffic sign manual may assist the driver and prevent them from breaking any traffic rules.

To increase accuracy of the developed Signboard Classifier, new image recognition technologies are included, and a large data set was used including images of traffic signs of different countries. This approach is important to allow the system to recognize as many signs as possible and this is when the conditions are proper in terms of light, objects are not partially over other objects. Also, to enhance the multilingualism aspect, there is the feature of translating the content in real time to other languages for the international drivers.

Such updates allow the classifier to inform the driver about the content of the signs using both sound and light on the car's dashboard to facilitate the identification and prompt action to the signs. Such improvements are important in cutting incidences of traffic violations and in degrading standards of driving. Thus, using the advanced technologies in combination with the extensive training data set within Signboard Classifier creates a necessity for a contemporary driver, enhancing the general safety level on roads.

5 Results and Discussion

Driver drowsiness detection alerts drivers to sleepiness and potential road hazards. The path to be traveled can be determined by the drivers, provided the lines are physically marked, unless there is snow covering the bottom, particularly severe rainfall, the road is extremely unclean or in disrepair. In this paper, the shoulder often appears as a long and straight line in the image, the shoulder lane of the road is generally identifiable in comparison to a traffic lane for lane detection.

In the average picture, the adaptive threshold is applied to recover the lane markers. The system investigates and processes the generated image sequence, which automatically recognizes the lane lines. The results demonstrated that the proposed system performed effectively in a variety of circumstances; additionally, the computer response system is economical and nearly real-time.

Current exiting systems for vehicle detection employed deep learning approaches for distinguishing vehicles and its types in real-time. Such systems, with the help of data received from cameras, Light Detection and Ranging (lidar) and radio detection and ranging (radar), form a single picture of the situation in the surrounding space.

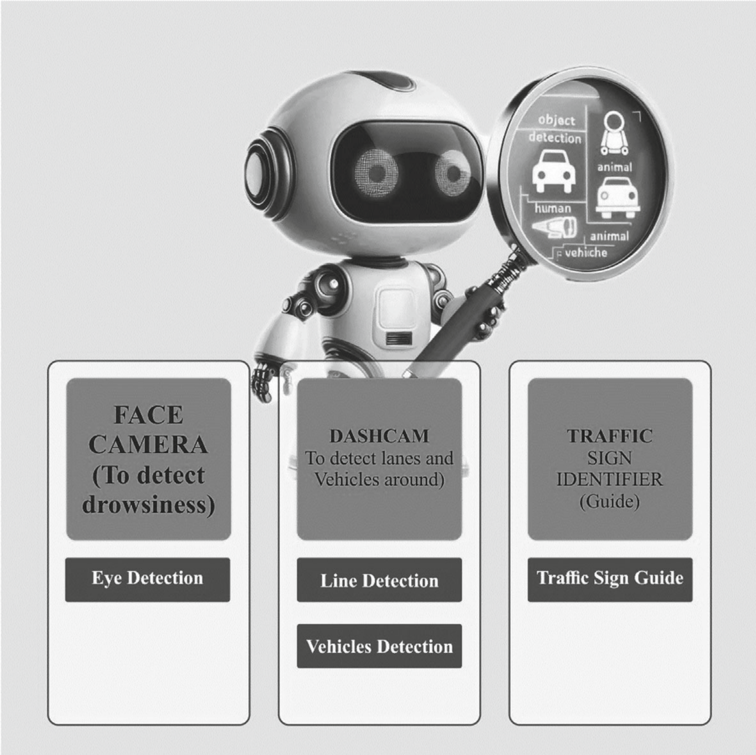

Fig. 7 Web page of the system

Vehicle identification and movement help in collision avoidance, lane detection and adaptive speed control to increase safety as shown in Fig. 7.

The Intelligent Transport Systems (ITS) combines technologies to offer current information and communication among vehicles and the infrastructures. V2X technology warns the drivers of the possible threats and changes in traffic conditions on the road hence helping the drivers to make the right decision that will enhance free flow of traffic.

Self-driving solutions are the new shifts in combating road safety. Intelligent cars employ an array of LiDAR's, lasers, cameras, and complex algorithms to make decisions on their own, and move from one point to another. Self-driving components such as autonomic reaction to possible crash situations, assistance in keeping the vehicle within the lane, and adaptive speed control are already improving the driver's safety in modern cars.

6 Empirical Analysis

Empirical analysis is a research approach that relies on the data evaluated and the results obtained by drawing conclusions and making evaluations using the data. The training and testing of results were carried out in this system, which will help to find the efficiency of the system there by improving the safety and security as discussed in Tables 1 and 2.

6.1 *Drowsiness Detection Performance Testing*

Conducting the performance testing of the system the competence and worth of the Drowsiness Detection system in making a distinction between the drowsed and the wake driver was considered. In the evaluation of the system performance in specific parameters, several evaluation parameters including true negative, false positive, false negative and true positive measures were employed. In the same period, the system managed to correctly identify 303 times the drivers who were awake and blinking as truly negative, which means the driver was awake and in the same process, the system also wrongly classified 27 times the driver as possibly positive—the driver was rather drowsy. This scenario allowed for a correctly overall classification of 91%.

The level of the accuracy of the system that successfully recognized non-drowsy drivers was established to be high as depicted by 27%. On the other hand, the system yielded high results with 187 true positive outcomes when the driver was actually drowsy, the system properly identified the driver is drowsy but failed to do so in 23 instances, which is equivalent to false negatives. At the same time, a true positive rate was achieved in a rather high level, thus confirming 89% of the initial hypothesis. 05%. Hence, the percentages of accuracy that has been obtained for the drowsiness detection system for all the above said cases are heading towards 90 percent.

Table 1 Duration of eye closure versus number of samples

Technique	Driver status	System result		System precision				
		Awake	Sleepy	TN	FP	FN	TP	Overall precision (in %)
Blinking	Awake	303	27	91.27%	81.8%	10.95%	89.05%	90.74%
	Sleepy	23	187					

Table 2 Lane detection

Algorithm	Mean absolute error	Standard deviation of error
Spline-based algorithm	5.910	27.502
Hough based algorithm	3.725	22.295

According to the study held by the authors, the percentage of accurate data recognized by the system reaches 74%, which represents high dependability of the system, especially when helping to distinguish between completely wakeful states and drowsy ones. This performance metric describes how the system helps in rating the safety of the drivers since it employs timely alerts that reduce the risk of accidents caused by drowsiness of the driver. In real time implementation there are false positives, and false negatives, meaning that the model can still be further refined. The proposed system could be enhanced in the future that could intend to reduce such errors to make the proposed system more effective and safer for the vehicles on the road.

6.2 Lane Detection Performance Testing

The performance testing for the Lane Detection system was evaluated using two different algorithms: The two discussed algorithms are Spline-based algorithm and Hough-based algorithm. The results that were employed largely in determining the performance were the Mean Absolute Error (MAE) and the Standard Deviation of Error (SDE). These provide information of how accurately and selectively each algorithm is in detecting the lane markings.

Employing Spline-based the MAE was closer to 5. Average identification score was 910 and SDE was 27. 502. The MAE displayed the difference between the identified lane and actual lane and larger values point to more numerous mistakes. The SDE is relatively large establishing the fact that the variation is relatively large compared to the error measurements used in the Spline-based algorithm and, therefore, the Spline-based algorithm's results from one scenario to another can highly vary.

On the other hand, Hough based algorithm MAE of 3. Hence, the value of is 725 suggesting that the Linear Regression based algorithm furnished a better identification of the lane markings than the Spline based algorithm. Finally, this proposed system describes that, the Hough-based algorithm resulted in the Average of Error being about 22 of the SDE 295, which although is still greater than the desired limit of less than 100, is lower than the Spline-based algorithm. This lattice means that while employing more complex Hough-based algorithm the user receives not only more precise detection of lanes but also the detection that operates best in different conditions. Thus, assessing the results of the evaluation, one can conclude that the imposed Hough-based algorithm is more accurate and reliable than the Spline-based algorithm.

The lower MAE and SDE also proved that the proposed Hough-based technique is better and accurate in finding the lane markings with minimum error hence suitable for real-time lane detection in ADAS. More refinements could be done to lessen variability in errors that would boost the accuracies of these algorithms increasing the reliability of the lane-keeping intervention to enable the drivers to safely use the lane and avoid an accident.

6.3 Vehicle Detection Performance Testing

Real-time vehicle detection works well and has a greater reaction rate and processing speed. The program has an accuracy of about 95% and can recognize vehicles driving at greater speeds as well. By solving the problem in real-time and in dynamically changing operational conditions, this technology is characterized by its fast response time and increased usability of complex computing methods distinct from the sequential ones.

As it has been proved that the performance of the developed system analyzed the collection, testing, and evaluation of the data and ensured its efficiency for different scenarios. Compared with this research, this study not only provided an analysis of true and false positive results but also referred to the true and false negatives, which contributed to a specific analysis of the precision and recall of the system.

These statistical results provide a high-accuracy proof to show that this method can be applied to many areas such as improving the traffic surveillance and promoting the more advanced intelligent navigation systems for automobiles. More importantly, the system has a true positive rate of 97%, thereby showing low false positive which means that the system can recognize vehicles without also recognizing other objects in the environment. These capabilities are essential in the enhancement of the road safety because they allow early intervention and systematic management.

The empirical analysis approach was characterized by large-scale data collection exercises under various conditions for example, speed, size, and the environment. Such an approach prevented the emergence of widespread problems in real-world utilization and fine-tuned the system's performance. The high percentage again counts for efficiency and reliability of the program and there is a very low probability of misdiagnosis.

The subsequent developments will be concentrated upon the flexibility concerning the changing environmental conditions and the reduction of the error rate to strive for maximum possible accuracy. In general, it can be stated that the presented vehicle detection system stands out as a major step for real-time object recognition methodology and can be regarded as a reliable and efficient tool for solving various traffic control and automotive safety issues. Further enhancements will continue being made to the advance new capabilities that will seek to really make it the most precise and efficient vehicle detection system in the world hence providing better road safety and traffic systems in the world.

7 Conclusion and Future Work

To make further modifications to this system, additional features that may be added as the project progresses are 'Vehicle velocity and distance detection between the automobile driving and the car in front', 'The voice helper (report the road information and warning)' and 'Gyro pilot.' Gyro pilot is a sophisticated driver assistance technology that improves motorist safety and comfort.

Each new Tesla vehicle includes eight external cameras, twelve ultrasonic sensors, and a powerful onboard computer to give you an extra layer of protection while you travel. This device can be installed in any car currently on the road to ensure safety and reduce the possibility of an accident caused by driver distraction. It will also help the motorist to obey the rules properly and avoid traffic tickets [8].

The use of a driver assistance system significantly increases road safety, and drivers must understand how it works and how to use it correctly. Users will ultimately trust these systems, enabling for the growth of artificial intelligence (AI)-powered solutions. Publications, competitions, and mass media may all be utilized to monitor progress. Regarding the references, they presented in combination with image processing techniques in order to find the best method that is simple to process and delivers the most accurate results [6].

Suggested improvements for the vehicles' detection in the future are the possibility to choose the car's speed and distance measurement, an active road conditions voice assistant, and Gyro pilot. Gyro pilot references cameras, sensors, and computers to offer driver comforts and safety features such as lane-change warning, automatic speed control, and emergency stopping. Though these technologies are highly beneficial, they have to be tested out for efficacy and should be learnt by the public through publishing research, organizing competitions, or educating through the media. Continued development of these systems will integrate it with other AI transport systems making roads wiser and safer.

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Technological Features of a Safe Monitoring System Based on the Use of Unmanned Aerial Vehicles

Alex Khang, Dmitry V. Efanov, Gasim Mammadov, Vugar Abdullayev, Tatiana S. Pogodina, and Abuzarova Vusala Alyar

Abstract We considers the organization of a subsystem for collecting diagnostic information about railway signaling and interlocking devices using unmanned aerial vehicles (UAVs) with a payload. An expanded architecture for the system of technical diagnosis and monitoring of railway signaling and interlocking equipment has been developed. Principles for ensuring the safety of measurement operations using UAVs have been discussed. A method for forming an overflight over route for UAV is proposed, considering the features of diagnosis objects and the specifics of the arrangement of railway infrastructure. Based on the analysis, work on manual technical diagnosis that is automated using UAVs has been highlighted. Many defects in trackside devices of railway signaling and interlocking have been identified, which distinguished by unmanned aerial vehicles. The use of the solutions proposed by the authors makes it possible in practice to expand many automatically recorded diagnostic events, as well as to reduce the period of diagnosis. This helps to maintain a high level of reliability and readiness of railway signaling and interlocking devices.

Keywords Technical diagnostics of critical infrastructure objects · Monitoring of railway signaling and interlocking systems · Unmanned aerial vehicles · Safe flight zone · Overflight over routes

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1 Introduction

Safe train traffic management relies on the use of highly reliable railway signaling and interlocking systems [1, 19, 20]. The means of railway signaling and interlocking are the actuators. Which are used to ensure the preparation of the track for the movement of trains or shunting consist, as well as for transmitting commands to the drivers.

Railway signaling and interlocking devices, as links of a critical application system, must have high reliability and safety indicators. Various events are held to ensure this. At the stage of development and configuration, railway signaling and interlocking devices are implemented using redundancy and diverse protection methods. Implemented self-checking circuit solutions, galvanic isolated circuits, multi-pole circuit openings and closures, secure software, etc. are also used [2, 8, 11, 21].

Many objects are created not only with checkable structures, but also with low–maintenance ones (for example, choke transformers or replaceable blocks of microprocessor control systems). At the stage of continuous operation, both automated and automatic monitoring of the operating parameters of railway signaling and interlocking devices is used. And maintenance operation and repair measures are also carried out (in fact, manual technical diagnosis using specially developed technological cards with different work intervals) are used [4].

There are both centralized and decentralized railway signaling and interlocking objects. The former are located at electric interlocking posts, in transportable modules, and relay cabinets, among other locations. The latter are distributed along railway tracks and some even utilize rails as a current conductor. Naturally, maintaining the reliability and safety indicators of centralized systems is much easier than that of decentralized ones.

Statistics indicate that up to 80% of failures in railway signaling and interlocking equipment occur at decentralized devices. They control and monitor train movement, also known as trackside railway signaling and interlocking devices. Such devices are frequently exposed to environmental factors and the impact of moving trains. This leads to physical wear and a gradual decline in reliability indicator. Therefore, methods of automation for obtaining objective data on the technical condition of railway signaling and interlocking trackside devices are continuously being developed and refined [3, 5].

The purpose of this paper is to present the technological features of a safe monitoring system for trackside devices of railway signaling and interlocking. In this paper, an unmanned aerial vehicle (UAV) [12] with a payload performs the main role of an «observer». It provides automatic collection of data on the condition of trackside devices of railway signaling and interlocking, which cannot be obtained by means of stationary monitoring. Interestingly, despite the development of unmanned technologies in the field of railway transport, they still do not have a deep application. Only some works are known concerning the use of UAVs to improve the technology of operation of railway infrastructure facilities [18].

2 Simplified Architecture of the Technical Diagnosis and Monitoing System

Various methods are employed to address all issues of technical diagnostics during the operation of trackside railway signaling and interlocking devices. The quality of diagnosis, as well as subsequent objectives such as genesis and forecast, depend on the comprehensiveness of objective information obtained about the status of railway signaling and interlocking equipment. Therefore, it is crucial to have a complete range of data regarding management and control objects in order to promptly carry out restoration works as shown in Fig. 1.

By now, manual diagnosis with periodic measurement work by operating personnel is widely used. For all railway signaling and interlocking objects, there are special technological cards for work of maintenance operation, which allow to maintain reliability indicators with different time intervals. Their implementation makes it possible to maintain the operational characteristics of control and checking devices within acceptable limits. A number of measurement procedures can be automated. For this purpose, sensors of physical quantities are installed in circuit assemblies of railway signaling and interlocking (as a rule, these are sensors of currents and voltages in circuits). They allow to receive primary data, which are then transmitted to data concentrators [4].

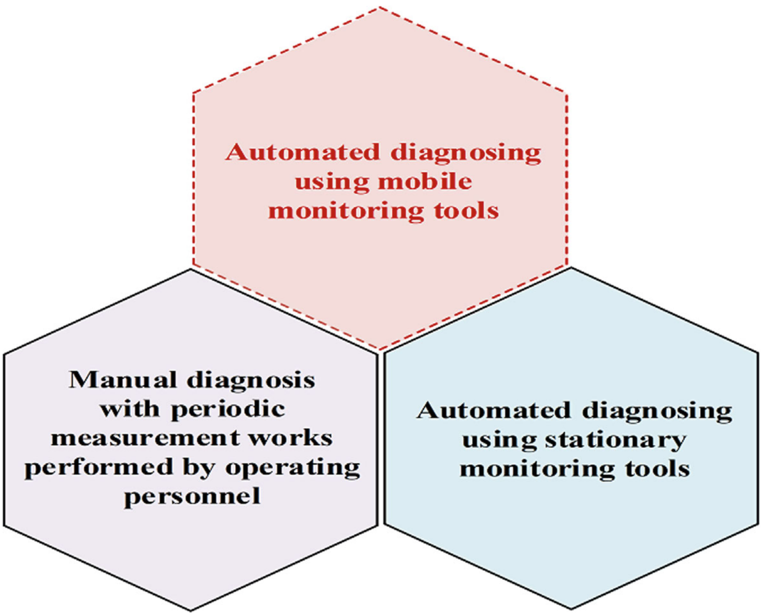

Fig. 1 The "Three Pillars" of technical approaches to diagnosis and monitoring

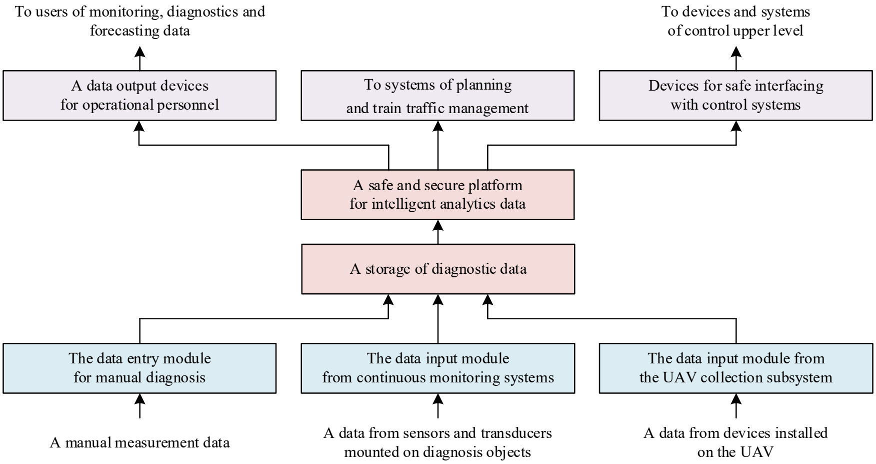

Fig. 2 A promising structure of interaction of components, including information interface with train control systems

The data is processed there. Such measurement procedures are carried out with much shorter periods (usually seconds). Therefore, in the time scale of operation of diagnosis objects, can be considered this a continuous monitoring procedure. However, not all working parameters of railway signaling and interlocking devices can be controlled using continuous monitoring tools. Only a small part of the electrical parameters is controlled. This does not allow making accurate diagnoses and forecasts.

Maintenance operation procedures carried out with long periods (weeks and even months) at the stages of the origin and development of failures do not always allow them to be prevented. Because they may simply not allow the changes to be fixed, and the failure itself may occur between maintenance operation periods. Therefore, the task arises of automating a number of measurement procedures using mobile technical facilities diagnosis and monitoring. Such mobile devices can be most effectively used as a payload on an unmanned aerial vehicle (UAV), which could automatically overflight over railway stations and hauls (naturally, under flight time restrictions), collecting diagnostic data. Thus, an integrated system of technical diagnosis and monitoring can be represented in the form of a diagram Fig. 2.

3 Safety Principles

The key issue of using UAVs with critical infrastructure facilities, which include the railway transport system, is to ensure its safety. Therefore, when using UAVs to implement a mobile subsystem for collecting data on railway signaling and interlocking facilities, it is necessary to follow the following safety concept: under no control and interfering influences should the UAV be able to collide with infrastructure facilities of the same roads, as well as intersections with the tracks of rolling stock. In fact, to ensure the safety of the railway transport system, the UAV can move in any space without affecting buildings and structures. However, from the point of view of safety, it is necessary to exclude the risks of collisions with both infrastructure facilities and rolling stock. This can be done by allocating a special corridor for the passage of UAVs without taking into account the timetable of moving trains. Let's call this corridor a "UAV safe flight zone".

Definition 1 The safe flight zone of a UAV is understood as a zone in which the UAV does not have a critical impact on railway infrastructure and rolling stock under any controlling and interfering influences.

No external destabilizing factors should lead to violation of the boundaries of the safe flight zone of the UAV. Data collection should primarily be conducted from this area, thanks to the payload mounted on the UAV. It is allowed to leave the safe flight zone to collect data, for example, on the visibility of signals, in the absence of train traffic, with the readiness to return to the safe flight zone if there is rolling stock at a dangerous distance. Such a distance l_S must be at least the distance that the train will travel at the maximum permitted $v_{\max}$ speed on the section during the t_{UAV} time required by the UAV to return to the safe flight zone:

$$l_S \geq t_{UAV} v_{\max}. \tag{1}$$

The UAV must be equipped with devices capable of detecting a moving train at a distance no less than l_S. In addition, he must keep in his own memory the distance that he needs to enter the safe flight zone. The safe flight zone should be determined based on the topology of the railway section (station or hauls) as shown in Fig. 3.

The border separating the safe flight zone of the UAV from the no-fly zone is highlighted in red. It should be noted that it may have boundaries that repeat the boundaries of engineering structures and buildings (in the example given, the location of the contact network objects is accepted as the last structures separating the railway infrastructure from the UAV safe flight zone. The actual location of the UAV during overflight over and data collection is shown in Fig. 4.

It should be noted that the task of ensuring the safety of UAVs is not only with control actions, but also with interfering ones. The latter include natural wind loads, as well as aerodynamic effects from rolling stock. UAV control algorithms should be developed in such a way that the power of the UAV engines is sufficient for stable movement in conditions of wind and aerodynamic effects. Therefore, it is essential to determine the allowable operating conditions for a UAV based on its specific characteristics, which necessitates thorough testing.

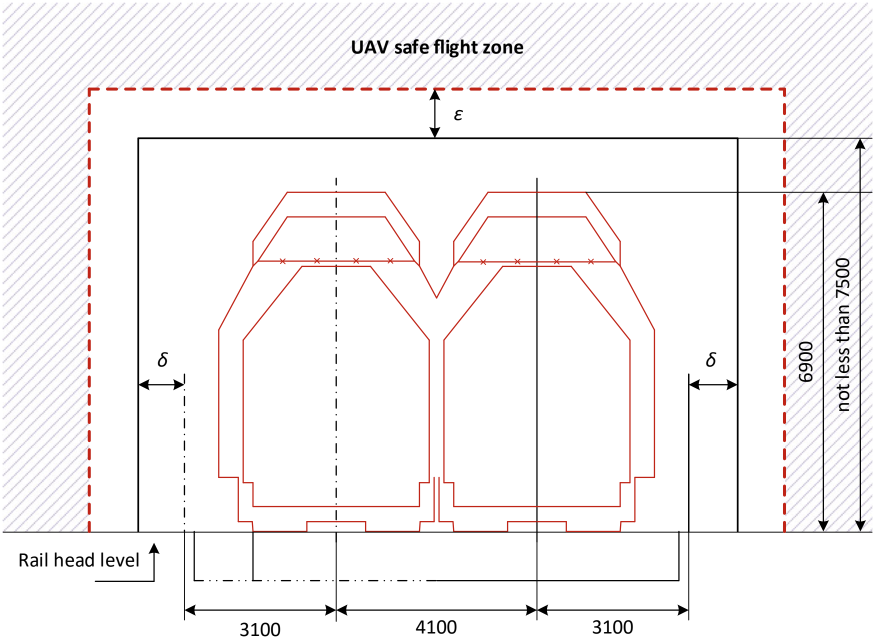

Fig. 3 Location of the UAV safe flight zone, taking into account the dimensions of the approaching buildings

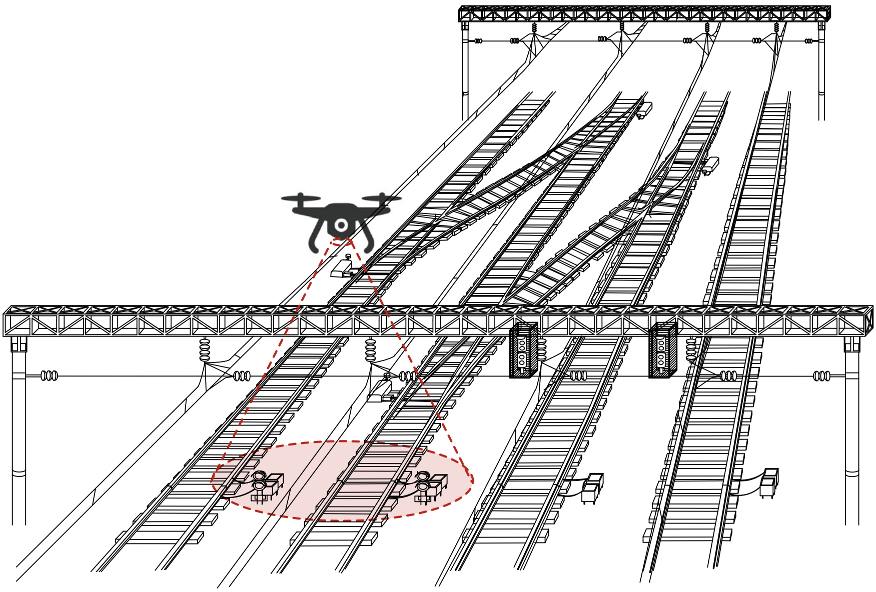

Fig. 4 Covering of trackside devices of railway signaling and interlocking with devices for removing diagnostic information from UAVs

4 Features of the Allocation of Overflight Over Route of an Unmanned Aerial Vehicle

To form a flight route for a railway UAV, it is necessary to determine the number of objects from which data will be collected. To do this, all trackside devices of railway signaling and interlocking are allocated directly at the facility, for example, stations. Since they are present on such a document as a single-stranded station plan, it is advisable to use it as the basic document based on which the UAV overflight over route is generated. In Fig. 5a, b shows an example of a yard neck with an indication on its schematic plan of all trackside devices of railway signaling and interlocking.

In Fig. 5, a) the devices themselves are shown in the legend (in the context of this paper, additional explanations are not required). In Fig. 5, b) the devices have been replaced by nodes. Moreover, some of the nodes have a larger outline—these are trackside devices of railway signaling and interlocking. Nodes with a smaller outline are auxiliary elements, such as, for example, electric traction and welded connectors, jumpers, insulating joints, etc.

Naturally, the UAV overflight over route is not generated directly by constructing a graph from the given points. This would be impractical. Therefore, we introduce the following approach.

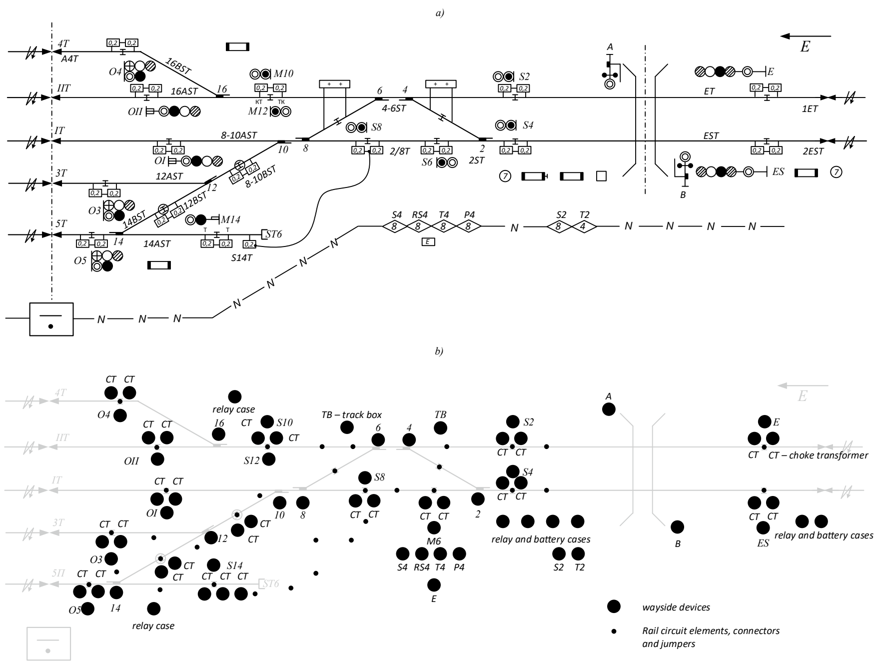

Fig. 5 **a**, **b** The allocation of graph nodes for generation of an overflight over route UAVs

Definition 2 A cluster of nodes in the primary graph can be called an area on station plan in single-stranded execution, in which the location of railway signaling and interlocking devices has a high density.

In Fig. 5 it is possible to identify various clusters of nodes of the primary graph, and it is possible to select zones in which devices are practically absent.

To collect data on railway signaling and interlocking devices, the UAV is equipped with a payload that allows data collection at a given distance. The following notions will be discussed below.

Definition 3 The radius of coverage, denoted as R, is the radius of a circle that covers the plane, given the payload being used.

Next, the task is reduced to covering the plane, taking into account the physical and geometric parameters of the location of railway infrastructure objects. They are covered with circles of radius R to form points of the modified graph in which the UAV will be located. A UAV overflight over route will be conducted using it.

The task of covering a flat figure with circles of various radii is extremely interesting and has been solved by mathematicians, for example, in work [17]. Therefore, we will not pay attention to its solution here. In practice, it is required to cover all clusters of nodes of the primary graph with circles of a given radius. This is done strictly individually for each section of the railway. As examples, Figs. 6, 7 and 8 demonstrate some railway section topologies and solve the task of coverage.

Further, the center of the circles correspond to the graphs vertices that the UAV needs to visit. They are used to create an overflight over route, which is forms a graph with cycle. The distances between nodes in the graph are known. Next, the well-known traveling salesman's task is solved in the software.

It should be noted that the task of choosing the coverage radius deserves a separate study. The trajectories shown in Figs. 6, 7 and 8 may differ greatly when the radius is reduced or increased. This is especially true for stations with a complex topology (see Fig. 6), where a large number of railway signaling and interlocking devices are located.

The UAV must have an electronic plan of the station in the software. It should include not only the coordinates and horizontal distances on the ground, but also vertical distances to safe flight zone. Next, onboard UAV devices carry out data collection tasks.

Here are the algorithms for performing an overflight.

4.1 Algorithm 1

Rules for the formation of an overflight route for trackside signaling and interlocking devices without violating the safe flight zone:

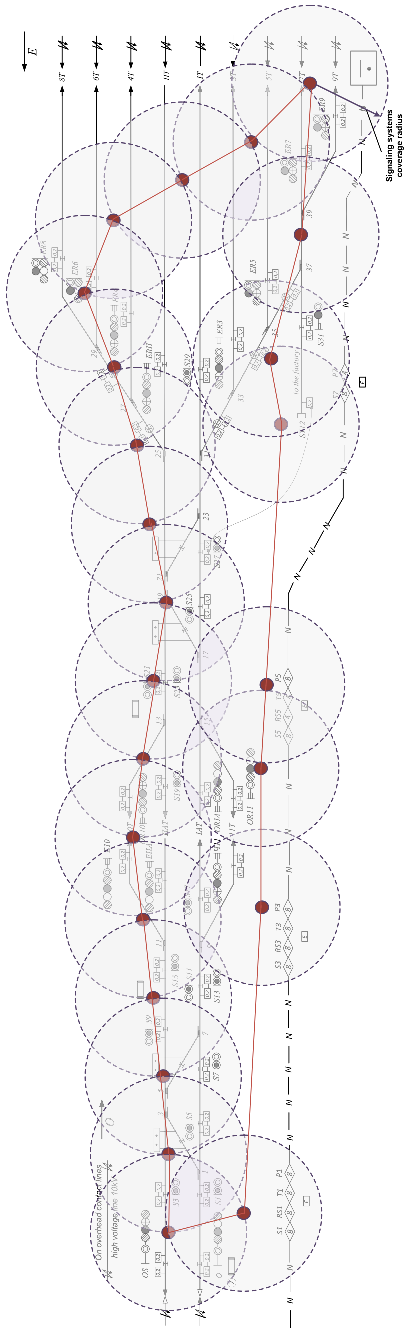

Fig. 6 Formation of the overflight over route at a precinct station with a complex topology (the starting and ending points of the route do not coincide)

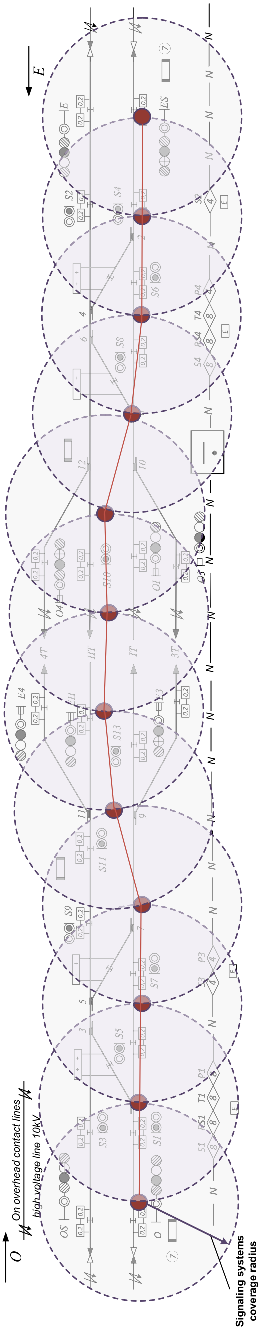

Fig. 7 Formation of the overflight over route at this switching track (the starting and ending points of the route do not coincide)

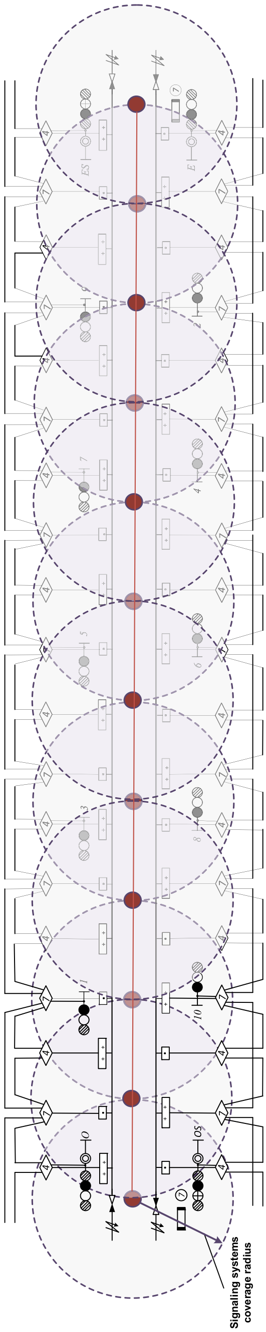

Fig. 8 Formation of the overflight over route at this haul (the starting and ending points of the route do not coincide)

- Based on the schematic plan of the station in a single-stranded or two-stranded execution, a set of main vertices of the primary graph of the station overflight or stage is formed.
- Based on the survey, the locations of additional vertices of the primary overflight graph are determined.
- The clusters of vertices of the primary overflight graph are covered with the smallest number of circles with radii r $\leq$ R.
- The vertices of the modified overflight graph are formed in the centers of the coverage circles.
- The vertices of the modified overflight graph are connected by edges.
- Taking into account the known ordinates of objects of railway signaling and interlocking, as well as taking into account the location of elements of track circuits, connectors and jumpers, as well as insulating devices, the distances between the vertices of the overflight graph are determined—the weights of the edges.
- Based on the topology of the station, the method of overflight is determined (overflight from one yard neck to another without return/with return, overflight of each yard neck separately with departure from the post of electric interlocking/from the central axis of the station with return/without return to the starting point, etc.).
- Based on the chosen overflight method, edges with knowingly increased weights are removed or not introduced from the graph.
- The optimal overflight route is determined.

The example in Fig. 5 demonstrates the transition from a schematic plan of a station with the location of railway signaling and interlocking devices to the formation of clusters of vertices, which are then covered with circles of a given radius. Examples of coverings are given in Figs. 6, 7 and 8.

Otherwise, the overflight graph will look like, which is formed with other conditions for collecting diagnostic information. For example, if you need to leave the safe flight zone to make measurements about the visibility of signals and the integrity of lens sets of traffic lights. In this case, the flat graph is modified.

4.2 Algorithm 2

Rules for the formation of an overflight route for trackside signaling and interlocking devices with violating the safe flight zone:

- Based on algorithm 1, a graph of the overflight of devices in the safe flight zone is constructed as a graph in a plane that is parallel to the plane of the location of railway tracks in straight sections.
- The locations and heights of the elements of the trackside devices of railway signaling and interlocking: h_i. $i = \overline{1,\ n}$, where n—the number of objects that are being surveyed.
- The values are calculated

$$g_i = g_{UAV} - h_i, \; i = \overline{1, \; n}, \tag{2}$$

where g_{UAV}—the flight altitude of the UAV.

- The graph, which is located in the plane, is modified and expanded. Next, vertices are added there indicating the values of g_i—a graph is formed in three–dimensional space.
- New vertices are connected by edges to the existing ones in the graph located in the safe flight plane.
- Taking into account the graph in the plane of safe overflight and the geometric location of the survey objects, the distances between the new vertices and the existing ones are determined—the weights of the edges are formed.
- Based on the topology of the station, the method of overflight is determined (overflight from one yard neck to another without return/with return, overflight of each yard neck separately with departure from the post of electric interlocking/from the central axis of the station with return/without return to the starting point, etc.).
- Based on the chosen overflight method, edges with deliberately increased weights are removed or not introduced from the graph.
- The optimal overflight route is determined.

Some of the vertices of the modified graph are shifted down relative to the vertices of the planar graph, that is, into the space between the planes of the lower boundary of the safe flight zone. Thus, you also need to visit these vertices. It is worth paying attention to the fact that the overflight algorithm in this case implies the implementation of all procedures in the safe flight zone and only part of the procedures for collecting diagnostic data requires violation of the boundaries of the safe flight zone [15].

4.3 Algorithm 3

Rules for overflight trackside devices with violation of the safe flight zone in the absence of train traffic:

- The UAV is flight in a safe flight zone.
- The absence of moving trains and shunting trains in the zones of the visited vertices of the graph under the plane of the lower boundary of the safe flight zone with continuous verification of condition (1) is determined.
- Descent is performed into the zone of accumulation of vertices outside the plane of the lower boundary of the safe flight zone, taking into account the calculated values of the required descent depth according to the formula (2).
- Measurement procedures are performed.
- The UAV returns to the safe flight zone.

Thus, following the described principles, it is possible to use UAVs to collect diagnostic information about trackside devices of railway signaling and interlocking.

5 Automation of Maintenance Processes

An analysis of the maintenance instructions for railway signaling and interlocking devices and systems has shown that the use of UAVs makes it possible to simplify maintenance procedures for certain types of routine maintenance (naturally, with a clearly defined sequence of actions while ensuring absolute safety of train traffic). Here is a listing of them. To some extent, part of the maintenance activities can be performed using UAVs for the following types of work:

- Checking the visibility of signal lights of green luminous strips and indicators light of traffic lights with incandescent lamps, as well as traffic lights with LED light-optical systems;
- Checking the visibility call to-enter signal light;
- Checking the visibility of traffic lights by the main tracks from locomotive level;
- Checking the burning of lamps and LED light-optical traffic light systems in an emergency power supply (by direct current);
- Verification for double-track and multi-track hauls of the implementation and control of the function of changing the direction of automatic blocking (main and auxiliary modes);
- Checking the condition of electric switch mechanism, switching headset, external locking, position locks of the movable point of frog, derailing brake-shoe by external inspection, as well as the density of closing of point to straight stock rail and the movable point of frog to the rail wing on the switch, the switching of which is excluded;
- Checking the condition of the working traction of the movable point of frog to identify endurance cracks (except for the working traction of the frog with an external locking);
- Checking the condition of insulating elements of track circuits, joint connectors and jumpers at the station;
- Checking the visibility of the lights of protecting and crossing traffic lights when powered by alternating and direct current;
- Checking the impossibility of opening the gate crossing with the emergency opening button when the protecting signaling is turned on, without time delay;
- Checking the effect of the protecting signaling on the entrance, exit, route, intermediate and shunting traffic lights used as protecting (one traffic light per group is checked);
- Checking the condition and operation of automation at pedestrian crossings, checking the visibility of traffic lights for pedestrians, the serviceability of sound signals;
- External inspection of aerial signaling line;

- Checking the condition of cable boxes;
- Participation in the inspection of intersections of aerial power line with aerial lines of the SCB, conducted by employees of the power supply distance;
- Checking of the above-ground portion of reinforced concrete structures;
- Checking the operation of tunnel (bridge) signaling;
- Checking the operation of the protecting signaling and visibility of lights of the protecting traffic lights;
- Checking the condition of the supporting structure and control device for foul-to-gauge detector;
- External inspection of track boxes containing trackside assets of system of axles count.

It will be important to use UAVs in the tasks of checking the availability and correctness of factory lacquering of trackside devices of railway signaling and interlocking, including the presence of peg, traffic light lettering plates, drives, etc., as well as in the tasks of checking the timeliness of work by maintainers. This, in turn, opens up ways to take into account the residual life of trackside railway signaling and interlocking devices to forecasting their service life and equipment replacements.

6 The Variety of Types of Defects in Trackside Devices

An analysis of technical solutions for railway signaling and interlocking, the principles of their location near railway tracks and operation showed that a large number of defects in trackside devices are fixed and controlled exclusively by manual technical diagnosis as shown in Table 1. Operational practice shows that many failures of trackside railway signaling and interlocking devices arise precisely because of the absence of operational data on their technical conditions and due to the absence of intervention and procedures rehabilitation. Table 1 shows the main faulty conditions of trackside devices of railway signaling and interlocking.

All defects listed in Table are associated with physical damage that does not affect electrical parameters and characteristics, which are successfully recorded by modern automatic measurement tools [4, 16]. The possibility of obtaining data on trackside devices of railway signaling and interlocking using UAVs will further allow distinguishing defects using of artificial intelligence [13].

In Fig. 9, a) two choke transformers are depicted, which have no markings, no hangers, and choking jumpers are not painted. In Fig. 9, b) the scale at the insulating joint is shown. Such a defect is captured in the electric interlocking by the logical occupancy of two adjacent track circuits, however, it can be prevented with proper maintenance of the track. In Fig. 9, c) the visor of the traffic light is shown, from which ice hangs, overlapping the indication of the traffic light. In Fig. 9, d) shows two defects at once—a chip on the rail and damage to the joint connector. All these defects can be identified by the UAV, but they may not immediately manifest themselves in the electric interlocking or automatic blocking system.

Table 1 The main fault conditions of trackside devices of railway signaling and interlocking

Trackside devices of railway signaling and interlocking	Defects distinguishable from UAVs
Traffic lights and route indicator	Unclosed traffic light head housings, coverage rust; abnormal condition of the head outside; defect of the visors; absence of caps on metal masts; displacement of the head relative to the bracket and mast; lens contamination; absence of marking; violations of the dimensions of the installation; distortions and abnormal vibration effects; proximity to the contact wire, etc
Electric switch mechanism	Violation of headset insulation, switch lugs, gauge rods and struts on railroad switch; violations in the location; knuckle kink of the switch point; presence of snow cover on the switch engine; defects in the drive lid; violations in box joints and switch engine; absence of peg; absence of factory lacquering, etc
Choke transformers	At least one jumper is disconnected from the rail; insulation wear; the housing lid is open (there are no bolts); there is no connection clip; protective paint of the choke transformer jumpers to avoid shorting them when illegal connection to wires; wear of the choking jumpers and connectors; violation of the insulation of jumpers and connectors; violations in the location; absence of factory lacquering, etc
Automation level crossing safety devices	Damage to the safety stop of the automatic barrier; structural violations; rupture of parts; defects in the shields of automatic level crossing safety installation, etc
Insulating joints	The absence of a gap between the deformation of the rail and top ballast; contamination of the ballast with salts and conductive materials; contamination of drainage from trackside devices of the SCB; violation of the integrity of the end post; absence of protective paint; presence of conditions the formation of metal chips, etc
Transformer chest, track boxes, cable sleeve, relay cases, electric heating control cases, etc	Opening the lids of chests and boxes or case doors; violations of the geometric parameters of the location (slopes and distortions); the presence of rust; cracks, chips and potholes on the housings and lids, fracture or progressive pitting of the lid or housing; wear of jumpers and connectors; absence of peg; absence of factory lacquering, etc

(continued)

Table 1 (continued)

Trackside devices of railway signaling and interlocking	Defects distinguishable from UAVs
Rail connections	Absence of welding connection or electric traction connectors; wear of welding connection or electric traction connectors, etc
The upper structure of the path	Significant contamination of ballast with fertilizers and petroleum products

a) *b)* *c)* *d)*

Fig. 9 **a**, **b**, **c**, **d** Some defects of trackside devices and elements

It is clear that even the use of UAVs will not always make it possible to obtain a complete set of states of trackside devices of railway signaling and interlocking. One of the indicators of the effectiveness of using UAVs on a section of a railway line may be the coefficient k_F of the completeness of coverage of potential defects, which is defined as the ratio of the number of detected defects n_{DET} to the total number of possible defects n:

$$k_F = \frac{n_{DET}}{n}. \tag{3}$$

The closer the k_F-value is to 1, the more efficient the UAV's operation in collecting primary diagnosis data will be. In our opinion, the k_F indicator should be normalized and in the course of mastering UAV technology for the railway transportation system, it should increase from the minimum level during the running-in stage to the maximum level during continuous operation.

7 Conclusion

The railway transport system is a complex organism, which has a "butterfly effect"—the slightest change in one of the sections due to some defect can lead to changes at some remote station, affect disruptions in the train schedule and cause train delays, and in the worst case—accidents and catastrophes. Railway signaling and interlocking are responsible for the reliable and safe movement of goods and passengers, among other things. They are built in such a way as to exclude dangerous effects on the technological process of transportation. Nevertheless, all indicators of the efficiency of the railway transport system depend on the quality of their work. The development of methods for their diagnostics and forecasting is an objective trend of our time [14].

The solutions proposed by the authors in this paper make it possible to organize a subsystem for collecting objective data on the condition of trackside devices of railway signaling and interlocking. The developed method of covering clusters of nodes of the primary graph for railway signaling and interlocking devices allows you to choose the best overflight over routes for UAVs, taking into account safety conditions. However, the very problem of safety in the use of UAVs at railway infrastructure facilities requires the development of optimal adaptive control algorithms. It should be noted once again that it is with the use of UAVs that the influence of the human factor on the process of collecting data on objects of critical use is reduced.

An interesting decision may also be the use of unmanned aerial vehicles in conjunction with radio-frequency identification technology [9, 10]. This, trackside railway signaling and interlocking objects can be equipped with radio-frequency tags operating in the L-band for the possibility of long distance identification with UAVs. This will allow receiving data on the maintenance operating performed by the maintainers. Personnel should be equipped with specialized equipment for overwriting data in radio-frequency tags.

However, the composition of the data that is recorded in radio-frequency tags, as well as the features of the organization of the data collection subsystem, are subject to future research. A like task is similar to the one considered in [22] for collecting data from labels that are located at certain points along the route. Naturally, the specifics of the location of railway signaling and interlocking facilities and the possibility of approaching them under flight safety restrictions are taken into account.

The development of technical diagnosis and monitoring technologies makes it possible to expand the variety of automatically detected diagnostic situations. This, in turn, when combined with information systems for the organization and management of train traffic [6, 7] creates prerequisites for the transition to a qualitatively new railway transport system from the point of view of reliability and safety.

Authors Contribution Alex Khang, Vugar Abdullayev, Dmitry V. Efanov, Tatiana S. Pogodina: Contributed experiments, conceptualization and methodology. Vugar Abdullayev, Dmitry V. Efanov, Tatiana S. Pogodina: Contributed Writing and Editing. Alex Khang: Contributed Writing – Review & Editing, and Supervision.

Declarations

Conflict of Interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this chapter.

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Battery Health Aware Energy Management Strategy for Hybrid Electric Vehicle Using Artificial Intelligence

Alex Khang and Khushwant Singh

Abstract Using Artificial Neural Networks (ANN), a battery health aware energy management strategy (EMS) is created for a power-split hybrid electric vehicle (HEV). To acquire a dataset, three distinct speed profiles are used. The highway speed profile is HWFET, the third speed profile is NEDC, and the dynamic, transient speed profile is WLTP. During these driving cycles, the vehicle is run in charge-sustaining mode utilising the Equivalent Consumption Minimisation Strategy (ECMS). In simulations, three distinct beginning State-of-Charge (SOC) values are employed. There are three distinct starting SOC levels for each cycle. The ICE torque and speed are controlled by two ANN controllers. The vehicle's torque requirement, the state of charge, and the fading of the battery capacity are chosen as the ANN's inputs. This research aims to investigate fuel usage and battery deterioration via the use of artificial neural networks. According to WLTP results, with the lowest starting SOC value, capacity fading may be decreased by up to 14.85% and fuel consumption can be lowered by 3.83%. Fuel consumption is lowered by 1.84% and capacity fading is decreased by 13.80% for intermediate starting SOC values. With a 5.75% rise in fuel consumption, capacity fading is decreased by 14.70% for the highest starting SOC value. For the other two driving cycles, the outcomes are the same. In HWFET and NEDC, battery deterioration is also decreased.

Keywords Artificial neural networks · Battery degradation · ECMS · Hybrid electric vehicle

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1 Introduction

Due to the limited reserves of fossil fuels and harmful emissions, countries all around the world are assessing the benefits of electrification in transportation [2, 4]. Electric motors offer quiet operation and excellent acceleration performance but battery technology still needs improvements because of their cost and range limitations. Hybrid electric vehicles (HEVs) are another alternative for the electrification of transportation. HEVs can decouple internal combustion engines from driven wheels and operate them in an efficient region. HEVs can increase the fuel economy and due to smaller battery packs, compared to battery electric vehicles (BEVs), they are less expensive than BEVs [8].

Energy management strategy (EMS) plays a key role for HEVs because of the operation of different powertrain components. HEV EMSs can be classified as optimization based methods, rule based methods and machine learning methods. Many different EMS algorithms are present in the literature. Until the last decade, most of the EMS research on HEVs was focused on the reduction of the fuel consumption. With the increasing number of BEVs and HEVs and the battery costs, researchers started to take battery degradation into account. Battery health conscious EMSs designed over the last years by using many different algorithms such as global and instantaneous optimization algorithms, rule based methods and machine learning methods.

Dynamic Programming (DP) is the most common global optimization algorithm and Equivalent Consumption Minimization Strategy (ECMS) is an instantaneous optimization algorithm that can achieve close results to DP. Fuzzy Logic is investigated for HEVs as a rule based method and proved that based on human intuition and expertise, satisfactory results can be achieved. Artificial Neural Networks (ANN) also gained attention from researchers in the last years and are used for different HEV applications. Literature Review below provides a summary of ANN methods used for HEV applications [7].

ANN has the ability to decipher complex non-linear relationships and emerge as a preferred tool for health management of lithium-ion batteries [16]. Various ANN architectures have been employed to predict the state of batteries including Convolutional Neural Network (CNN), Recurrent Neural Network (RNN), Feedforward Neural Network (FNN) [16].

A new Radial Basis Function Neural Network (RBFNN) is built in [3] and SOC estimation accuracy was increased. In [1], ANN is used for aging prediction and SOC estimation of a $LiFePO_4$ battery. Input time-delayed neural network technique is used and accurate state of charge and state of health estimation were achieved simultaneously. In [10], RNN is used for battery degradation prediction and compared to existing methods, proposed method predicts more accurately.

Apart from health management of lithium-ion batteries, ANN has been used for other HEV applications such as component sizing of a series HEV in [5]. In [14], ANN is used to enhance the EMS of the HEV and satisfactory fuel economy results were achieved. In [11], another neural network-based EMS is designed for a plug-in

HEV and reductions in the fuel consumptions were observed. As seen in the above examples, ANN can be used both for battery health management, SOC and degradation estimations of a hybrid electric vehicle and fuel consumption optimization, which are both important for HEVs and EMS design. This paper aims to investigate ANN as a battery health conscious EMS for a power-split HEV.

For this end, a dataset is obtained for charge-sustaining operation of the vehicle by using ECMS and battery capacity fade input is used in ANN controllers. Matlab Neural Networks toolbox is used to design ANN controllers and dataset is divided into 70% training data, 15% testing data and 15% validation data. Two ANN controllers are designed to control ICE torque and speed with the inputs of torque request of the vehicle, SOC and capacity fade. Three different speed profiles are selected as one dynamic transient profile, one highway speed profile and one intermediate speed profile.

Designed ANN controllers are tested in all speed profiles and results show that battery degradation is reduced in all cases. The rest of this paper is organized as follows; Sect. 2 explains the vehicle model, Sect. 3 explains implementation of ECMS, Sect. 4 explains ANN implementation, Sect. 5 compares the results of ECMS and ANN for all drive cycles and Sect. 6 includes conclusions.

2 Vehicle Model

A power-split HEV is modeled by using backward quasi-static approach in Simulink. The traction force required is calculated by the equation;

$$F_t = F_r + F_{aero} + F_{acc} \tag{1}$$

where F_t is the traction force, F_r is the rolling resistance, F_{aero} is the aerodynamic resistance and F_{acc} is the acceleration resistance. Rolling resistance, aerodynamic resistance and acceleration resistance are calculated by the equations given below.

$$F_r = mgfr \tag{2}$$

$$F_{aero} = \frac{1}{2}\rho C_D A f V^2 \tag{3}$$

$$F_{acc} = ma \cdot \delta \tag{4}$$

$$\mathrm{f}_r = 0.01\left(1 + \frac{3.6}{160}\mathrm{V}\right) \tag{5}$$

$$\delta = 1.04 + 0.025_{FD} \tag{6}$$

Table 1 Vehicle parameters

Vehicle mass (m)	1361 kg
Air density (ρ)	1.23 kg/m^3
Aerodynamic coefficient (C_D)	0.26
Frontal Area (A_f)	2.33 m$_2$
Final drive ratio (i_{FD})	3.267
Wheel radius (r_W)	0.31075 m

where m is the vehicle mass (kg), g is the gravitational acceleration (m/s^2), f_r is the rolling resistance coefficient, ρ is the air density (kg/m^3), C_D is the aerodynamic coefficient, A_f is the frontal area of the vehicle (m^2), V is the vehicle speed (m/s), a is the acceleration of vehicle (m/s^2), δ is the rotational inertia factor and i_{FD} is the final drive ratio as shown in Table 1.

Rotational effect of planetary gear set is not taken into account for simplification, just the rotational effect of final drive is included in the vehicle model. After required traction force is calculated, wheel torque and torque request are calculated by the equations given below Fig. 1.

Internal combustion engine (ICE) is connected to the carrier of the planetary gear, Motor/Generator 1 (MG1) is connected to sun gear and Motor/Generator 2 (MG2) is connected to driven wheels. ICE power is split in planetary gear to charge the battery pack through MG1 and provide traction torque through ring gear. Torque request of the vehicle, T_{req} is the combination of the torque provided by MG2 and ICE torque through ring gear. Torque and speed equations of the planetary gear set

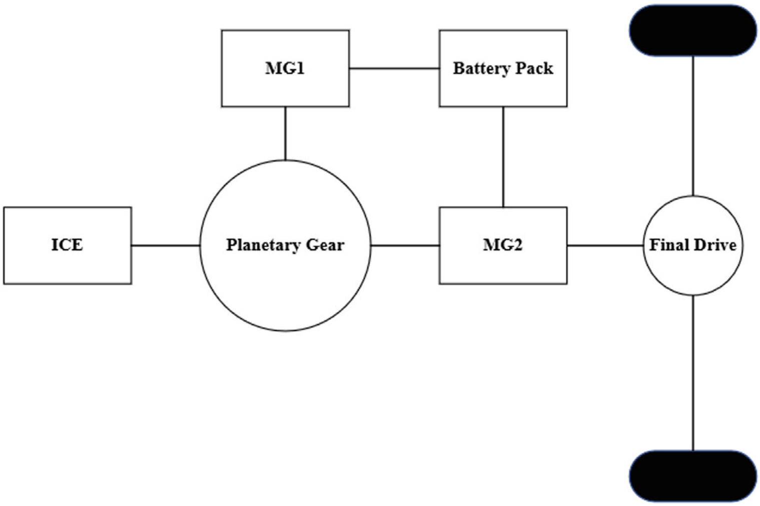

Fig. 1 Power-split configuration

$$\omega_{MG2} = \omega_r = \omega_{wheel} \cdot i_{FD} \tag{7}$$

where ω_{wheel} is the wheel angular velocity in rad/s, ω_{MG2} is the angular velocity of MG2 in rad/s and ωr is the angular velocity of ring gear in rad/s. Angular velocities of MG2 and ring are equal and proportional to the angular velocity of the wheels. Speed equation of the planetary gear set is given below and powertrain specification are given in Table 2.

$$(1+)\omega_{ICE} = i_{PG}\ \omega_{MG1} + \omega_{MG2} \tag{8}$$

In this study, ICE torque and speed are determined by the vehicle controller. As seen in above equations, when the ICE torque and speed are determined by the control algorithm, *LiFePO₄* battery cells are used in the model and cell parameters are given below in Table 3.

Capacity fade model in [15] is used as the degradation model.

Where α and β are fitting coefficients, E_a is the activation energy, η is the compensation factor of C_{rate}, R_{gas} is the gas constant, T_K is the ambient temperature in (K), Ah is the Ah-throughput and z is the power law factor. Parameters of the capacity fade model are given below in Table 4.

Table 2 Powertrain specifications

Maximum torque of ICE	115 Nm@4200 rpm
Maximum speed of ICE	5000 rpm
Maximum torque of electric motor (MG2)	400 Nm
Maximum speed of electric motor (MG2)	6000 rpm
Maximum torque of generator (MG1)	145 Nm
Maximum speed of generator (MG1)	10,000 rpm
Number of teeth of sun gear *Ns*	30
Number of teeth of sun gear *Nr*	78
Planet gear ratio, $i\left(\frac{N_s}{PG\ N_r}\right)$	0.384

Table 3 Cell parameters

Nominal capacity (Ah)	2.5
Nominal Voltage (V)	3.3
Maximum discharge current (A)	50

Table 4 Aging model parameters

Fitting coefficient α	$\begin{cases} 2896.6 & SOC \leq 0.45 \\ 2694.5 & SOC > 0.45 \end{cases}$
Fitting coefficient β	$\begin{cases} 7411.2 & SOC \leq 0.45 \\ 6022.2 & SOC > 0.45 \end{cases}$
η	152.5
$E_a\left(\frac{\mathrm{j}}{mol}\right)$	31,500
$R_{gas}(J/(\text{mol. K}))$	8.314
z	0.57

3 Equivalent Consumption Minimization Strategy

To obtain a dataset for ANN, ECMS is used. ECMS was first introduced by [13] and used extensively in the literature. It can achieve results close to global optimization algorithms such as DP. ICE torque and speed are controlled by using ECMS for the charge sustaining operation of the HEV.

The ECMS is based on the notion that, in charge-sustaining hybrid electric vehicles, the difference between the initial and final state of charge of the battery is very small, negligible with respect to the total energy used. This means that all energy comes from fuel, and the battery can be seen as an auxiliary, reversible fuel tank [12].

ICE torque and speed are discretized as the control variables. Fuel rate of the engine $\dot{m}_f$ in kg/s is a function of ICE torque and speed.

$$\dot{m}_f = (T, \omega_{ICE}) \tag{9}$$

Since ICE is not connected to the driven wheels in the power-split configuration, it can be operated at the most efficient region. Cost function, J, of ECMS can be written as follows:

$$\mathrm{J} = P_{ICE} + \lambda(SOC)_{hatt} \tag{10}$$

$$P_{ICE} = \dot{m}_f\ Q_{lhv} \tag{11}$$

$$(SOC) = 1 - \left(\frac{(t) - SOC_{t\arg et}}{(Soc_{\max} - SOC_{\min})/2}\right)^3 \tag{12}$$

where P_{ICE} is the fuel power of ICE (kW), λ is the equivalence factor and $p(SOC)$ is the penalty function for state- of-charge, Q_{lhv} is the lower heating value of the fuel (MJ/kg). Initial value of equivalence factor is taken as 3.385 and a discrete PI block is used for adaptation of equivalence factor. Implemented ECMS is subjected to following powertrain constraints;

$$\omega_{ICE,} \leq \omega_{ICE} \leq \omega_{ICE,ax} \tag{13}$$

$$T_{ICE,} \leq T_{ICE} \leq T_{ICE,ax} \tag{14}$$

$$\omega_{MG1,} \leq \omega_{MG1} \leq \omega_{MG1,ax} \tag{15}$$

$$T_{MG1,} \leq T_{MG1} \leq T_{MG1,ax} \tag{16}$$

$$\omega_{MG2,} \leq \omega_{MG2} \leq \omega_{MG2,ax} \tag{17}$$

$$T_{MG2,} \leq T_{MG2} \leq T_{MG2,ax} \tag{18}$$

$$SOC_{\min,} \leq SOC \leq SOC_{\max} \tag{19}$$

$$I_{batt,} \leq I_{batt} \leq I_{batt,ax} \tag{20}$$

Simulink model of ECMS and equivalence factor are given below in Figs. 2 and 3.

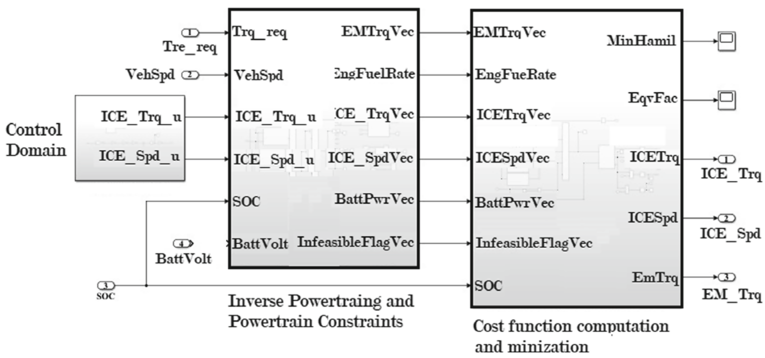

Fig. 2 ECMS Controller in Simulink

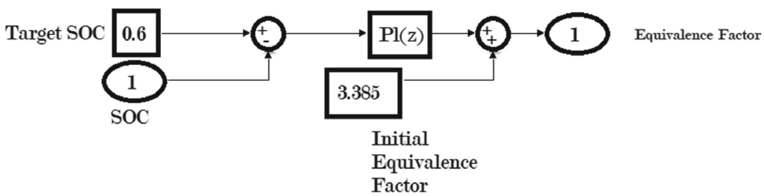

Fig. 3 Equivalence factor adaptation based on SOC

After ECMS is implemented in the vehicle model, three different speed profiles are selected. Worldwide Harmonized Light Vehicles Test Procedure (WLTP) is selected as the most dynamic, transient drive cycle which represents real driving conditions. The Highway Fuel Economy Test (HWFET) drive cycle is selected as the highway speed profile and New European Driving Cycle (NEDC) is selected as an intermediate speed profile. Vehicle is operated in charge sustaining mode for three different initial SOC values.

SOC values are selected as 20% as the lowest SOC, 60% as the medium SOC and 80% as the highest SOC. For each drive cycle, three different simulations are conducted for different initial SOC values and in total, nine simulations are conducted to obtain a dataset. Drive cycles and results of ECMS are given below Figs. 4, 5, 6 and 7.

The reason to choose low, medium and high SOC levels is that the SOC is one of the parameters in the aging model as shown in Fig. 8.

Figures 9 and 10 show capacity fade and fuel consumptions results for WLTP drive cycle. As seen in these results, there is a trade-off between battery usage and

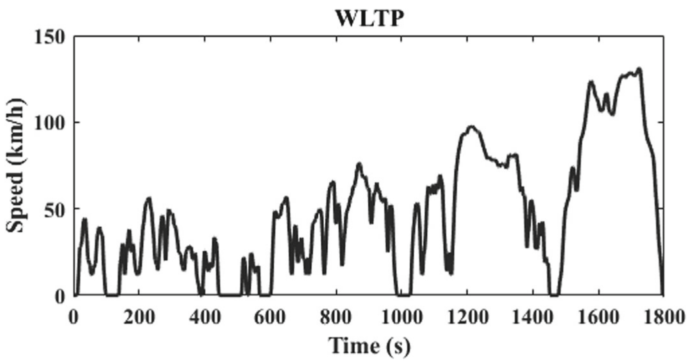

Fig. 4 WLTP Speed- Time graph

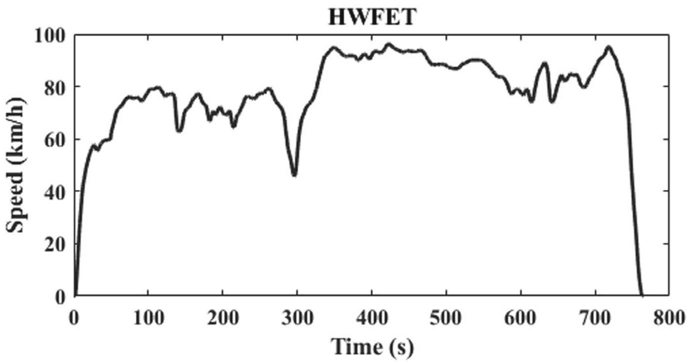

Fig. 5 HWFET Speed-Time graph

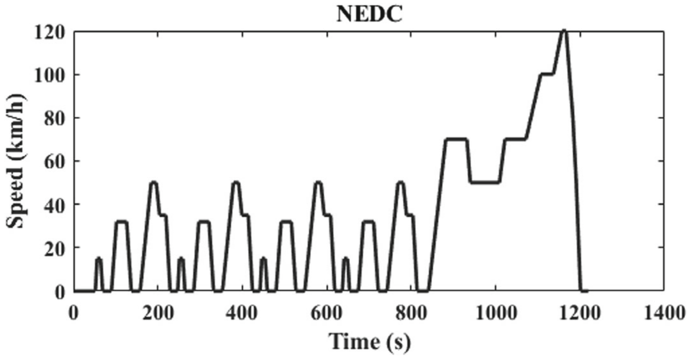

Fig. 6 NEDC Speed-Time graph

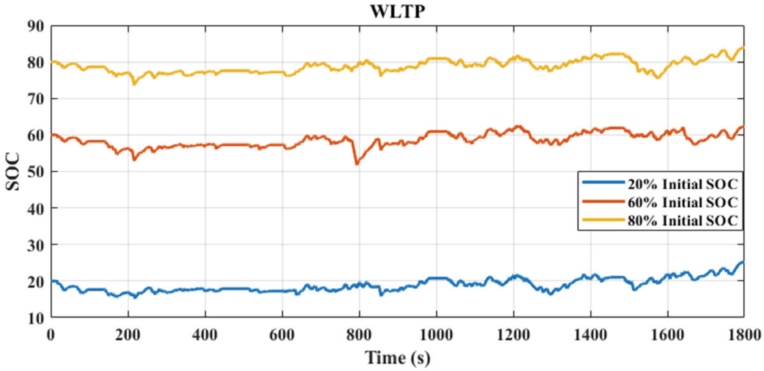

Fig. 7 SOC profiles in WLTP

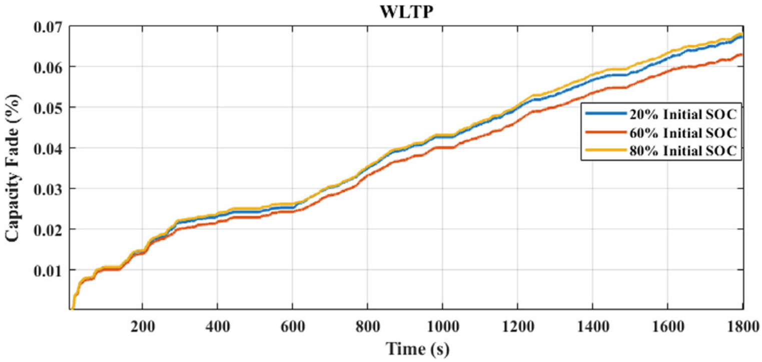

Fig. 8 WLTP SOC- time graph

fuel consumption. Figure 8 shows that minimum battery degradation occurs for 60% initial SOC level, which is the highest fuel consumption according to Fig. 9. For low and high SOC levels, battery degradation and fuel consumption are very close, as seen in Figs. 9 and 10.

Figures 11, 12 and 13 show ECMS results for HWFET drive cycle. The trade-off between battery degradation and fuel consumption can be seen in this drive cycle as well. Figure 11 shows that capacity fade is highest for lowest SOC level, 20%. In this case, more battery power is used, therefore fuel consumption is reduced as seen in Fig. 12. Compared to intermediate and high SOC levels, fuel consumption is minimum for 20% SOC level.

Results for NEDC are given above in Figs. 14 and 15. NEDC is not as dynamic as WLTP and has lower average speed compared to HWFET. Required driving power is relatively low in NEDC compared to other two drive cycles.

As a result of this, fuel consumption for different SOC levels is almost same according to Fig. 14 and there is very small difference in battery degradation.

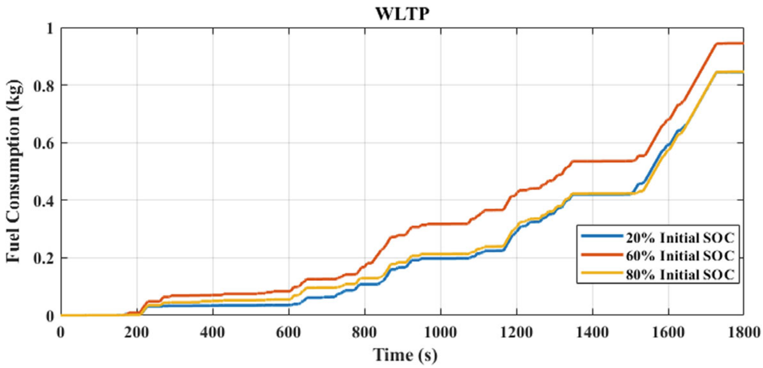

Fig. 9 WLTP capacity fade-time graph

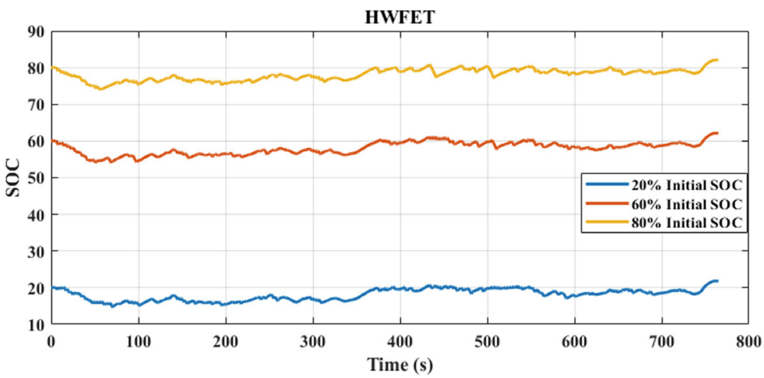

Fig. 10 WLTP fuel consumption-time graph

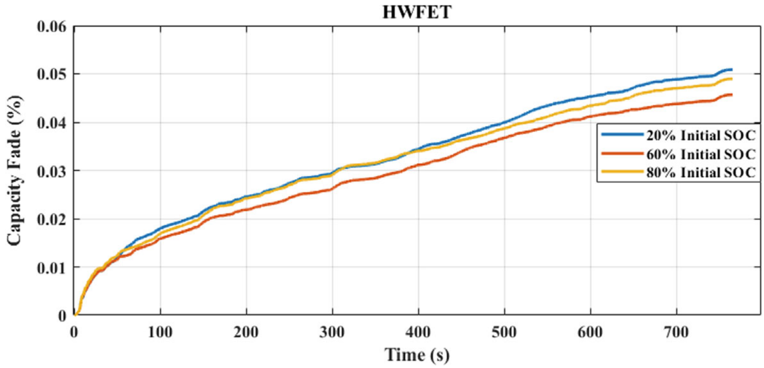

Fig. 11 HWFET SOC-time graph

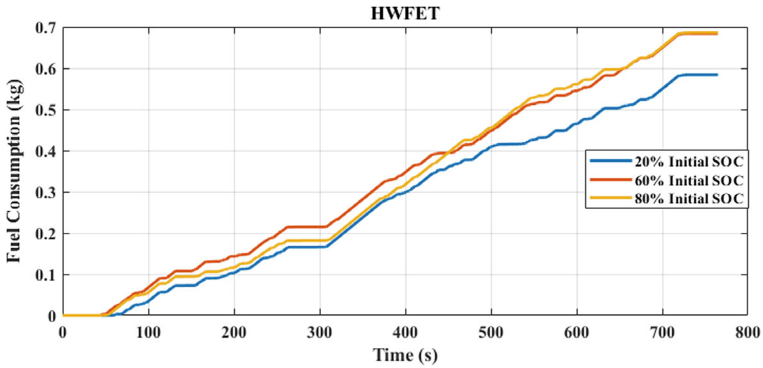

Fig. 12 HWFET capacity fade-time graph

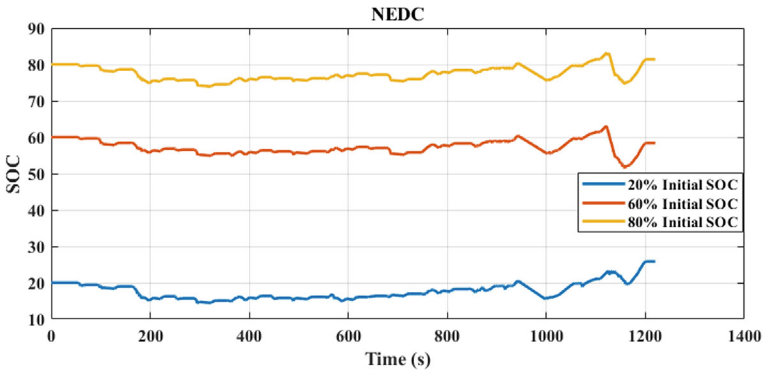

Fig. 13 HWFET fuel consumption-time graph

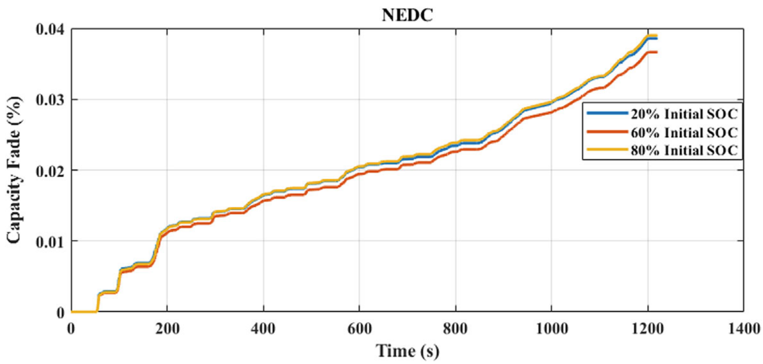

Fig. 14 NEDC SOC-Time graph

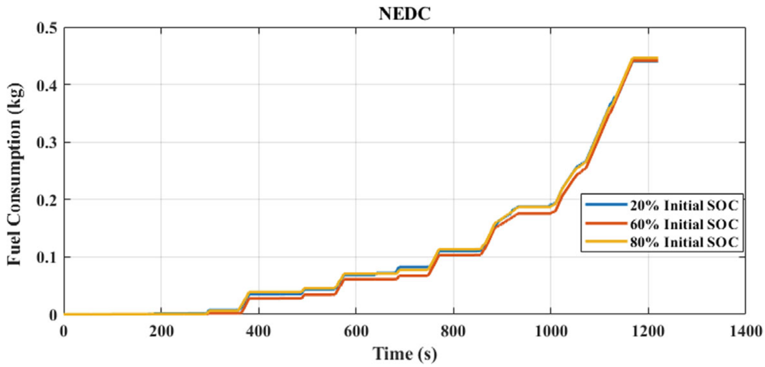

Fig. 15 NEDC fuel consumption-time graph

After ECMS is implemented and dataset is obtained. Two ANN controllers are designed to control ICE torque and speed. Capacity fade is used as one of the inputs for both controllers. Design of ANN controllers are explained in the next section.

4 Artificial Neural Network Based Controller Design

Matlab Neural Network Toolbox is used to design ANN controllers, torque request of the vehicle, SOC and capacity fade are the inputs of the controllers and the outputs are ICE torque and ICE speed. WLTP, HWFET and NEDC were run for three different initial SOC values. Number of data points for nine simulations is 11364. The dataset is divided as 70% for training, 15% for testing and 15% for validation. ANN settings are given below in Fig. 16.

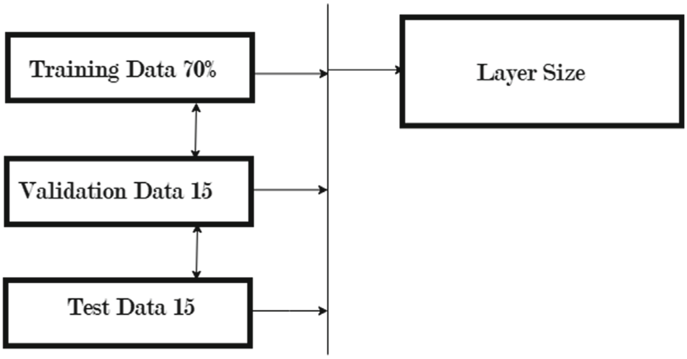

Fig. 16 ANN settings

Results of ANN controllers are given in the next section and compared with the results of ECMS for three drive cycles and three initial SOC scenarios.

5 Results and Discussion

Figures 17, 18 and 19 shows SOC profiles in WLTP for ECMS and ANN. As seen in these graphs, vehicle operates close to charge-sustaining mode when ANN controller is employed.

Figures 20, 21, 22, and 23 show capacity fade results of ANN and ECMS controllers for WLTP. Results show that capacity fade is reduced for all cases when ANN controller is employed.

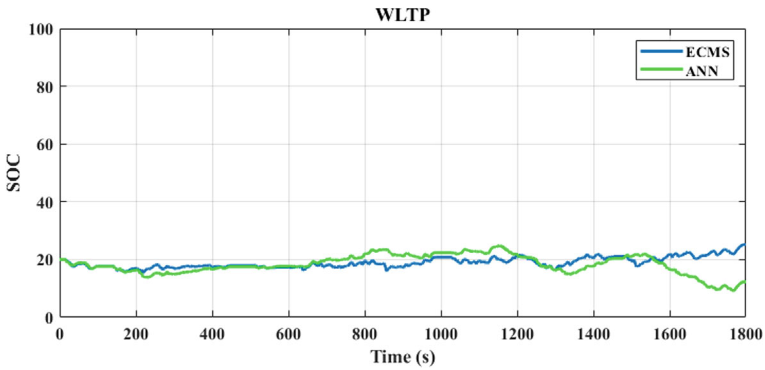

Fig. 17 SOC-Time graph for 20% Initial SOC in WLTP

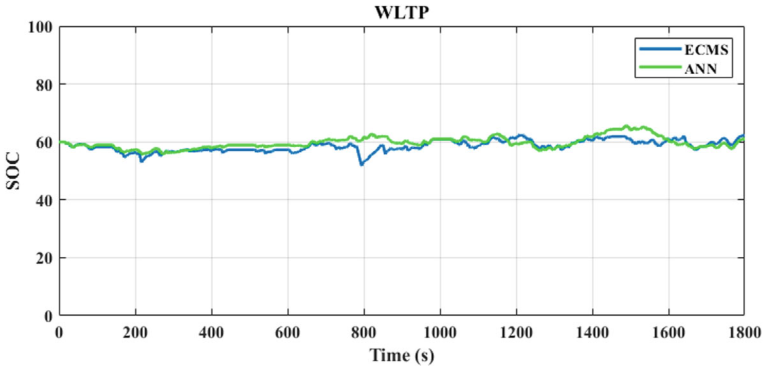

Fig. 18 SOC-Time graph for 60% Initial SOC in WLTP

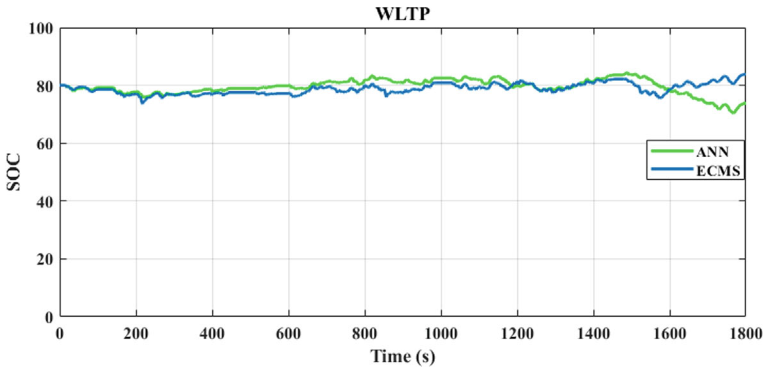

Fig. 19 SOC-Time graph for 80% Initial SOC in WLTP

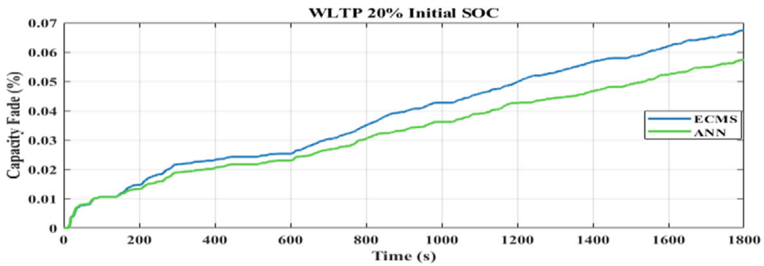

Fig. 20 Capacity fade results of ANN and ECMS controllers for WLTP

Figures 24 and 25 show fuel consumption results for WLTP. As seen in these results, fuel consumption is increased in just 80% initial SOC level. For other cases, fuel consumption is decreased slightly when ANN is used.

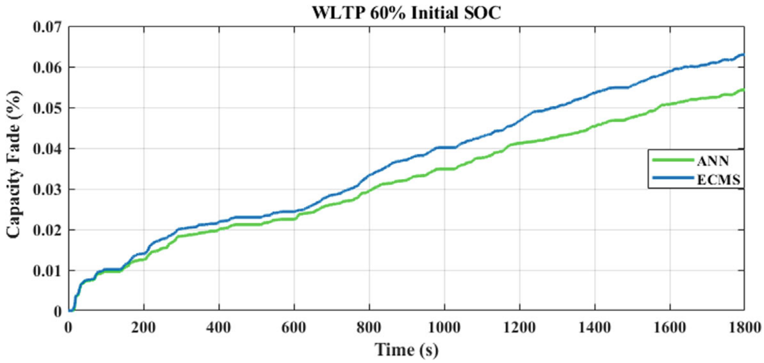

Fig. 21 Capacity fade-time graph for 20% Initial SOC in WLTP

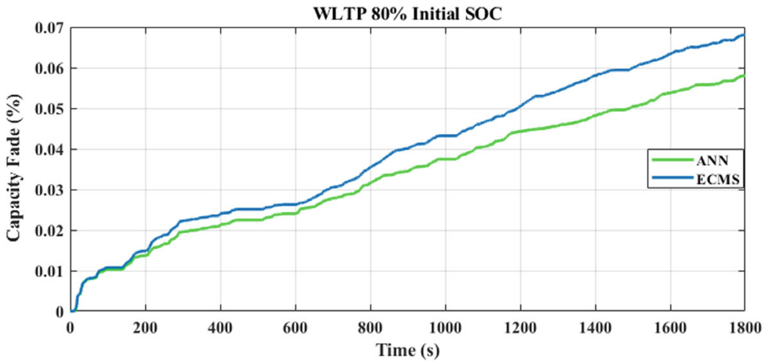

Fig. 22 Capacity fade-time graph for 60% Initial SOC in WLTP

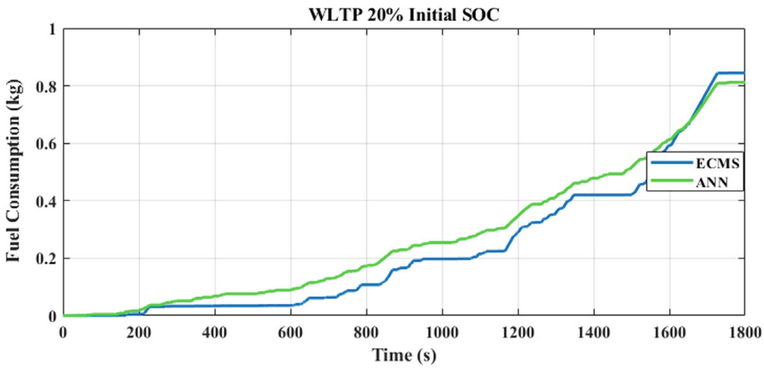

Fig. 23 Capacity fade-time graph for 80% Initial SOC in WLTP

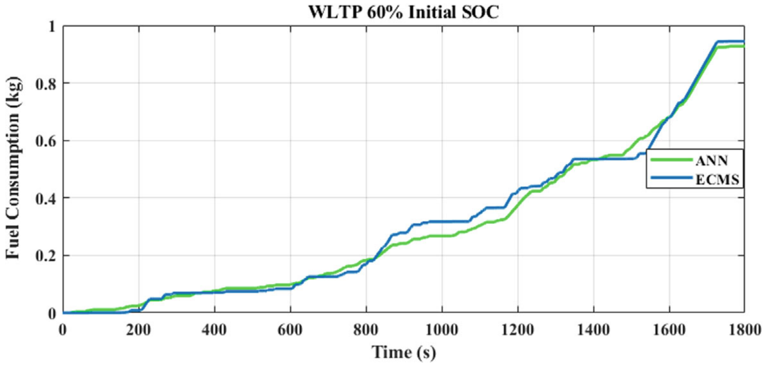

Fig. 24 Fuel consumption-Time graph for 20% Initial SOC in WLTP

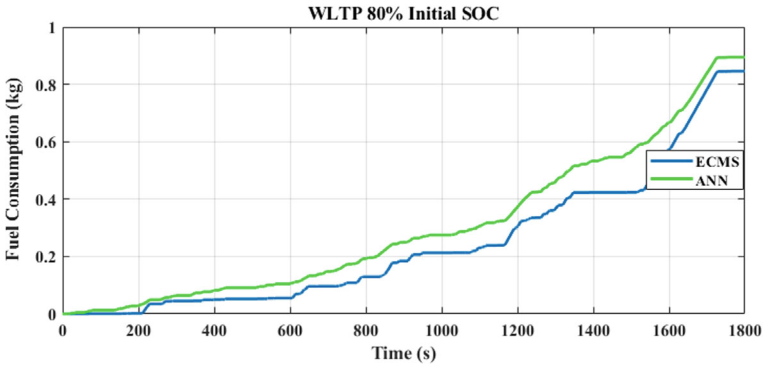

Fig. 25 Fuel consumption-Time graph for 60% Initial SOC in WLTP

Figures 26, 27 and 28 show the SOC results and Table 5 shows capacity fade and fuel consumption at the end of drive cycle.

Results for HWFET are given below in Figs. 26, 27 and 28 and Table 5.

Results for HWFET show that capacity fade is decreased in all cases while fuel consumption is increased in one case. As seen in Figs. 27, 28 and 29, the vehicle is operating in a charge depleting mode in HWFET, the only case that fuel consumption is increased is the initial SOC level of 20%. In this case, since the SOC level is low and vehicle is operating in a highway cycle, ICE must use more fuel to prevent total discharge of the battery, which results in an increase in fuel consumption. For intermediate and high SOC levels, the vehicle is depleting the battery, thus reducing the fuel consumption.

HWFET results show that for low SOC level, capacity fade is decreased as 39% and fuel consumption is increased as 7.9%. For medium SOC level, capacity fade is decreased as 20.5% and fuel consumption is decreased as 22.5% and for high

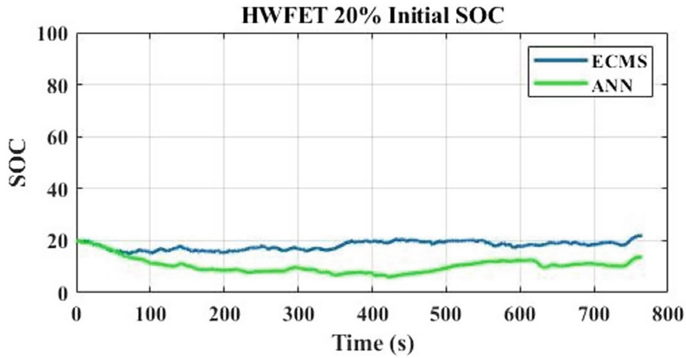

Fig. 26 SOC-Time graph for 20% Initial SOC in HWFET

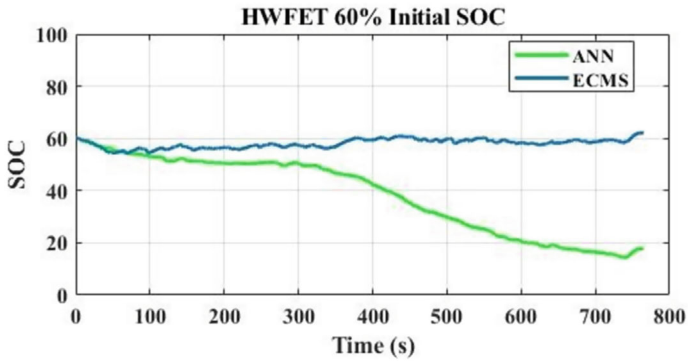

Fig. 27 SOC-Time graph for 60% Initial SOC in HWFET

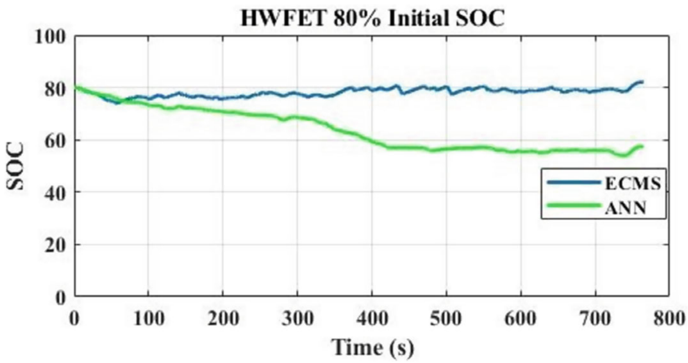

Fig. 28 SOC-Time graph for 80% Initial SOC in HWFET Table 5: HWFET results

Table 5 HWFET Results

HWFET	ECMS	ANN
Capacity Fade for 20% Initial SOC (%)	0.0509	0.0310
Capacity Fade for 60% Initial SOC (%)	0.0457	0.0363
Capacity Fade for 80% Initial SOC (%)	0.0490	0.0299
Fuel Consumption for 20% Initial SOC (kg)	0.5837	0.6303
Fuel Consumption for 60% Initial SOC (kg)	0.6839	0.5294
Fuel Consumption for 80% Initial SOC (kg)	0.6862	0.5732

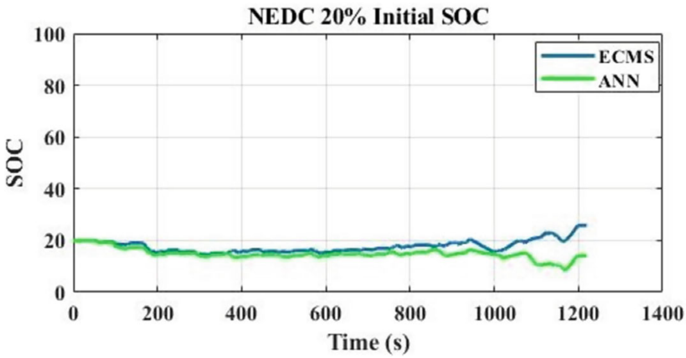

Fig. 29 SOC-Time graph for 20% Initial SOC in NEDC

SOC level, capacity fade is decreased as 38.9% and fuel consumption is decreased as 16.46%. Results for NEDC are given in Figs. 29, 30 and 31 and Table 6.

NEDC results show that capacity fade is decreased in all cases as well as fuel consumption. For low SOC level, capacity fade is decreased by 13.9% and fuel consumption is decreased by 11.73%. For medium SOC level, capacity fade is

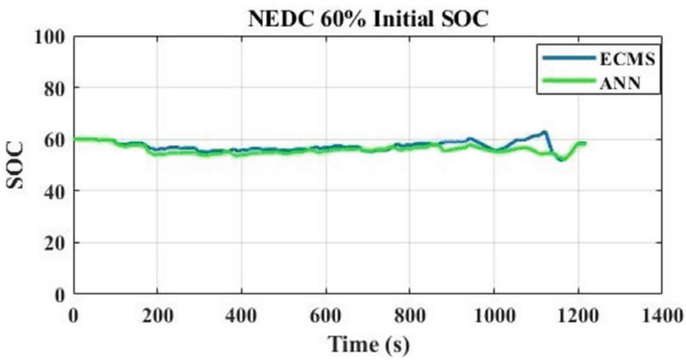

Fig. 30 SOC-Time graph for 60% Initial SOC in NEDC

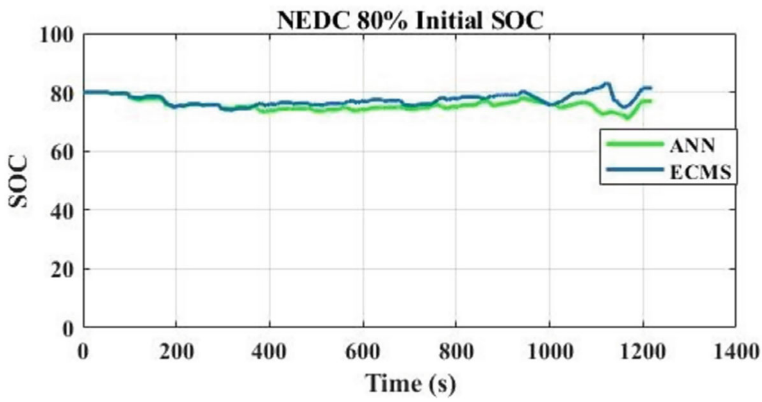

Fig. 31 SOC-Time graph for 80% Initial SOC in NEDC Table 6: NEDC results

Table 6 NEDC results

NEDC	ECMS	ANN
Capacity Fade for 20% Initial SOC (%)	0.0386	0.0332
Capacity Fade for 60% Initial SOC (%)	0.0366	0.0293
Capacity Fade for 80% Initial SOC (%)	0.0390	0.0336
Fuel Consumption for 20% Initial SOC (kg)	0.4406	0.3889
Fuel Consumption for 60% Initial SOC (kg)	0.4415	0.4052
Fuel Consumption for 80% Initial SOC (kg)	0.4462	0.3824

decreased by 19.94% and fuel consumption is decreased by 8.22%. For high SOC level, capacity fade is decreased by 13.84% and fuel consumption is decreased by 14.29% as shown in Table 6.

6 Conclusion

Three different speed profiles are selected and applied for three different initial SOC values. In total, nine different cases are investigated and results of ECMS and ANN are compared in terms of SOC, capacity fade and fuel consumption. SOC profiles are included in the results because SOC is one of the parameters in the capacity fade model. This is why results are evaluated for charge-sustainability, degradation and fuel consumption.

Results show that capacity fade of the battery is decreased in all cases when a control-oriented degradation model is used as an input for ANN controller [9]. Fuel consumption is only increased in two cases. This shows that the proposed ANN-based controller can reduce battery degradation and fuel consumption depending on the initial SOC level and drive cycle.

For further research, the dataset size will be increased by using more drive cycles and capacity fade will be investigated further by aging the battery through simulations. Battery degradation is a very complex phenomenon and ANN has proven to be useful for battery health management. Training ANN for the further aging conditions and investigating battery degradation will be the focus of further research [6].

Authors Contribution Alex Khang and Khushwant Singh: Contributed experiments, conceptualization and methodology. Khushwant Singh: Contributed Writing and Editing. Alex Khang: Contributed Writing – Review & Editing, and Supervision.

Declarations

Conflict of Interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this chapter.

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The Role of Sensors in Shaping Future Transportation Systems

Gobinath Arumugam, Rajeswari Packianathan, Anandan Malaiarasan, and Suresh Kumar Natarajan

Abstract Smart transportation systems represent a transformative approach to managing urban mobility, leveraging advanced technologies to enhance efficiency, safety, and sustainability. Central to these systems are various types of sensors, which gather real-time data critical for informed decision-making. This chapter explores the diverse applications of sensors within smart transportation, categorizing them into traffic, environmental, vehicle, and infrastructure sensors. It delves into how these sensors are utilized for traffic management and control, public transportation optimization, autonomous and connected vehicle functionality, environmental monitoring, and smart infrastructure management. The integration of Internet of Things (IoT) technology and sophisticated communication protocols such as 5G and Dedicated Short-Range Communications (DSRC) underpins the seamless operation of these systems. Despite the promising advancements, challenges such as sensor accuracy, data security, and privacy concerns persist, necessitating ongoing research and development. Future trends point towards further integration of artificial intelligence and machine learning to enhance predictive capabilities and decision-making processes. Through detailed case studies and real-world implementations, this chapter illustrates the practical benefits and lessons learned from deploying sensor technologies in various urban settings. By synthesizing current research and technological innovations, it provides a comprehensive overview of the critical role

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sensors play in realizing the vision of smart transportation. The chapter concludes with an outlook on future developments, emphasizing the continuous evolution and potential of sensor applications to revolutionize urban mobility.

Keywords Sensors · Future transportation systems · Intelligent traffic management · Autonomous vehicles · Predictive maintenance · Urban mobility · Real-time data collection · Environmental impact

1 Introduction

With transportation systems among the most transforming elements of everyday life, the fast development of technology has greatly affected many facets. Intelligent Transportation Systems (ITS) bring a paradigm change in our management and interaction with transportation systems [1]. ITS hopes to increase transportation system sustainability, safety, and efficiency by including cutting-edge technologies. The deployment and use of sensors is fundamental in this change as they significantly improve the functionality and efficiency of ITS [2].

1.1 Intelligent Transportation Systems' (ITS) Overview

Intelligent Transportation Systems (ITS) are a spectrum of applications and technology meant to enhance the running of transportation systems by means of data and communication technologies. Its integrated hardware, software, and communication technologies helps to control and maximize transportation infrastructure and services [3]. While improving consumers' whole travel experience, these technologies seek to solve important issues such traffic congestion, road safety, and environmental effect.

1.2 Its May Be Generally Separated into Various Parts

Traffic Management Systems: These systems concentrate on maximizing traffic flow, thus lowering congestion, and so enhancing the road network efficiency. Among these are real-time traffic monitoring, adaptive traffic signal regulation, and incident management systems.

Traveler information systems give passengers real-time data like public transit timetables, route recommendations, and traffic conditions. Among examples are mobile applications, GPS-based navigation systems, and dynamic message signs.

ITS usage in public transportation consist of automated fare collecting, passenger information systems, and real-time bus and rail tracking. Vehicle-to- Everything (V2X) communication is the information-exchanging between infrastructure, other road users, and automobiles to improve safety and efficiency. Vehicle-to- Vehicle-to-Pedestrian (V2P), Vehicle-to-Infrastructure (V2I), and Vehicle-to- V2V interactions comprise V2X communication.

These parts taken together form a complete ITS ecosystem meant to increase sustainability, safety, and transportation efficiency [4].

1.3 Sensors' Significance in Contemporary Transportation

ITS's ability to be functional depends on sensors, which also provide vital data and support real-time decision making. For intelligent systems, they are their eyes and ears; they compile data on user behavior, vehicle performance, and environmental conditions [5]. The following features of contemporary transportation help to emphasize the value of sensors:

- Sensors gather real-time data on several criteria including traffic flow, vehicle speed, road conditions, and environmental elements. Monitoring and running transportation networks, spotting trends, and rendering wise judgments all depend on this information.
- Sensors are essential in improving safety as they give accurate and timely information about possible threats. Advanced driving assistance systems (ADAS) for instance employ lidar and radar sensors to identify people, cars, and other objects, therefore lowering the chance of collisions.
- Sensors offer real-time data on traffic congestion, signal timings, and vehicle counts, therefore helping to maximize traffic flow. This data helps traffic management systems to control congestion, change signal timing, and raise general traffic efficiency.
- Development of autonomous cars mostly depends on sensors like lidar, radar, and cameras. These sensors let cars see their surroundings, make judgments, and negotiate safely free from human direction.
- Sensors in public transportation systems enable tracking of vehicle positions, counting of passengers, and scheduling management. This information raises public transportation operations' efficiency and improves the passenger experience.

Environmental sensors track elements including noise level and air quality. The environmental effect of transportation networks is evaluated using this data, which also helps to establish policies aiming at lower emissions and enhanced sustainability. ITS is mostly based on sensors, which help to gather and analyze data necessary for decision-making and improvement of transportation system performance.

1.4 Chapters' Goals and Chapter Scope

This chapter's main goal is to give a thorough picture of how sensors will shape next transportation systems. It seeks to investigate the several kinds of sensors ITS employs, their uses, and how they affect sustainability, safety, and transportation effectiveness. Future trends and developments in sensor technology will also be covered in the chapter together with the difficulties with sensor integration.

1.5 The Chapter's Focus Spans the Following Main Topics

Chapters will go over in great depth the several kinds of sensors utilized in ITS: radar, lidar, ultrasonic, infrared, cameras, environmental sensors, and so on. Every kind of sensor will be examined in terms of their usefulness, applicability, and support of intelligent transportation systems.

Applications of Sensors: The chapter will investigate in ITS traffic management, safety systems, autonomous cars, public transportation, and infrastructure monitoring the several uses of sensors. Case studies and real-world examples will help to show how these sensors may be practically implemented and how they might affect transportation networks.

The chapter will stress the main advantages of sensor integration in ITS—that is, better safety, more efficiency, and more sustainability. It will also cover data integration, pricing issues, and privacy concerns—among other sensor deployment obstacles.

1.6 Future Trends and Innovations

The chapter will address developments in sensor technologies including improvements in sensor capabilities, integration with Internet of Things (IoT) systems, and possible influence on next transportation systems.

By tackling these topics, the chapter will give readers a comprehensive knowledge of the function of sensors in ITS and their relevance in determining the direction of traffic. It will investigate the possibility for future developments in this exciting sector and provide insights on how sensors help to create smarter, safer, and more efficient transportation networks [6].

2 Types of Sensors Used in Intelligent Transportation Systems

Intelligent Transportation Systems (ITS) use a range of sensors to improve traffic management, safety, and the overall transportation experience. These sensors gather and interpret data that is critical for making real-time decisions and maximizing system efficiency. In this part, we will look at the many types of sensors widely used in ITS, including their capabilities, uses, and contributions to current transportation systems.

2.1 Radar Sensors

Radar sensors employ radio waves to determine the speed, distance, and direction of objects. They function by producing electromagnetic waves and evaluating the reflected waves from nearby objects. The time delay between emission and reception, together with the Doppler shift of the reflected waves, is used to calculate the object's distance and speed.

2.1.1 Applications

- Adaptive Cruise Control: Radar sensors keep a fixed distance between cars by altering speed based on traffic conditions. This feature is essential for current driver assistance systems.
- Collision Avoidance Systems: Radar sensors identify possible collisions with cars or barriers and inform the driver or automatically use the brakes to avoid an accident.
- Lane Departure Warning Systems: These sensors identify unintentional lane deviations and give alarms or remedial measures to avoid accidents.

2.1.2 Advantages

- Effective in a variety of weather situations, including fog, rain, and snow.
- Provides precise distance and speed readings.
- Reliable for long-range detection.

2.1.3 Limitations

Relatively low resolution compared to other sensor types, which may impair the ability to discern between closely placed objects.

2.2 Lidar Sensors

Lidar (Light Detection and Ranging) sensors generate high-resolution, three-dimensional maps of their surroundings using laser beams. Lidar sensors can accurately measure the distance of an item by measuring the time it takes for laser pulses to return after hitting it.

2.2.1 Applications

- Autonomous Cars: Lidar sensors allow autonomous cars to see their environment, recognize impediments, and maneuver safely.
- Object Detection and Recognition: Lidar offers comprehensive spatial information that may be used to detect and categorize items such as pedestrians, automobiles, and traffic signs.
- Mapping and Surveying: Lidar is used to create comprehensive maps of highways and infrastructure to aid in transportation planning and management duties.

2.2.2 Advantages

- High precision and accuracy in 3D mapping.
- Effective at discriminating between several things and their relative placements.
- Provides thorough environmental information.

2.2.3 Limitations

- Higher cost than other sensor kinds.
- Environmental variables like heavy rain or intense sunshine might have an impact on performance.

2.3 Ultrasonic Sensors

Ultrasonic sensors detect objects and measure distances using sound waves at higher frequencies than human hearing. They generate ultrasonic pulses and monitor how long it takes for the pulses to return after reflecting off an item.

2.3.1 Applications

- Parking Assistance: Ultrasonic sensors are often employed in parking systems to detect barriers and assist drivers in parking securely by alerting them to their proximity.
- Blind Spot Detection: These sensors identify cars or objects in a vehicle's blind areas, increasing safety during lane changes.
- Obstacle Detection: Ultrasonic sensors are employed in many safety systems to identify close objects and inform the driver.

2.3.2 Advantages

Cost-effective and reasonably cheap.

- Suitable for short-range detection and proximity sensing.
- Simple and straightforward to incorporate into numerous systems.

2.3.3 Limitations

- In comparison to radar and lidar sensors, they have a limited range.
- Environmental elements like rain and snow can have an impact on performance.

2.4 Infrared Sensors

Infrared sensors detect heat emissions from objects and turn them into electrical impulses. They can detect the presence and temperature of things by measuring their infrared radiation intensities.

2.4.1 Applications

- Night Vision Systems: Infrared sensors improve vision in low-light circumstances by detecting heat signatures from things like pedestrians and animals.
- Pedestrian Detection: These sensors identify pedestrians and inform drivers or self-driving systems to prevent crashes.
- Traffic Flow Monitoring: Infrared sensors detect heat patterns from car engines and exhaust systems to monitor traffic flow and vehicle occupancy.

2.4.2 Advantages

- Effective in low-light and nighttime environments.
- Can identify heat signals and distinguish between live and non-living items.

- Effective in detecting pedestrians and animals.

2.4.3 Limitations

- Limited efficacy for identifying things in intense sunlight.
- Weather conditions and other environmental elements might have an impact on performance.

2.5 Cameras

Cameras capture visual pictures and videos of the surroundings. They can be outfitted with a variety of technologies, including visible light, infrared, and thermal imaging, to collect various sorts of data.

2.5.1 Applications

- Traffic Surveillance: Cameras monitor traffic conditions, capture photographs of traffic offenses, and provide live feeds to traffic control centers.
- License Plate Recognition: Specialized cameras that use optical character recognition (OCR) technology can scan and record vehicle license plates for law enforcement and toll collection.
- Advanced Driver Assistance Systems (ADAS): Cameras provide visual data for lane departure alerts, traffic sign recognition, and adaptive cruise control.

2.5.2 Advantages

- Offers extensive visual information and high-resolution photos.
- Versatile and suitable for a variety of applications.
- Enables powerful image processing and machine learning methods.

2.5.3 Limitations

- Lighting, glare, and the weather may all have an impact on performance.
- Image analysis and interpretation need a large amount of computing power.

2.6 Accelerometers

Accelerometers measure acceleration forces on an item. They detect changes in velocity and direction, delivering information about the object's movement.

2.6.1 Applications

- Vehicle Stability Control: Accelerometers monitor and regulate vehicle stability by sensing rapid acceleration or deceleration.
- Airbag Deployment: When these sensors detect fast deceleration during a collision, they deploy the airbags.
- Collision Detection: Accelerometers detect collisions and collect data for impact analysis and crash detection systems.

2.6.2 Advantages

- Accurately measures acceleration and movement.
- Effective for detecting changes in vehicle dynamics and stability.
- Essential for a variety of safety and control systems.

2.6.3 Limitations

- Limited ability to provide information about the surrounding surroundings.
- Calibration and integration with additional sensors are required to ensure precise functioning.

2.7 Gyroscopes

Gyroscopes measure both angular velocity and direction. They detect rotations and changes in an object's orientation.

2.7.1 Applications

- Navigation Systems: Gyroscopes are used in navigation systems to measure vehicle orientation and movement, allowing GPS-based navigation.
- Stability Control: They contribute to vehicle stability and control by collecting data on rotational motions and detecting skidding or spinning.
- Inertial Measurement Units (IMUs): Gyroscopes are part of IMUs, which are used in autonomous cars and sophisticated driver assistance systems to monitor motion accurately.

2.7.2 Advantages

- Provides accurate measurements of rotational motions and orientation.
- Required for navigation and stability control systems.

- Works well with accelerometers to provide full motion sensing.

2.7.3 Limitations

- Long-term drift and calibration difficulties may have an impact on performance.
- Limited ability to provide environmental information.

2.8 Magnetometers

Magnetometers measure and detect changes in the Earth's magnetic field. They are used to assess orientation and identify magnetic abnormalities.

2.8.1 Applications

- Compass Functionality: Magnetometers measure the Earth's magnetic field and hence give compass capability to navigation devices.
- Vehicle Detection: They can detect the presence of automobiles at junctions or parking lots by recognizing magnetic field disruptions.
- Navigation and Orientation: Magnetometers contribute to navigation systems by supplying orientation data and assisting with heading computations.

2.8.2 Advantages

- Gives precise orientation and heading information.
- Suitable for navigation and location-based applications.
- Effective at detecting magnetic abnormalities and disturbances.

2.8.3 Limitations

- Local magnetic interference and ambient variables might have an impact on performance.
- Limited ability to provide information about the surrounding surroundings.

2.9 GPS Sensors

GPS (Global Positioning System) sensors use satellite signals to precisely locate an item. GPS sensors use signals from many satellites to compute latitude, longitude, and altitude.

2.9.1 Applications

- Navigation Systems: GPS sensors offer real-time position data to navigation systems, allowing drivers to identify the best routes and avoid traffic.
- Fleet Management: GPS sensors detect the whereabouts of vehicles in a fleet, allowing for route planning, scheduling, and monitoring.
- Autonomous Vehicles: GPS sensors enable autonomous cars by giving position data and aiding in course planning and navigation.

2.9.2 Advantages

- Provides precise and trustworthy location information.
- Required for navigation, tracking, and positioning applications.
- Works anywhere in the world as long as the sky is visible.

2.9.3 Limitations

- Signal blockage, such as that seen in tunnels or congested metropolitan environments, can have an impact on performance.
- For best accuracy, satellites must be within a clear line of sight.

2.9.4 Inductive Loop Sensors

Inductive loop sensors are wire loops placed in the road surface. When a vehicle travels over the loop, it causes a change in the magnetic field, which is sensed by the sensor.

2.9.5 Applications

- Traffic Signal Control: Inductive loop sensors detect cars at junctions and adjust traffic signals accordingly.
- Vehicle Counting: These sensors are used to count the number of cars that pass through the loop and monitor traffic flow.
- Parking Management: Inductive loop sensors detect vehicle presence and occupancy, assisting in the management of parking spots.

2.9.6 Advantages

- Vehicle detection and counting are both reliable and accurate.
- Simple installation and integration into roads.
- Effective for traffic signal and parking management.

2.9.7 Limitations

- Installing a road surface is necessary, which may be disruptive and expensive.
- Road wear and damage may have an impact on performance.

2.9.8 Piezoelectric Sensors

Piezoelectric sensors create electricity in reaction to mechanical stress or pressure. They measure pressure, acceleration, and strain.

2.9.9 Applications

- Weigh-in-Motion Systems: Piezoelectric sensors detect the weight and speed of cars as they pass over them, giving information for traffic control and road maintenance.
- Road Surface Monitoring: These sensors monitor changes in road surface conditions, such as cracks and deformation, and provide data for maintenance and repair.
- Structural Health Monitoring: Piezoelectric sensors are used to monitor the condition of transportation infrastructure, such as bridges and tunnels.

2.9.10 Advantages

- Accurately measures pressure, strain, and weight.
- Suitable for monitoring and maintaining road surfaces and infrastructure.
- Sensitive and responsive to mechanical changes.

2.9.11 Limitations

- Temperature variations and environmental variables can also have an impact.
- To ensure correct performance, calibration and appropriate installation are required.

2.9.12 Fiber Optic Sensors

Fiber optic sensors monitor environmental factors by transmitting light through optical fibers. Variations in light transmission are used to determine strain, temperature, and pressure.

2.9.13 Applications

- Structural Health Monitoring: Fiber optic sensors measure strain and deformation in bridges, tunnels, and other structures.
- Road Condition Monitoring: These sensors can evaluate road surface conditions and detect changes in temperature and pressure.

2.9.14 Environmental Monitoring

Fiber optic sensors assess environmental characteristics such as temperature and humidity in transportation infrastructure.

2.9.15 Advantages

- Excellent sensitivity and accuracy in sensing environmental changes.
- Resistant to electromagnetic interference and rust.
- Capable of measuring over extended distances with minimum signal loss.

2.9.16 Limitations

- Installation is costly and difficult.
- To analyze and understand data, specialist equipment is required.

2.9.17 Environmental Sensors

Environmental sensors assess a variety of atmospheric characteristics, including air quality, temperature, humidity, and noise levels. They give information on environmental conditions that may affect transportation networks.

2.9.18 Applications

- Air Quality Monitoring: Environmental sensors detect pollutants and particulate matter in the air, giving data for determining the influence of transportation on air quality.
- Weather Monitoring: These sensors monitor weather parameters such as temperature, humidity, and precipitation to aid traffic management and safety.
- Noise Monitoring: Environmental sensors detect noise levels in cities, allowing researchers to examine the influence of traffic on noise pollution.

2.9.19 Advantages

- Provides crucial information on environmental conditions and impacts.
- Promotes sustainability and public health initiatives.
- Useful for including environmental considerations into transportation planning.

2.9.20 Limitations

- Can be influenced by environmental factors such as weather and location.
- Maintenance and calibration are required on a regular basis to ensure accurate readings.

Sensors play an important role in the operation of Intelligent Transportation Systems (ITS), providing critical data for controlling and improving transport networks. Each sensor type has distinct functionality and uses, which contribute to the overall efficiency, safety, and sustainability of transportation systems. Understanding the various types of sensors and their responsibilities allows us to better appreciate the achievements in ITS and their influence on modern transportation.

3 Applications of Sensors in Intelligent Transportation Systems

Sensors are critical components of Intelligent Transportation Systems (ITS), allowing a wide range of applications to improve traffic management, safety, autonomous driving, fleet management, and infrastructure monitoring [7]. The following are brief summaries of the many applications of sensors in ITS as shown in Fig. 1.

3.1 Traffic Management

3.1.1 Real-Time Traffic Monitoring

Traffic conditions are monitored in real time using sensors such as cameras, radar, and inductive loops. They capture data on traffic flow, vehicle speed, and congestion levels, which are subsequently evaluated to offer real-time updates and effective traffic management [8].

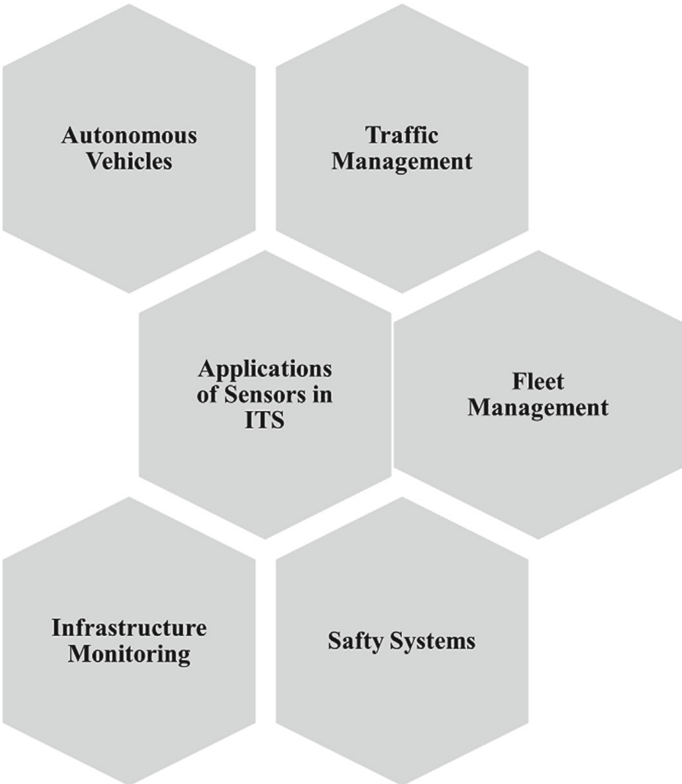

Fig. 1 Application of sensor in ITS

3.1.2 Traffic Signal Optimization

Inductive loop sensors and cameras at junctions monitor vehicle presence and flow, allowing traffic signal systems to dynamically modify timing. This helps to cut wait times, eliminate congestion, and enhance overall traffic flow.

3.1.3 Incident Detection and Management

Sensors identify accidents, halted cars, and road debris. Cameras, radar, and acoustic sensors can detect these incidents fast, sending notifications to traffic management centers for prompt response and resolution.

3.2 Safety Systems

3.2.1 Collision Avoidance

Radar, lidar, and camera sensors are all used in collision avoidance systems. They continually examine the vehicle's surroundings for possible problems. If a collision is near, the system can warn the driver or automatically use the brakes to avoid an accident [9].

3.2.2 Pedestrian and Cyclist Detection

Infrared and video sensors identify people and bicycles in close proximity to the car. These devices improve safety by alerting the motorist or taking preventative measures to avoid crashes, particularly in metropolitan areas.

3.2.3 Driver Assistance Systems (ADAS)

Advanced driver assistance systems rely on data from sensors like radar, lidar, and cameras. These systems include features such as lane departure alerts, adaptive cruise control, and automatic parking, all of which aim to improve driver safety and comfort.

3.3 Autonomous Vehicles

3.3.1 Navigation and Path Planning

GPS sensors, lidar, and cameras give exact position data and environmental mapping, allowing self-driving cars to navigate properly. They aid in the design of optimal pathways and real-time route changes.

3.3.2 Obstacle Detection and Avoidance

Lidar, radar, and ultrasonic sensors identify potential obstructions in the vehicle's route. Autonomous cars utilize this information to navigate safely, avoiding accidents with both static and moving objects.

3.3.3 Environmental Mapping

Lidar and camera sensors provide precise three-dimensional maps of the vehicle's surroundings. This geographical information is critical for autonomous cars to perceive and interpret their surroundings, resulting in safe and efficient operation.

3.4 Fleet Management

3.4.1 Vehicle Tracking

GPS sensors monitor the real-time position of each vehicle in a fleet. This data enables fleet managers to track vehicle movements, assure timely deliveries, and increase overall fleet efficiency.

3.4.2 Route Optimization

Data from GPS sensors and traffic monitoring systems are utilized to improve fleet vehicle routes. Route optimization lowers travel time, fuel consumption, and operating expenses while enhancing service delivery.

3.4.3 Maintenance Scheduling

Sensors monitor vehicle health and performance, identifying problems such as engine failure or wear and tear. This data enables proactive maintenance scheduling, decreasing downtime and prolonging the life of fleet vehicles.

3.5 Infrastructure Monitoring

3.5.1 Structural Health Monitoring

Fiber optic and piezoelectric sensors are used to monitor the structural integrity of bridges, tunnels, and other infrastructure. They detect stress, strain, and deformation, giving early warning of probable breakdowns while also guaranteeing structural integrity [10, 11].

3.5.2 Environmental Impact Assessment

Environmental sensors analyze air quality, noise levels, and other elements to determine how transportation systems affect the environment. This data contributes to efforts to reduce negative environmental impacts and encourage sustainable behaviors.

3.5.3 Road Condition Monitoring

Piezoelectric and inductive loop sensors monitor road surface characteristics for cracks, potholes, and deformations. This information aids in timely maintenance and repair, ensuring that cars travel safely and smoothly.

4 Key Advantages of Sensor Integration

The use of sensors in Intelligent Transportation Systems (ITS) has several advantages, including better safety, efficiency, mobility, and sustainability. These benefits are critical to the development of contemporary transportation networks [12].

4.1 Improved Safety

4.1.1 Collision Prevention

Sensors such as radar, lidar, and cameras identify potential dangers and barriers, allowing collision avoidance systems to inform drivers or perform automatic remedial measures. This drastically minimizes the chance of an accident.

4.1.2 Pedestrian and Cyclist Protection

Infrared and video sensors detect pedestrians and bicycles, improving urban safety by avoiding collisions and alerting vehicles to their presence.

4.1.3 Enhanced Driver Assistance

Advanced Driver Assistance Systems (ADAS) use sensor data to deliver features including lane departure alerts, adaptive cruise control, and automated emergency braking. These devices help drivers maintain safe driving behaviors.

4.2 Increased Efficiency

4.2.1 Optimized Traffic Flow

Real-time traffic monitoring and signal adjustment help to control congestion and enhance vehicle flow. Sensors collect data that enables traffic management systems to dynamically modify signal timings and alleviate bottlenecks.

4.2.2 Efficient Incident Management

Sensors identify accidents or breakdowns in real time, allowing traffic management centers to respond rapidly. This minimizes inconvenience and keeps traffic flowing smoothly.

4.2.3 Proactive Vehicle Maintenance

Sensors monitor vehicle health and performance, enabling predictive maintenance. This lowers downtime, increases vehicle life, and ensures that vehicles run smoothly.

4.3 Enhanced Mobility

4.3.1 Accurate Navigation

GPS sensors and environmental mapping technology allow for accurate navigation, assisting drivers and autonomous cars in finding the most efficient routes. This saves travel time and increases the dependability of transportation services.

4.3.2 Adaptive Route Planning

Sensor data from traffic monitoring systems helps with dynamic route planning and optimization. This guarantees that cars can react to changing traffic circumstances and choose the most efficient routes.

4.3.3 Seamless Fleet Management

Real-time tracking and monitoring of fleet vehicles enables improved coordination and dispatch. This enhances both service delivery and operational efficiency in commercial transportation.

4.4 Sustainability

4.4.1 Reduced Emissions

Optimized traffic flow and route design lead to lower fuel consumption and greenhouse gas emissions. Sensors help to promote sustainable mobility by reducing idling and stop-and-go traffic [13].

4.4.2 Environmental Monitoring

Sensors that evaluate air quality, noise levels, and other environmental parameters aid in the evaluation of transportation systems. This data contributes to efforts to reduce negative environmental impacts and encourage sustainable behaviors.

4.4.3 Resource Management

Sensor data enables efficient maintenance scheduling and resource allocation, which reduces waste and improves transportation infrastructure's sustainability.

4.5 Future Trends and Innovations

The evolution of sensor technology continues to shape the future of Intelligent Transportation Systems (ITS). Key trends and innovations include advancements in sensor technology, emerging applications in smart cities, integration with the Internet of Things (IoT), and the potential impact on future transportation systems.

4.6 Advancements in Sensor Technology

4.6.1 Increased Accuracy and Resolution

Future sensors will offer higher accuracy and resolution, enabling more precise detection and measurement of environmental and vehicular parameters. This will enhance the reliability of data used in traffic management and safety systems.

4.6.2 Miniaturization and Cost Reduction

Advancements in sensor design and manufacturing will lead to smaller, more affordable sensors. This will facilitate widespread adoption across various transportation applications, including in personal vehicles and public infrastructure.

4.6.3 Enhanced Durability and Reliability

Next-generation sensors will be more robust, with improved resistance to environmental factors such as extreme weather conditions, vibrations, and electromagnetic interference. This will ensure consistent performance and longevity in diverse transportation environments.

4.7 Emerging Applications in Smart Cities

4.7.1 Integrated Traffic Management

Smart cities will leverage advanced sensors to create integrated traffic management systems. These systems will use real-time data to optimize traffic flow, reduce congestion, and improve public transportation efficiency [14].

4.7.2 Smart Parking Solutions

Sensors will be used to develop smart parking systems that provide real-time information on parking availability. This will reduce the time drivers spend searching for parking spaces, leading to lower emissions and improved urban mobility.

4.7.3 Environmental Monitoring

Sensor networks in smart cities will monitor air quality, noise levels, and other environmental factors. This data will support initiatives aimed at reducing pollution and promoting sustainable urban living.

4.8 Integration with the Internet of Things (IoT)

4.8.1 Interconnected Transportation Networks

The integration of sensors with IoT will create interconnected transportation networks where vehicles, infrastructure, and devices communicate seamlessly. This will enhance data sharing and enable coordinated responses to traffic conditions and incidents.

4.8.2 Predictive Maintenance and Diagnostics

IoT-enabled sensors will provide continuous monitoring of vehicle and infrastructure health. Predictive analytics will identify potential issues before they become critical, allowing for timely maintenance and reducing downtime.

4.8.3 Enhanced User Experience

IoT integration will offer personalized services to commuters, such as real-time traffic updates, route suggestions, and automated toll payments. This will improve the overall user experience and convenience in transportation systems.

4.9 Potential Impact on Future Transportation Systems

4.9.1 Autonomous and Connected Vehicles

The advancements in sensor technology and IoT integration will accelerate the development and deployment of autonomous and connected vehicles. These vehicles will rely on sophisticated sensor networks to navigate, communicate, and operate safely in complex environments.

4.9.2 Sustainable and Efficient Transportation

Future transportation systems will prioritize sustainability through the use of sensors that optimize fuel consumption, reduce emissions, and promote the use of electric and hybrid vehicles. Smart infrastructure will support energy-efficient transportation modes and practices.

4.9.3 Enhanced Safety and Security

Improved sensors and data analytics will enhance the safety and security of transportation systems. Real-time monitoring and early warning systems will prevent accidents, manage emergencies, and ensure the safety of passengers and pedestrians.

4.9.4 Data-Driven Decision Making

The integration of advanced sensors and IoT will generate vast amounts of data, enabling data-driven decision making in transportation planning and management. This will lead to more informed policies, better resource allocation, and improved overall system performance.

The future of Intelligent Transportation Systems will be shaped by continuous advancements in sensor technology, innovative applications in smart cities, seamless integration with IoT, and a significant impact on the efficiency, safety, and sustainability of transportation systems.

5 Conclusion

Sensors in Intelligent Transportation Systems (ITS) are transforming modern transportation. Sensors improve traffic management, safety, autonomous driving, fleet management, and infrastructure monitoring by collecting and analyzing real-time data. Sensors are crucial to road safety. Collision avoidance, pedestrian and cyclist identification, and ADAS employ radar, lidar, cameras, and other sensors to prevent accidents and protect vulnerable road users. Traffic accidents are reduced by these measures, making roadways safer for everyone.

Real-time traffic sensor monitoring enables traffic signal optimization, incident management, and predictive vehicle maintenance. These features improve traffic flow, minimize congestion, and lower operational expenses. Sensors improve transportation efficiency for rising urban populations by reducing delays and enhancing vehicle performance. Accurate navigation and adaptive route planning require sensors. Routes are optimized using GPS sensors, environmental mapping technology, and real-time traffic data, saving drivers and autonomous cars time and enhancing transportation dependability.

Fleet management also benefits from real-time tracking and monitoring, leading to greater coordination, dispatch, and overall operational efficiency. Sensor-based ITS improve sustainability by lowering emissions through better traffic flow and route planning. Environmental sensors monitor air quality, noise levels, and other parameters, enabling communities to analyze and reduce the environmental impact of transportation systems. Efficient maintenance scheduling and resource management further contribute to the sustainability of transportation infrastructure, preserving its longevity and minimizing waste.

The future of ITS is optimistic, with developments in sensor technology opening the way for potential applications in smart cities and integration with the Internet of Things (IoT). These advances are projected to expand the capabilities of ITS, enabling new solutions for urban transportation, environmental monitoring, and infrastructure management. The ongoing advancement of sensor technology will have a tremendous influence on the future of transportation systems, encouraging innovation and increasing quality of life.

Real-world implementations of sensor-based ITS, such as those in Stockholm, Singapore, Los Angeles, London, and Copenhagen, highlight the real benefits of these technologies. These case studies illustrate effective techniques, lessons gained, and best practices that can guide future ITS installations. The favorable effects observed in these cities, including decreased traffic congestion, increased safety, greater mobility, and better environmental performance, underline the benefits of sensor integration in transportation systems.

In conclusion, sensors are crucial to the growth of ITS, giving major benefits that solve the urgent difficulties of modern transportation. By enhancing safety, efficiency, mobility, and sustainability, sensor-based ITS are altering the way we navigate our cities and operate our transportation networks. As technology continues to grow, the potential for further breakthroughs and improvements in ITS is tremendous, offering a future of smarter, safer, and more sustainable transportation.

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Analyzing Citizen Acceptance of AI-Driven Green Transportation: Mixed-Method Approach of Insights and Strategies for Enhancing Adoption

Sowmya Gopisetti, Rashmitha Sai Chidirala, Pallavi Lanke, and Madhu Babu Chunduri

Abstract Artificial Intelligence (AI) and automation hold significant promise for revolutionizing green transportation systems, offering solutions that can enhance efficiency, reduce emissions, and promote sustainable urban mobility. However, the success of these technologies hinges on user acceptance and engagement. Understanding user behavior and acceptance of AI-driven green transportation solutions is crucial for the successful implementation and adoption of these technologies. Despite advancements in AI and automation, there is limited research on how users perceive and engage with these systems. This study addresses this gap by examining the factors influencing user acceptance and behavior towards AI-powered green transportation. Utilizing a mixed-methods approach, the research will collect data through surveys, focus groups, and real-world usage analytics to identify key determinants of user trust, satisfaction, and adoption. The study will explore perceived safety, convenience, environmental impact, and cost-efficiency variables. Additionally, it will investigate demographic differences in acceptance levels and the role of effective communication in fostering user confidence in AI technologies. By understanding these dynamics, the research seeks to develop strategies that enhance user engagement and facilitate the widespread adoption of green transportation systems. The findings will provide valuable insights for policymakers, developers, and stakeholders to design user-centric AI solutions that are not only technologically advanced

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but also socially accepted and embraced, driving the transition towards sustainable urban mobility.

Keywords Artificial intelligence · Automation · User acceptance · Focus groups · Perceived safety · Demographic differences · User-centric AI solutions · Mixed-method approach

1 Introduction

Artificial Intelligence (AI) and Automation are important parts of transforming into green transportation systems. These advances improve proficiency and reduce global warming and carbon footprint. In spite of these advancements, the usage of AI-driven green transportation majorly depends on citizen acknowledgement and engagement. Without a careful understanding of citizen behavior and acknowledgement, the potential of these innovations may stay underutilized.

The primary objective of this research is to analyze the components that impact citizen acceptance and behavior towards AI-powered green transportation. By addressing the gap in existing research, this analysis aims to analyze factors affecting citizen acceptance so that, AI-driven green transportation solutions are seamlessly integrated into daily life, making them both accessible and beneficial for all. Exploring factors such as security, comfort, environmental aspects, and cost-efficiency. Investigating statistic contrasts in acceptance levels.

To accomplish these targets, this research utilizes a mixed-methods approach, which includes:

- Online Survey: To accumulate quantitative information on citizen behavior.
- Real-World Usage Analytics: To get a wider scenario on citizen behavior and perspective with AI-driven green transportation systems.
- Focus group: To gain qualitative insights into user experiences and expectations.

2 Literature Survey

The study aimed to understand factors influencing the acceptance of autonomous vehicles (AVs). The methodology involved designing and distributing a comprehensive online survey in English, Spanish, and Catalan to gather diverse respondent profiles. The survey addressed sociodemographic, travel patterns, driving profiles, safety perceptions, affinity for technology, and willingness to adopt AVs. It utilized a mix of binary, categorical, and Likert scale questions. Data from the survey were analyzed using confirmatory factor analysis and regression models to validate the scales and assess the influence of various factors on attitudes and willingness to adopt AVs [6].

The study compares user acceptance of integrated and retrofit driver assistance systems in real-traffic conditions, focusing on low-emission zones (LEZ) and school zones (SZ). The methodology involved 43 participants testing an integrated system with a dashboard HMI and 42 participants testing a retrofit system with an external screen HMI over eight weeks. Surveys assessed acceptance based on satisfaction, usefulness, usability, and workload. Results showed high overall acceptance, with integrated systems receiving higher satisfaction and usability ratings. The study highlights the need for improved HMI in retrofit systems for broader adoption by transport authorities [7].

The study investigates citizens' acceptance of autonomous buses in Norway, integrating perceived value theory, the unified theory of acceptance and use of technology (UTAUT2), and mental model theory. The methodology employs a qualitative case study approach, collecting data through in-depth interviews with residents along a new autonomous bus route in Bodø (Bodø is officially operating the northernmost autonomous shuttle bus route in the world). The process involved both inductive and deductive analysis to establish themes and validate findings. Reliability and validity were ensured through meticulous documentation, diverse literature review, and strategic informant selection [1].

3 Research Methodology

This research follows a methodology which is mixed method approach which includes online survey, focus groups and real-world sentimental analysis through web scraping. The combination of quantitative surveys and qualitative focus groups allows for a comprehensive understanding of user perceptions and behaviors [8].

3.1 Online Survey

This is the first method in the mixed-method approach. In which an online survey was conducted for quantitate analysis of user behavior towards AI-driven green transportation. The survey consisted of scale questions, multiple-choice questions, and open-ended questions to capture a range of user opinions. This survey was divided into three-sections namely, demographics, usage and experience, and environmental impacts. The survey was distributed online to a diverse sample of residents. Their responses were collected over a period of time as shown in Fig. 1.

The analysis of the responses reveals valuable information on, how demographics impact their acceptance and also how important it is for them to choose their priorities of transportation considering the environment. The results have shown that majority of them have given high priority to environment friendly transportations and are also willing to pay 10–30% more compared to traditional transportation options as shown in Fig. 2a, b, c.

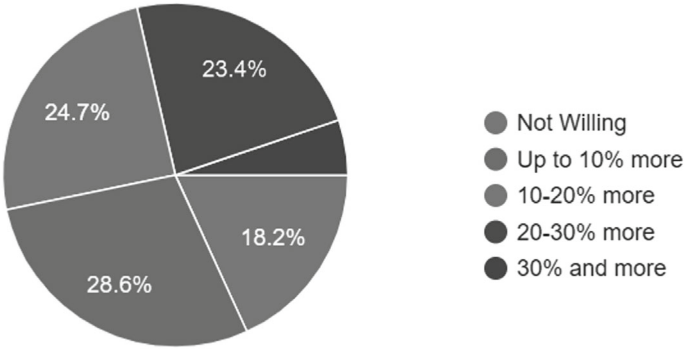


Fig. 1 Supports the above-presented statements

The key factors affecting user acceptance are identified by plotting a scatter plot between demographics such as age, income and educational levels against the overall acceptance. Collinearity is considered for final conclusions.

3.2 Focus Groups

To complement the survey data, focus groups were conducted to gain deeper qualitative insights into user perceptions and behaviors towards AI-driven transportation systems. The primary objective of this focus group study is to gain in-depth insights into user perspectives, attitudes, and concerns regarding AI-driven green transportation systems. Participants were selected based on diverse demographics such as age, gender, occupation, and familiarity with AI and green transportation, with 6–8 participants per group to ensure meaningful discussions. Each session lasts approximately 60–90 min.

A semi-structured discussion guide with open-ended questions covered topics like awareness, perceived benefits and drawbacks, trust and safety concerns, and factors influencing acceptance and willingness to use AI-driven green transportation. Sessions began with an introduction and ice-breaking activities to ensure participant comfort. The moderator followed, the guide while probing deeper into interesting points and ensuring all key topics were discussed. Findings were compiled into a comprehensive report, highlighting key themes, user sentiments, and actionable insights. This structured methodology aims to provide a thorough understanding of user perspectives, crucial for the successful adoption of AI-driven green transportation systems.

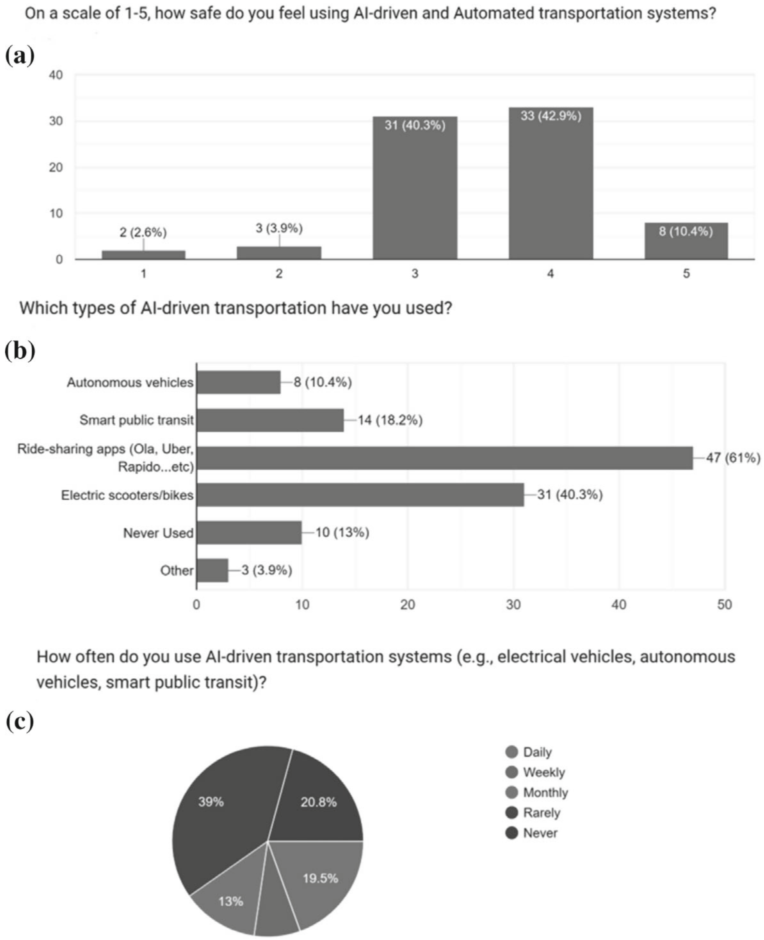


Fig. 2 **a** The survey results showing how safe AI driven transportation is perceived by the users. **b** The survey results show types of AI-driven transportation modes used. **c** The survey results show how often AI-driven transportations are opted by citizens

4 Real-World Usage Analytics

The Online survey and Focus group methods reach may be affected by the demographics of the author, so the next method is considered to overcome this, by analyzing real-world data. As a part of Real-World Usage Analytics, this research followed a methodology of scraping comments of a YouTube video titled “How green are Electric cars? |It’s complicated”. Sentimental analysis, engagement analysis and temporal trends analysis were done on scraped data, which provided valuable insights into real-world usage and citizen acceptance of AI-driven transportation and to reach a diverse audience and gather more information.

Once the data was collected, we conducted a basic overview to understand the general nature of the comments. This involved cleaning the data by removing duplicates, filtering out non-English comments, and eliminating any irrelevant or spammy content (Content created by bots, automated processes, or AI that's typically stuffed with keywords and lacks user value). A summary statistics analysis was performed to gain insights into the dataset's overall structure. Key metrics such as the total number of comments, average length of comments, distribution of likes and replies, and the frequency of comments over time were calculated.

To analyze the temporal distribution of comments, a graph was plotted displaying the frequency of comments over time. This helped in identifying patterns and trends in user engagement, such as peaks in activity that could correlate with specific events or releases of related content. The analysis also included examining the time of day and days of the week when comments were most frequently posted, providing insights into user behavior and engagement patterns [2].

Sentiment analysis was a critical component of this study. Using Libraries such as Text Blob which offers a simple API to calculate the sentiment of text, which returns a polarity score ranging from − 1 (very negative) to 1 (very positive), This assessed the sentiment of each comment, categorizing them as positive, negative, or neutral. This analysis helped in understanding the overall sentiment distribution and identifying any significant trends or outliers. This also visualized the sentiment scores to provide a clear representation of public opinion on the topic.

To further enrich the analysis, the research examined the correlation between the number of replies a comment received and its sentiment score. A scatter plot was generated to visualize this correlation, allowing us to observe any patterns or anomalies. This analysis provided insights into how the sentiment of a comment might influence user engagement and interaction.

The comprehensive approach of combining web scraping, summary statistics, temporal distribution analysis, sentiment analysis, and correlation analysis provided a robust methodology for understanding public opinion on electric cars' environmental impact. This methodology not only offered a detailed view of user sentiments and engagement but also highlighted the underlying themes and patterns in the discourse. By presenting these findings in a structured and visually appealing manner, this aimed to provide valuable insights into the public's perception of electric cars, contributing to the broader discussion on sustainable transportation and environmental impact. This multifaceted analysis methodology ensures that the research is thorough, data-driven, and capable of providing actionable insights for stakeholders interested in the topic.

5 Main Work Section

5.1 Online Survey

This survey aims to know the perspectives of citizens from various demographics on AI-driven transportation and green transportation. The results are organized based on different demographic factors as shown in Fig. 3a and b.

The highest number of respondents 37.7%, rated the influence of age as 4, suggesting a substantial effect. This is followed by 27.3% who rated it as 3, indicating a moderate effect. 18.2% believed age has a significant influence, rating it as 5. A smaller number of respondents, 9.1%, and 7.8%, rated the influence of age as 1 and 2 respectively, indicating minimal to moderate impact. This distribution shows that most respondents feel that age significantly affects their acceptance of AI-driven transportation, with a notable portion perceiving a strong influence as shown in Fig. 3 b.

Again, rrespondents rated this influence on a scale from 1 to 5, with 1 indicating minimal impact and 5 indicating a significant impact. The highest number of respondents 37.7%, rated the influence of age as 4, suggesting a substantial effect. This is followed by 27.3% who rated it as 3, indicating a moderate effect. 18.2% believed age has a significant influence, rating it as 5. A smaller number of respondents, 9.1%,

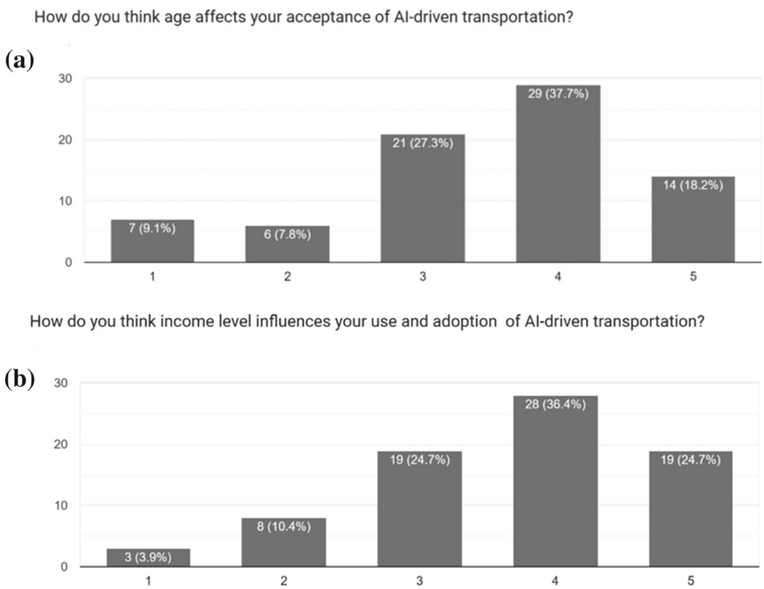


Fig. 3 **a** The survey results show how age and income level influence the adoption of Green Transportation. **b** The survey results show how income level influences the adoption of Green Transportation

and 7.8%, rated the influence of age as 1 and 2 respectively, indicating minimal to moderate impact. This distribution shows that most respondents feel that age significantly affects their acceptance of AI-driven transportation, with a notable portion perceiving a strong influence.

The second chart on the right assesses how income level influences the use and adoption of AI-driven transportation. Again, respondents rated this on a scale from 1 to 5. The highest number of respondents, 36.4%, rated the influence of income as 4, suggesting a strong effect. This is closely followed by 24.7% who rated it as 3 and 5, indicating moderate to strong influence. A smaller group, 10.4%, rated it as 2, and 3.9% rated it as 1, indicating minimal impact. This suggests that a significant majority believe that income level plays an important role in the adoption and usage of AI-driven transportation systems, with many seeing it as a strong determining factor.

In summary, the charts highlight that both age and income are perceived as influential factors in the acceptance and adoption of AI-driven transportation systems. Most respondents believe that these factors play a significant role, although there is some variation in the degree of influence perceived as shown in Fig. 4a, b.

The most significant source is social media, with 79.2% indicating it as their primary source. This is followed by word of mouth, used by 41.6%, and news

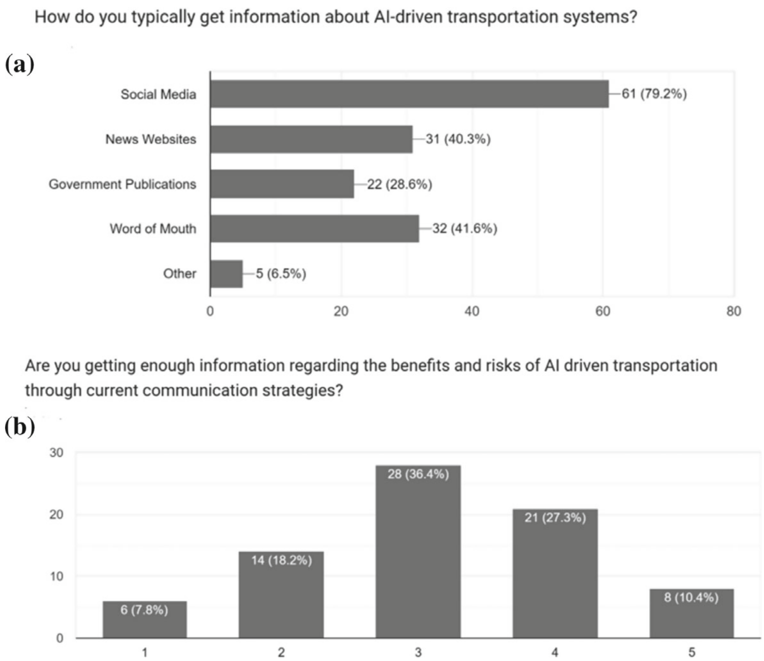


Fig. 4 **a** The survey results on sources of communication. **b** The survey results on the effectiveness of current communication strategies

websites, chosen by 40.3%. Government publications are a source for 28.6%, while a smaller segment, 6.5%, relies on other unspecified sources as shown in Fig. 4 b.

The responses are rated on a scale of 1–5, where 1 signifies strong dissatisfaction and 5 signifies strong satisfaction. The largest group, 36.4%, rated their satisfaction level as 3, indicating a neutral stance. 27.3% rated it as 4, suggesting they are somewhat satisfied. 18.2% rated it as 2, showing some dissatisfaction, while 8 respondents 10.4% gave the highest rating of 5, indicating they are very satisfied. Finally, 7.8% rated their satisfaction as 1, showing strong dissatisfaction.

The data suggests that while social media is the predominant source of information about AI-driven transportation, there is a mixed level of satisfaction with the current communication strategies about the benefits and risks associated with such systems. A notable portion of the respondents feel that there is room for improvement in how information is disseminated, as indicated by the varied satisfaction ratings.

5.2 *Focus Group*

Participants of the focus groups discussed their experiences, concerns, and expectations regarding these technologies. A significant theme that emerged was the perceived safety of AI-driven transportation. While many participants expressed a general sense of trust in established AI systems like ride-sharing apps, there were notable apprehensions about fully autonomous vehicles. Communication strategies were also a focal point of discussion, with participants indicating that current efforts to inform the public about the benefits and risks of AI-driven transportation are insufficient. They emphasized the need for more transparent and comprehensive information to build confidence and trust.

Additionally, participants highlighted the types of AI-driven transportation they frequently use, such as ride-sharing apps and electric scooters, and discussed barriers to adopting other technologies like autonomous vehicles. These focus groups provided rich, context-specific insights that helped to explain the quantitative survey findings, revealing the nuanced attitudes and behaviors that influence the adoption of AI-driven transportation systems.

In one of the sessions, participants highlighted several key challenges hindering the adoption of Electrical vehicles (EVs). A primary concern is the high cost of EV batteries, which typically last only up to eight years and can cost between Rs 5 lakh and Rs 5.5 lakh to replace, making them less appealing to cost-conscious consumers. Participants also expressed frustration with the early models of EVs, which often come with glitches that require expensive upgrades, costs that ultimately fall on the owner.

Range anxiety was another major issue discussed, with users noting the significant gap between promised and real-world mileage, especially when cars are fully loaded. This anxiety is compounded by the fact that electricity generation in the world relies on fossil fuels, and many charging stations are powered by diesel generators, which contradicts the eco-friendly promise of EVs.

Additionally, participants pointed out the lack of trained maintenance personnel and the higher costs of servicing and spare parts, along with the underdeveloped infrastructure for mechanical support and breakdown services. Finally, the varying temperatures across world were mentioned as a factor that adversely affects battery performance, further complicating the decision to adopt EVs. These insights from the focus groups underline the multifaceted barriers to EV adoption in the market.

6 Real-World Analytics

A histogram was plotted as Fig. 5 illustrating the distribution of sentiment polarity scores from YouTube comments. Sentiment polarity ranges from − 1 to 1, where − 1 indicates very negative sentiment, 1 indicates very positive sentiment, and 0 represents neutral sentiment. The x-axis of the graph displays this range, while the y-axis represents the number of comments falling into each sentiment polarity bin.

Upon examining the distribution, it becomes evident that the data is centered on 0, with a pronounced peak at this value. This concentration at the center suggests that the majority of the comments have a neutral sentiment, reflecting a general lack of strong feelings, either positive or negative, towards the topic of the YouTube video.

The histogram's distribution is roughly symmetrical around the center, although there is a slight skewness. This skewness indicates that while there are both positive and negative comments, these are less frequent compared to the neutral ones. The symmetrical nature, combined with the central peak, underscores that most viewers expressed neutral sentiments, implying that the content neither strongly resonated with nor strongly repelled the audience.

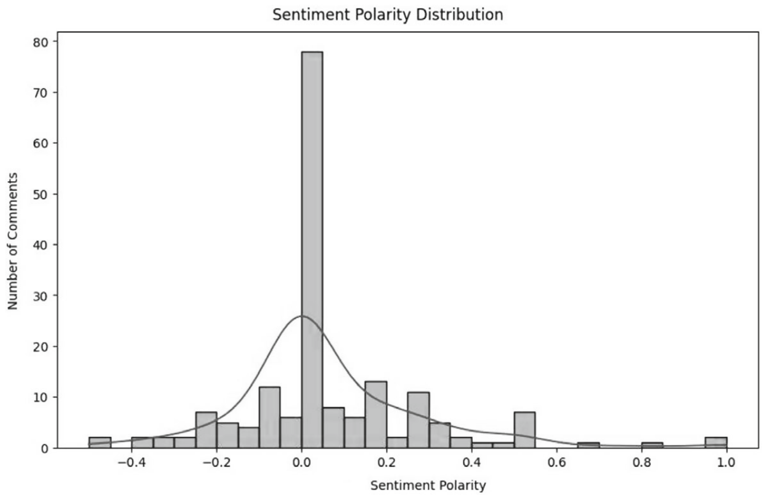


Fig. 5 The sentimental polarity of YouTube comments

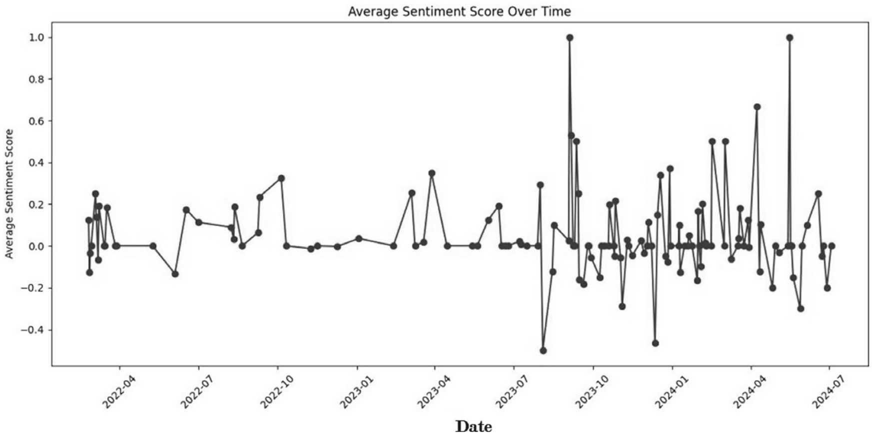


Fig. 6 The average Sentiment score over time

Furthermore, the distribution shows that there are some comments with extremely positive or negative sentiments, as evidenced by the tails extending towards both ends of the polarity spectrum. These tails, although less populated, are significant because they highlight the presence of viewers with strong opinions about the content. This spread of comments, ranging from very negative to very positive, indicates that while a large portion of the audience remained neutral, there were still notable fractions of viewers who felt strongly enough to express clear positive or negative sentiments. This balanced presence of varied sentiments implies that while the content did not provoke strong emotions in the majority, it did have a significant impact on a smaller segment of the audience.

In summary, this generally mild sentiment indicates that the video did not evoke strong opinions among most viewers, but it did elicit significant reactions from a smaller subset of the audience as shown in Fig. 6.

Analyzing the graph, it is evident that the average sentiment score fluctuates over the period observed, spanning from early 2022 to mid-2024. Initially, the sentiment scores appear to be relatively stable around the neutral mark, with minor fluctuations observed throughout 2022. This suggests that during this period, the audience's reactions were generally moderate, with no significant spikes indicating extreme positive or negative sentiments.

As we move into mid-2023, the graph starts to exhibit more pronounced fluctuations. There are several peaks and troughs, indicating periods where the sentiment of comments swung more significantly between positive and negative. For instance, around mid-2023, there is a noticeable spike where the average sentiment score rises sharply, suggesting a period of heightened positive reactions from the audience. Conversely, there are also sharp declines, particularly in the latter part of 2023 and early 2024, indicating times when the sentiment turned markedly negative.

The increased volatility in the sentiment scores during 2023 and 2024 could be attributed to various factors such as changes in content, significant events related to the video topic, or broader societal influences affecting viewer opinions. The presence of these fluctuations highlights the dynamic nature of audience engagement, where reactions can vary widely over time.

Towards the most recent data points in 2024, the sentiment scores continue to display variability, with several peaks and valleys. This ongoing fluctuation suggests that the content continues to evoke diverse reactions from the audience, without settling into a stable pattern of sentiment. The graph's overall trend does not indicate a clear upward or downward trajectory in sentiment, rather it portrays a complex picture of audience engagement characterized by periods of positive and negative reactions. This variability suggests that the content has consistently elicited a range of emotional responses, reflecting the diverse perspectives and reactions of the audience over the observed period as shown in Fig. 7a, b.

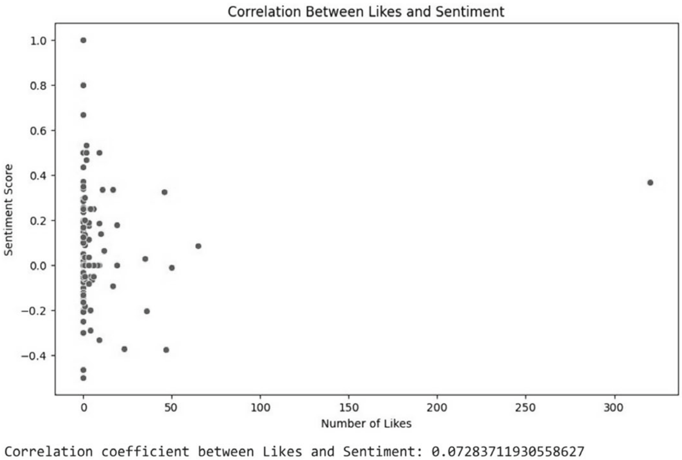
A correlation between likes and sentiment and reply count and sentiment. In the first graph, the x-axis represents the sentiment score and the y-axis represents the Number of Likes. In the second graph, the x-axis represents the sentiment score and the y-axis represents the Number of Replies.

A correlation coefficient close to zero suggests there is little to no linear relationship between the variables. For Likes and Sentiment, a coefficient of 0.0728 implies that the number of Likes on comments does not strongly correlate with the sentiment (positive or negative) of those comments. Similarly, the coefficient of 0.0495 between Replies and sentiment indicates that the number of replies on comments does not correlate with the sentiment (positive or negative) of those comments.

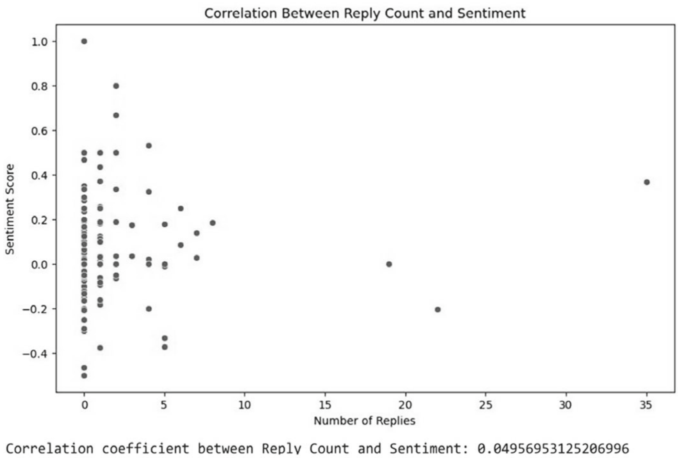
Both coefficients are positive, which means there is a weak positive correlation in both cases. For the Likes and Sentiment relationship, the positive sign (+ 0.0728) suggests that as the number of Likes increases, there is a slight tendency for the sentiment to also be slightly positive. However, the strength of this relationship is minimal, meaning it is not a reliable indicator of sentiment. For Replies and sentiment, the positive sign (+ 0.0495) similarly suggests a there is a slight tendency for the sentiment to also be slightly positive as the number of Replies increases. Again, this relationship is very weak and not significant.

The content of the comment, the relevance of the comment to the topic, the visibility of the comment, and the engagement of the community are all likely to play a much more significant role in determining the number of Likes and replies a comment receives than the sentiment. Additionally, external factors such as the time of posting and the overall activity level of the platform at the time can also influence these metrics.

In practical terms, a correlation coefficient of 0.0728 for Likes and Sentiment and a correlation coefficient of 0.0495 for Replies and sentiment suggests that while there may be a slight tendency for positive sentiment to attract slightly more Likes and Replies, this relationship is too weak to be meaningful for making predictions or drawing strong conclusions [5].



(a)



(b)

Fig. 7 **a** The correlation between likes and sentiment. **b** The correlation between reply count and sentiment

7 Conclusion

This research highlights the crucial factors influencing user acceptance and engagement with AI-powered green transportation solutions. The mixed-methods approach, incorporating surveys, focus groups, and real-world analytics, provided comprehensive insights into user perspectives and behaviors.

The survey results revealed that demographic factors such as age and income significantly impact the adoption of AI-driven transportation systems. A substantial proportion of respondents believed these factors played a crucial role, with age and income levels affecting user acceptance and usage patterns. Moreover, the survey indicated that social media is the predominant source of information about AI-driven transportation, yet satisfaction with current communication strategies remains mixed. This underscores the need for improved and transparent communication to enhance public understanding and trust in these technologies [4].

Focus group discussions further emphasized the importance of perceived safety, cost-efficiency, and environmental impact in shaping user attitudes. Participants expressed trust in established AI systems but showed apprehension towards fully autonomous vehicles. The high cost of EV batteries range anxiety, and insufficient infrastructure for maintenance were identified as significant barriers to adopting electric vehicles. These discussions revealed the nuanced concerns and expectations of users, providing a deeper understanding of the factors influencing their acceptance and adoption behaviors.

Real-world analytics, specifically sentiment analysis of YouTube comments, demonstrated a generally neutral sentiment towards AI-driven transportation, with occasional spikes in positive or negative reactions. The correlation analysis showed a weak positive relationship between sentiment and both likes and replies, suggesting that other factors, such as content relevance and visibility, play a more significant role in user engagement [3].

Overall, the findings indicate that while AI-powered green transportation solutions hold promise for sustainable urban mobility, their successful implementation and widespread adoption depend on addressing user concerns and enhancing communication strategies. Policymakers, developers, and stakeholders must prioritize user-centric design and transparent communication to build trust and confidence in these technologies. By understanding and addressing the diverse factors influencing user acceptance, this research provides valuable insights for developing effective strategies to promote the adoption of AI-driven green transportation systems, ultimately contributing to the transition towards sustainable urban mobility.

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Green Transportation and Moral Licensing: Navigating Ethical Challenges with Artificial Intelligence (AI) and Automation

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Abstract The integration of artificial intelligence (AI) and automation into green transportation systems holds significant promise for advancing sustainable mobility solutions. However, these efforts are facing ethical challenges associated with moral licensing that can result in undoing the initiatives. This chapter relates travel behavior associated with green transportation initiatives to the psychological effect of moral licensing whereby people justify socially detrimental behaviors because of their engagement in sustainable practices. In that regard, we introduce moral licensing and its relation and effect on green transportation. Secondly, we will be discussing how AI and automation can be both painkillers and pain points for such ethical dilemmas. We borrow lessons from case studies and empirical research to capture how moral licensing affects policy implementation, consumer behavior, and technological adoption in relation to green transportation. Finally, ways of leveraging AI and automation in building robust and ethical frameworks to help make true sustainability a reality are presented. In this respect, this chapter aims to contribute to the process of evolving a more holistic and pragmatic mode of transportation ensuring that green transportation systems drive forward under the thrust of advanced technologies without the drag of moral licensing.

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1 Introduction

1.1 Overview of Green Transportation Systems

Green transportation systems, also known as sustainable transportation, refer to modes of transport and infrastructure that have a low environmental impact and promote energy efficiency. These systems aim to reduce greenhouse gas emissions, minimize pollution, and promote the use of renewable energy sources. Here are key components and benefits of green transportation systems:

1.1.1 Public Transportation

Public transportation, such as buses, trains, and subways, is a cornerstone of green transportation. It reduces the number of individual vehicles on the road, thus decreasing overall emissions. Modern public transport systems are increasingly powered by electricity, often sourced from renewable energy, which further minimizes their carbon footprint (Givoni and Banister 2013).

1.1.2 Electric and Hybrid Vehicles

Electric vehicles (EVs) and hybrid vehicles are pivotal in the shift towards green transportation. EVs produce zero tailpipe emissions, significantly lowering urban air pollution and greenhouse gas emissions compared to conventional internal combustion engine vehicles. The adoption of hybrid vehicles, which combine an internal combustion engine with an electric motor, also contributes to fuel efficiency and reduced emissions [47].

1.1.3 Active Transportation

Active transportation includes non-motorized forms of transport, such as walking and cycling. These modes not only reduce emissions but also offer significant health benefits by promoting physical activity. Cities are increasingly investing in infrastructure to support active transportation, such as bike lanes and pedestrian-friendly urban designs [43].

1.1.4 Sustainable Urban Planning

Urban planning plays a critical role in promoting green transportation. Sustainable urban planning involves designing cities to reduce the need for long-distance travel and encourage the use of public and active transportation. This includes mixed-use developments, transit-oriented developments, and green spaces [38].

1.2 Renewable Energy Integration

Integrating renewable energy sources into transportation infrastructure is essential for sustainable mobility. This includes the use of solar, wind, and other renewable energies to power public transportation systems and EV charging stations. Such integration reduces reliance on fossil fuels and supports the transition to a more sustainable energy system [41].

Green transportation systems are integral to reducing environmental impacts and promoting sustainable mobility. Through public transportation, electric and hybrid vehicles, active transportation, sustainable urban planning, and the integration of renewable energy, these systems offer a comprehensive approach to achieving environmental and health benefits.

1.3 Role of AI and Automation in Sustainable Mobility

Artificial intelligence (AI) and automation are transforming the landscape of sustainable mobility by enhancing efficiency, reducing emissions, and improving the overall transportation experience. These technologies contribute to sustainable transportation systems in several ways:

1.3.1 Intelligent Transportation Systems (ITS)

AI-driven intelligent transportation systems optimize traffic management and reduce congestion. These systems use real-time data analytics to monitor traffic flow, predict congestion, and adjust traffic signals dynamically, leading to smoother traffic patterns and reduced vehicle emissions (Zhang 2019).

1.3.2 Autonomous Vehicles

Autonomous vehicles (AVs) are at the forefront of AI applications in transportation. By using AI for navigation, sensing, and decision-making, AVs can operate with greater precision and safety than human-driven vehicles. This leads to reduced accidents, optimized fuel efficiency, and lower emissions. AVs are particularly beneficial in creating more efficient public transportation systems and shared mobility services [31].

1.3.3 Predictive Maintenance

AI-powered predictive maintenance uses data from sensors on vehicles and infrastructure to predict and address maintenance needs before they become critical issues. This not only extends the lifespan of transportation assets but also ensures that vehicles operate at optimal efficiency, reducing energy consumption and emissions [16].

1.3.4 Route Optimization and Shared Mobility

AI algorithms enhance route optimization for both individual and public transportation. For instance, AI can calculate the most efficient routes for buses and trains, taking into account real-time traffic conditions and passenger demand. Additionally, AI enables the effective management of shared mobility services, such as ride-sharing and bike-sharing, by optimizing the allocation and distribution of resources [51].

1.3.5 Energy Management

AI and automation play a crucial role in the management of energy resources for transportation. AI can optimize the charging and discharging cycles of electric vehicle (EV) batteries, reducing energy costs and ensuring the availability of renewable energy sources. Furthermore, AI can manage the integration of renewable energy into transportation systems, balancing supply and demand to minimize environmental impact [52].

AI and automation significantly enhance sustainable mobility by optimizing traffic management, enabling autonomous vehicles, predicting maintenance needs, optimizing routes, and managing energy resources. These technologies are essential in creating efficient, safe, and environmentally friendly transportation systems.

1.4 Purpose and Scope

1.4.1 Objectives of the Chapter

The chapter "Green Transportation and Moral Licensing: Navigating Ethical Challenges with AI and Automation" aims to achieve the following objectives:

- Provide a Comprehensive Overview of Green Transportation Systems: Explain the various components and benefits of green transportation systems, including public transportation, electric and hybrid vehicles, active transportation, sustainable urban planning, and renewable energy integration.
- Explore the Concept of Moral Licensing: Define and explain the concept of moral licensing, its historical and psychological underpinnings, and its relevance to sustainable practices, particularly in the context of transportation behavior.
- Analyze the Role of AI and Automation in Sustainable Mobility: Discuss advancements in AI and automation technologies and their potential benefits for green transportation. Examine the ethical dilemmas and challenges associated with the implementation of these technologies, particularly how they may exacerbate moral licensing.
- Present Case Studies and Empirical Research: Provide detailed case studies to illustrate the effects of moral licensing in green transportation. Analyze the impact of policy implementation, consumer behavior, and technological adoption on moral licensing and sustainable outcomes.

1.4.2 Propose Strategies to Address Moral Licensing in Green Transportation

Develop frameworks for ethical AI and automation, including guidelines and best practices. Recommend policy interventions to mitigate moral licensing and promote responsible consumer behavior. Offer strategies to leverage AI and automation for achieving true sustainability in transportation.

1.4.3 Summarize Key Points and Identify Future Directions

Recap the relationship between moral licensing, AI, and green transportation. Highlight the importance of addressing ethical challenges and outline areas for further research. Present a long-term vision for sustainable transportation incorporating AI and automation.

2 Understanding Moral Licensing in the Context of Green Transportation

2.1 Definition and Conceptual Framework

Moral licensing is a psychological phenomenon where individuals permit themselves to engage in behaviors that are considered immoral, unethical, or less virtuous after having performed an action that is morally positive. Essentially, it is the mental balancing act where a good deed is perceived as granting permission to act in a less commendable manner subsequently. This behavior stems from the need to maintain a self-image as a moral person.

Conceptual Framework of Moral Licensing, the conceptual framework of moral licensing is rooted in theories of self-regulation and cognitive dissonance. Key components of this framework include:

2.1.1 Moral Credentialing

This occurs when a person believes that their past moral behavior provides them with a license to act immorally without fear of damaging their self-image. For example, someone who donates to charity might feel justified in indulging in a selfish behavior later on [36].

2.1.2 Moral Credits

This concept likens moral actions to a ledger, where good deeds add credits that can offset future unethical actions. It posits that individuals keep a mental account of their behaviors, balancing positive and negative actions [39].

2.1.3 Self-Perception Theory

According to this theory, individuals infer their own values and beliefs by observing their actions. Thus, after performing a good deed, they might feel more confident in their moral standing and, consequently, more licensed to perform a questionable action [3].

2.1.4 Cognitive Dissonance

Moral licensing can help reduce the discomfort (dissonance) that arises when one's actions are inconsistent with their self-image. By licensing themselves to act unethically after a good deed, individuals reconcile their behavior with their self-perception [12].

2.2 Historical and Psychological Underpinnings of Moral Licensing

2.2.1 Historical Underpinnings

The concept of moral licensing has roots in historical theories of moral behavior and self-regulation. Over the years, scholars have explored how people balance their actions to maintain a positive self-concept.

Moral Balance and Equilibrium

The idea of moral balance dates back to ancient philosophical and religious teachings, where individuals were encouraged to maintain a balance between their virtuous and less virtuous actions. This equilibrium was believed to contribute to overall moral integrity.

In more recent history, behavioral scientists began to systematically study how people manage their moral and immoral actions to preserve a coherent self-image. This led to the development of the moral licensing theory.

Economic Models of Behavior

Early economic models, such as those proposed by Jeremy Bentham and John Stuart Mill, likened moral decision-making to a cost–benefit analysis. People were seen as rational actors who weighed the benefits of moral actions against the costs of immoral ones.

These models laid the groundwork for understanding how individuals might accumulate "moral credits" through good deeds, which they could then "spend" on less virtuous actions without feeling guilty [4].

2.2.2 Psychological Underpinnings

The psychological mechanisms underlying moral licensing are complex and multifaceted, involving cognitive processes, self-perception, and social influences.

Self-Perception Theory

Developed by Daryl Bem in the 1970s, self-perception theory posits that individuals infer their own attitudes and beliefs by observing their behavior. When someone performs a good deed, they perceive themselves as a moral person, which can then justify subsequent unethical behavior [3].

Cognitive Dissonance

Leon Festinger's theory of cognitive dissonance explains the discomfort people feel when their actions are inconsistent with their self-image. Moral licensing can be seen as a way to reduce this dissonance by allowing individuals to rationalize their less virtuous actions after performing a good deed [12].

Moral Credentialing and Credits

Moral credentialing occurs when individuals use their past good deeds as evidence of their morality, which gives them a perceived license to act less ethically in the future. This is closely related to the concept of moral credits, where people maintain a mental ledger of their moral and immoral actions [36].

Social and Cultural Influences

The social context in which actions are performed can influence moral licensing. Cultural norms and societal expectations play a significant role in shaping what behaviors are considered moral or immoral, and thus, how licensing is manifested.

For instance, in collectivist cultures, where group harmony and collective well-being are emphasized, moral licensing might manifest differently compared to individualist cultures, where personal achievement and autonomy are prioritized [33].

Situational Factors

The specific context in which moral actions and subsequent behaviors occur can greatly affect moral licensing. Situational factors such as the visibility of actions to others, the perceived importance of the moral act, and immediate versus delayed consequences all play a role in this psychological process [44].

Understanding the historical and psychological underpinnings of moral licensing is essential for addressing the ethical challenges it presents, particularly in the context of green transportation and sustainable practices. These insights help explain why individuals may engage in less virtuous behaviors following morally positive actions and provide a foundation for developing strategies to mitigate such effects.

2.3 Relevance to Green Transportation: How Moral Licensing Manifests in Sustainable Practices

Moral licensing can significantly impact the effectiveness and adoption of green transportation initiatives. Understanding how this psychological phenomenon manifests in sustainable practices is crucial for developing strategies to mitigate its effects. Here are some key ways moral licensing affects green transportation:

2.3.1 Overcompensation with High-Emission Activities

Individuals who adopt green transportation methods, such as cycling or using public transport, may feel justified in engaging in high-emission activities later. For instance, someone might drive a fuel-inefficient vehicle for a long trip, rationalizing it by their regular use of a bicycle for commuting [9].

2.3.2 Reduction in Overall Effort Towards Sustainability

After making a single green choice, such as purchasing an electric vehicle, individuals might reduce their overall efforts towards sustainability. This can manifest as neglecting other environmentally friendly practices, such as reducing energy consumption at home or recycling, due to a perceived moral balance [34].

2.3.3 Increased Consumption

The adoption of sustainable transportation methods can lead to an increase in consumption in other areas. For example, someone who uses public transportation might justify frequent air travel, a high-emission activity, as a reward for their daily green commuting choices [21].

2.3.4 Perceived Moral Credits

Individuals might accumulate "moral credits" through consistent use of green transportation, which they then "spend" on environmentally detrimental behaviors. This concept is particularly relevant in behaviors like upgrading to a larger, less efficient home or purchasing non-essential goods with high environmental costs [44].

2.3.5 Reduced Advocacy for Broader Policy Changes

Individuals who practice sustainable transportation might feel less compelled to advocate for broader systemic changes or policies. This is because they perceive their personal actions as sufficiently impactful, leading to complacency in supporting larger-scale environmental initiatives [50].

Moral licensing can undermine the goals of green transportation by encouraging compensatory behaviors that offset the environmental benefits of sustainable practices. Recognizing and addressing these manifestations is essential for maximizing the positive impact of green transportation initiatives and fostering a truly sustainable lifestyle.

2.3.6 Examples of Moral Licensing in Transportation Behavior

Moral licensing in transportation behavior can manifest in various ways, often undermining the positive impacts of sustainable practices. Here are some specific examples:

Example 1: Driving More After Using Public Transport

Individuals who regularly use public transportation might feel justified in driving more frequently on weekends or for long trips, believing that their daily use of greener transport options offsets occasional use of a personal vehicle. This compensatory behavior can diminish the overall environmental benefits of using public transport [9].

Example 2: Increased Air Travel After Buying an Electric Vehicle

After purchasing an electric vehicle (EV), some individuals may feel morally licensed to engage in high-emission activities such as frequent flying. The significant reduction in their carbon footprint from driving an EV might lead them to overlook the environmental impact of increased air travel [34].

Example 3: Using Green Credentials to Justify Other Non-Green Purchases

Consumers who invest in green transportation options, like a bicycle or an electric scooter, may use this action to justify purchasing non-essential or environmentally harmful products. This behavior stems from the perception that their initial green investment has earned them moral credits that can be “spent” on other indulgences [44].

Example 4: Reduced Advocacy for Sustainable Policies

People who adopt green transportation habits might feel less inclined to support broader environmental policies, assuming that their personal efforts are sufficient. This can lead to a lack of advocacy for systemic changes needed to achieve substantial environmental impact, such as supporting public transportation funding or stricter emissions regulations [50].

Example 5: Justifying High-Energy Recreational Activities

After engaging in daily sustainable transportation methods like walking or cycling, individuals might justify participating in high-energy recreational activities, such as off-roading or motorized water sports, assuming their everyday actions sufficiently balance out these occasional indulgences [21].

Moral licensing in transportation behavior illustrates how sustainable actions can paradoxically lead to less environmentally friendly choices in other areas. Recognizing these patterns is crucial for developing strategies that ensure sustainable practices have a genuine, lasting impact.

3 AI and Automation: Potential and Challenges

3.1 Advancements in AI and Automation for Green Transportation

Key Technologies and Innovations.

Advancements in artificial intelligence (AI) and automation are revolutionizing green transportation, making it more efficient, sustainable, and accessible [26]. Here are some key technologies and innovations driving this transformation:

3.1.1 Autonomous Vehicles (AVs)

Autonomous vehicles use AI for navigation, sensing, and decision-making, enabling them to operate without human intervention. These vehicles can optimize routes, reduce traffic congestion, and improve fuel efficiency, leading to lower emissions and energy consumption. Key technologies in AVs include:

- Machine Learning and Deep Learning: Algorithms that allow vehicles to learn from vast amounts of data and improve their performance over time [15].
- Lidar and Computer Vision: Sensors and cameras that provide real-time data on the vehicle's surroundings, helping it to navigate and avoid obstacles [30].

3.1.2 Intelligent Transportation Systems (ITS)

ITS integrates AI and automation to improve the efficiency and safety of transportation networks. These systems use real-time data analytics to manage traffic flow, reduce congestion, and enhance public transport services. Innovations in ITS include:

- Traffic Management Systems: AI algorithms that optimize traffic light timings, predict traffic patterns, and manage incidents to minimize delays (Zhang 2019).
- Smart Public Transportation: Automated scheduling and routing of buses and trains based on real-time demand and traffic conditions [6].

3.1.3 Electric and Hybrid Vehicles

AI enhances the performance and efficiency of electric and hybrid vehicles through advanced energy management systems. These systems optimize battery usage, manage power distribution, and integrate renewable energy sources. Key innovations include:

- Battery Management Systems (BMS): AI algorithms that monitor and optimize battery health, charging, and discharging cycles to extend battery life and improve efficiency [53].
- Energy Optimization Systems: AI-driven systems that manage the energy flow in hybrid vehicles to maximize fuel efficiency and reduce emissions (Liu 2020).

3.1.4 Shared Mobility Services

AI and automation play a crucial role in the efficiency of shared mobility services such as ride-sharing, car-sharing, and bike-sharing. These services reduce the number of vehicles on the road and promote more sustainable travel options. Innovations in this area include:

- Dynamic Ride-Sharing Algorithms: AI algorithms that match riders with drivers in real-time, optimizing routes and reducing wait times [2].
- Fleet Management Systems: Automated systems that manage the deployment, maintenance, and recharging of shared vehicles to ensure availability and efficiency [11].

3.1.5 Predictive Maintenance

AI enables predictive maintenance for transportation infrastructure and vehicles, reducing downtime and improving reliability. By analyzing data from sensors, AI can predict when maintenance is needed, preventing breakdowns and optimizing maintenance schedules. Key technologies include:

- IoT Sensors: Internet of Things (IoT) devices that collect real-time data on the condition of vehicles and infrastructure.
- Data Analytics and Machine Learning: Tools that analyze sensor data to identify patterns and predict maintenance needs [42].

AI and automation are driving significant advancements in green transportation through technologies such as autonomous vehicles, intelligent transportation systems, electric and hybrid vehicles, shared mobility services, and predictive maintenance. These innovations enhance efficiency, reduce emissions, and contribute to a more sustainable transportation future [28].

3.2 Benefits and Potential for Sustainable Mobility

Advancements in AI and automation offer numerous benefits for sustainable mobility, enhancing efficiency, reducing environmental impact, and improving the overall transportation experience. Here are some key benefits and potentials:

3.2.1 Reduced Emissions and Pollution

AI and automation can significantly reduce greenhouse gas emissions and air pollution by optimizing transportation systems and promoting the use of green technologies:

- Efficient Traffic Management: Intelligent transportation systems (ITS) reduce traffic congestion by optimizing traffic flow and minimizing idle times, leading to lower emissions from vehicles (Zhang 2019).
- Electric Vehicles (EVs): AI-enhanced battery management systems improve the efficiency and lifespan of EVs, making them more viable and reducing reliance on fossil fuels (Xiong et al. 2018).

3.2.2 Improved Energy Efficiency

AI and automation contribute to more efficient use of energy resources in transportation:

- Optimized Route Planning: AI algorithms optimize routes for public and private transportation, reducing travel distances and fuel consumption [2].
- Energy Management in Hybrid Vehicles: AI-driven energy management systems in hybrid vehicles ensure optimal use of electric and fuel power, maximizing fuel efficiency and reducing emissions [52].

3.2.3 Enhanced Public Transportation

AI and automation improve the reliability, efficiency, and attractiveness of public transportation:

- Smart Scheduling and Routing: Real-time data analytics enable dynamic scheduling and routing of buses and trains based on demand, reducing wait times and improving service efficiency [6].
- Passenger Information Systems: AI-powered information systems provide real-time updates to passengers, enhancing the user experience and encouraging the use of public transport.

3.2.4 Increased Adoption of Shared Mobility

AI and automation facilitate the growth and efficiency of shared mobility services, reducing the number of private vehicles on the road:

- Dynamic Ride-Sharing: AI algorithms match passengers with drivers in real-time, optimizing ride-sharing routes and reducing the total number of vehicle trips [11].
- Efficient Fleet Management: Automated fleet management systems ensure that shared vehicles are well-maintained and strategically located to meet demand, improving service efficiency and reducing operational costs (Zhang 2019).

3.2.5 Predictive Maintenance and Reduced Downtime

AI-driven predictive maintenance minimizes vehicle downtime and extends the lifespan of transportation infrastructure:

- Real-Time Monitoring: IoT sensors and AI analytics monitor the condition of vehicles and infrastructure, predicting maintenance needs before failures occur.
- Cost Savings: Preventive maintenance reduces the costs associated with unexpected breakdowns and prolongs the useful life of transportation assets (Lee et al. 2014).

AI and automation offer substantial benefits for sustainable mobility, including reduced emissions, improved energy efficiency, enhanced public transportation, increased adoption of shared mobility, and predictive maintenance. These advancements are essential for creating efficient, environmentally friendly transportation systems that support long-term sustainability goals [23].

3.3 *Ethical Dilemmas and Moral Licensing*

3.3.1 Ethical Dilemmas

The integration of AI and automation into green transportation systems, while beneficial, raises several ethical dilemmas that must be addressed to ensure sustainable and fair outcomes.

1. Privacy and Surveillance

   - Data Collection: AI systems often require extensive data collection to function effectively. This data can include personal information, travel patterns, and even biometric data. The collection and use of this data raise concerns about privacy and surveillance.
   - Misuse of Data: There is a risk that the data collected could be misused by governments or corporations, leading to invasive surveillance practices and potential breaches of individual privacy (Zhang 2019).

2. Bias and Fairness

   - Algorithmic Bias: AI systems can perpetuate and even exacerbate existing biases in transportation systems. For example, algorithms might unfairly prioritize services in wealthier neighborhoods over less affluent ones, leading to unequal access to transportation benefits [15].
   - Equitable Access: Ensuring equitable access to AI-enhanced transportation services is a significant challenge. There is a risk that these technologies could widen the gap between different socioeconomic groups if not implemented with inclusivity in mind [31].

3. Accountability and Transparency

   - Decision-Making Transparency: The complexity of AI algorithms can make it difficult to understand how decisions are made, leading to a lack of transparency. This is problematic when errors occur or when decisions have significant impacts on individuals' lives [30].
   - Accountability for Errors: Determining who is accountable for errors made by AI systems, such as accidents involving autonomous vehicles, remains a complex ethical and legal issue [15].

3.3.2 Moral Licensing

Moral licensing refers to the phenomenon where individuals allow themselves to indulge in less ethical behaviors after having performed a good deed. In the context of green transportation, this can undermine sustainable efforts.

- Overcompensation with High-Emission Activities: Individuals who engage in green transportation practices, such as using public transport or cycling, might feel justified in compensating with high-emission activities, like taking frequent flights. This behavior can negate the environmental benefits gained from their sustainable actions [9].

- Reduced Effort in Other Sustainable Practices: After making a single green transportation choice, such as purchasing an electric vehicle, individuals may reduce their efforts in other areas of sustainability, like recycling or conserving energy at home. This reduction in overall sustainable behavior is a direct manifestation of moral licensing [34].
- Increased Consumption: Adopting green transportation methods can sometimes lead individuals to increase their consumption in other domains, believing that their transportation choices compensate for other unsustainable behaviors. For example, a person might purchase more goods with a high environmental cost because they feel their use of public transportation justifies it [44].
- Perceived Moral Credits: Individuals might accumulate "moral credits" from consistent use of green transportation, which they then "spend" on environmentally detrimental behaviors. This concept leads to a balancing act where the initial positive impact is offset by subsequent negative actions [50].

The integration of AI and automation into green transportation presents significant ethical dilemmas related to privacy, bias, and accountability. Additionally, moral licensing can undermine the positive impacts of sustainable practices by encouraging compensatory behaviors. Addressing these challenges is crucial for ensuring that the benefits of green transportation are fully realized and equitably distributed.

3.4 How AI and Automation May Exacerbate Moral Licensing

The integration of AI and automation into green transportation, while offering significant benefits, can also exacerbate the issue of moral licensing. Here's how these technologies may contribute to this phenomenon:

3.4.1 Increased Reliance on Technology as a Moral License

AI and automation can lead individuals to over-rely on technological solutions to justify environmentally detrimental behaviors: Perceived Offset: People may believe that using AI-optimized transportation systems or autonomous electric vehicles (AVs) absolves them from other environmentally harmful practices. For instance, they might justify frequent flying or high consumption of goods due to their use of AI-driven green transportation [34].

3.4.2 Reduction in Personal Responsibility

AI and automation can lead to a perceived reduction in personal responsibility for environmental sustainability: Delegation of Responsibility: As AI systems take over decision-making and optimization tasks, individuals might feel less personally responsible for making sustainable choices. This can result in complacency and a decrease in proactive sustainable behaviors [9].

3.4.3 Illusion of Comprehensive Solutions

The implementation of AI and automation can create an illusion that comprehensive solutions are already in place, leading to moral licensing: Overestimation of Impact: Individuals might overestimate the environmental benefits provided by AI and automated systems, believing that these technologies alone can solve sustainability issues. This overconfidence can lead to a decrease in other sustainable efforts, such as reducing overall consumption or advocating for broader policy changes [50].

3.4.4 Inconsistent Implementation and Equity Issues

AI and automation can exacerbate moral licensing due to inconsistencies in their implementation and the resulting equity issues: Selective Benefits: If AI and automation technologies are primarily implemented in wealthier areas or among certain populations, it can lead to a perception that these areas are doing enough for sustainability, while ignoring broader systemic issues. This can create a false sense of achievement and justify neglecting other sustainable actions [15].

3.4.5 Ethical Oversights in AI Systems

The ethical dilemmas inherent in AI and automation systems themselves can contribute to moral licensing: Bias and Fairness: AI systems can perpetuate existing biases, making certain groups believe they are contributing to sustainability when, in fact, the benefits are unevenly distributed. This selective moral licensing can result in some individuals feeling justified in reducing their sustainable efforts [30].

While AI and automation hold great potential for enhancing green transportation, they can also exacerbate moral licensing by reducing personal responsibility, creating illusions of comprehensive solutions, and contributing to equity issues. Addressing these challenges requires careful consideration of how these technologies are implemented and ensuring that they complement broader sustainable efforts.

4 Case Studies and Empirical Research

4.1 Case Study 1: Policy Implementation and Moral Licensing

- Example of a Green Transportation Policy: The London Ultra Low Emission Zone (ULEZ) is a significant green transportation policy aimed at reducing vehicle emissions in central London. Introduced by the Mayor of London, Sadiq Khan, the ULEZ requires vehicles driving within the designated area to meet strict emissions standards or face a daily charge. This policy aims to improve air quality and encourage the use of cleaner vehicles.
- Analysis of Moral Licensing Effects on Policy Outcomes: The implementation of ULEZ has led to unintended moral licensing effects, where individuals or organizations feel justified in engaging in less sustainable behaviors due to their compliance with the policy.

4.1.1 Increased Private Vehicle Use Outside ULEZ

Compliance with ULEZ restrictions by using cleaner vehicles or public transport within the zone can lead to increased use of higher-emission vehicles outside the ULEZ. For example, residents might drive older, more polluting vehicles more frequently outside the zone, believing their compliance within the ULEZ offsets these behaviors. Studies have indicated a shift in emissions patterns, with areas outside the ULEZ seeing less significant air quality improvements [32].

4.1.2 Reduced Advocacy for Broader Environmental Initiatives

Residents and businesses that comply with ULEZ regulations may feel a sense of moral satisfaction, reducing their motivation to support broader environmental initiatives. For instance, compliance with ULEZ might lead some individuals to believe they have done their part for air quality, becoming less active in supporting other measures such as expanding cycling infrastructure or advocating for stricter national emissions standards [50].

4.1.3 Increased Consumption of Other Resources

Organizations that invest in green transportation infrastructure to comply with ULEZ regulations might increase consumption in other areas, feeling morally licensed to do so. For example, a company like Deliveroo, which uses electric bicycles for deliveries within the ULEZ, might feel justified in increasing energy use or waste generation in other parts of its operations [44].

4.1.4 Selective Implementation and Equity Issues

The ULEZ policy may disproportionately affect certain populations, leading to selective moral licensing. Wealthier individuals and businesses can more easily afford to upgrade to compliant vehicles, while lower-income residents and smaller businesses may struggle. This disparity can lead wealthier individuals to feel morally licensed to engage in other unsustainable practices, while less affluent individuals bear the brunt of restrictions without comparable compensatory behaviors [15].

4.1.5 Detailed Case Study: London Ultra Low Emission Zone (ULEZ)

The ULEZ was introduced in April 2019 by the Mayor of London, Sadiq Khan, and covers the same area as the Congestion Charge Zone. Vehicles that do not meet the emissions standards must pay a daily charge of £12.50 for cars, vans, and motorcycles, and £100 for heavier vehicles such as trucks and buses. The aim is to reduce nitrogen dioxide (NO2) levels and particulate matter (PM) emissions.

1. Impact on Air Quality

    - Improved Air Quality: Reports indicate a significant reduction in NO2 levels within the ULEZ. According to a study by King's College London, there was a 29% reduction in roadside NO2 concentrations in the first six months after the ULEZ was introduced [7].
    - Displacement Effect: However, areas just outside the ULEZ have seen less improvement, suggesting that some drivers may be avoiding the ULEZ by driving around it, thereby shifting emissions rather than reducing them overall (Ellison et al. 2020).

2. Behavioral Responses

Compliance and Moral Licensing: Compliance with ULEZ has led to moral licensing behaviors. For example, businesses such as Addison Lee, a private hire vehicle company, upgraded their fleet to meet ULEZ standards. However, this compliance might lead them to justify other environmentally harmful practices, like increasing fleet size or not supporting broader environmental policies [44].

The London ULEZ demonstrates how green transportation policies can lead to moral licensing, where individuals and organizations justify less sustainable behaviors due to their compliance with the policy. This case study illustrates the need for comprehensive strategies and continuous monitoring to ensure that such policies lead to broader and more consistent sustainable practices.

4.2 Case Study 2: Consumer Behavior and Moral Licensing

Consumer Adoption of Green Technologies.

Green technologies, such as electric vehicles (EVs), solar panels, and energy-efficient appliances, are increasingly adopted by consumers aiming to reduce their environmental impact. These technologies offer significant benefits, including reduced carbon footprints, lower energy costs, and support for sustainable practices.

4.2.1 Example: Electric Vehicles (EVs)

The adoption of electric vehicles (EVs) has been growing rapidly. Governments around the world, including the United States, Norway, and China, have implemented policies to encourage EV adoption through subsidies, tax incentives, and the development of charging infrastructure. For instance:

- California: The state has been a leader in promoting EV adoption through initiatives such as the California Clean Vehicle Rebate Project (CVRP), which offers rebates for the purchase or lease of new, eligible zero-emission vehicles.
- Norway: The Norwegian government offers substantial incentives for EV owners, including exemptions from VAT, road tolls, and reduced parking fees. This has made Norway a global leader in EV market penetration.
- China: The Chinese government has implemented a range of policies to support EV adoption, including subsidies, tax breaks, and investment in charging infrastructure, contributing to China becoming the largest EV market in the world [5].

4.2.2 Example: Solar Panels

The installation of residential solar panels has also been rising, supported by policies such as feed-in tariffs, tax credits, and rebates. Notable examples include:

- Germany: The Renewable Energy Sources Act (EEG) has been pivotal in promoting solar energy adoption through feed-in tariffs, making Germany a leader in solar installations.
- California: The California Solar Initiative (CSI) offers incentives for residential solar installations, contributing to California having the highest number of residential solar installations in the United States.
- Australia: The Small-scale Renewable Energy Scheme (SRES) provides financial incentives for households to install solar panel systems, driving significant growth in residential solar adoption.

4.2.3 Impact of Moral Licensing on Consumer Choices

While the adoption of green technologies has positive environmental impacts, it can also lead to moral licensing, where consumers feel justified in making less sustainable choices elsewhere. Here are some ways moral licensing manifests in consumer behavior:

- Increased Energy Consumption: Consumers who install energy-efficient appliances or solar panels might feel justified in using more energy, believing that their green investments offset their increased consumption. For example, a household with solar panels in California may feel less guilty about leaving lights on or using energy-intensive devices more frequently [34].
- Higher Spending on Non-Green Products: After purchasing an electric vehicle, consumers might feel entitled to spend more on other, less sustainable goods and services. For instance, Tesla owners in Silicon Valley might justify frequent air travel or buying luxury goods because they believe their EV purchase offsets these high-emission activities (Kaklamanou and Jones et al. 2015).
- Reduced Support for Additional Environmental Measures: Adopting green technologies can lead to a sense of having "done enough" for the environment, resulting in reduced support for broader environmental policies. For example, individuals who drive electric vehicles in London might be less inclined to support public transportation initiatives or advocate for stricter environmental regulations, believing their personal actions are sufficient [50].
- Increased Use of Single-Occupancy Vehicles: While electric vehicles reduce emissions compared to traditional cars, their convenience can lead to increased use of single-occupancy vehicles. Consumers who might have otherwise used public transportation or carpooled may opt to drive their EVs alone, thus not fully capitalizing on the potential environmental benefits of reduced traffic and lower emissions [6].

4.3 Case Study Example: Tesla Owners

Tesla, a leader in the electric vehicle market, has seen its customer base rapidly expand. While Tesla owners significantly reduce their transportation-related carbon footprint, studies have shown that some Tesla owners engage in compensatory behaviors:

4.3.1 Luxury Consumption

Tesla owners, who typically have higher incomes, might feel justified in engaging in other luxury and high-emission activities, such as frequent international travel or purchasing large homes that consume more energy. Elon Musk, Tesla's CEO, has often highlighted the environmental benefits of Tesla cars, which can contribute to this compensatory mindset among owners [17].

4.3.2 Reduced Advocacy for Public Transport

Some Tesla owners feel their personal vehicle choice sufficiently addresses their environmental impact, leading to decreased advocacy for public transportation improvements or other community-level sustainability initiatives. For instance, in areas like Los Angeles, this attitude can undermine broader efforts to reduce car dependency [37].

The adoption of green technologies such as electric vehicles and solar panels has clear environmental benefits, but it can also lead to moral licensing, where consumers justify less sustainable behaviors in other areas. Understanding and addressing these behaviors is crucial to ensuring that the positive impacts of green technology adoption are not undermined by compensatory actions.

4.4 Case Study 3: Technological Adoption and Moral Licensing

Deployment of AI and Automation in Transportation.

The deployment of AI and automation in transportation is transforming how people and goods move, leading to increased efficiency, safety, and sustainability. Key examples of AI and automation in transportation include:

4.4.1 Example: Autonomous Vehicles

Autonomous vehicles (AVs) are being developed and tested by companies like Waymo, Tesla, and Uber. These vehicles use AI for navigation, sensing, and decision-making, aiming to reduce human error, optimize traffic flow, and lower emissions. For instance, Waymo operates a fleet of autonomous taxis in Phoenix, Arizona, offering a glimpse into the future of urban transportation [29].

4.4.2 Example: Intelligent Transportation Systems (ITS)

Intelligent transportation systems (ITS) use AI and automation to manage traffic, reduce congestion, and improve public transport efficiency. Cities like Singapore have implemented ITS that include real-time traffic monitoring, adaptive traffic signals, and automated public transport scheduling, significantly enhancing mobility and reducing emissions (Zhang 2019).

4.4.3 Example: AI in Public Transport

AI is also being deployed in public transportation to optimize routes, schedules, and maintenance. For example, Transport for London (TfL) uses AI to predict passenger flow and adjust services accordingly, improving efficiency and reducing wait times for passengers (Transport for London 2018).

4.4.4 Ethical Considerations and Moral Licensing Impacts

While AI and automation in transportation offer numerous benefits, they also raise ethical considerations and can exacerbate moral licensing. Here's how:

- Privacy and Surveillance: AI systems in transportation often require extensive data collection, raising privacy concerns. For instance, autonomous vehicles and ITS collect and process vast amounts of data on users' locations, behaviors, and preferences. This data can be vulnerable to misuse, leading to surveillance and privacy invasions (Zhang 2019).
- Bias and Fairness: AI algorithms can perpetuate and even exacerbate existing biases in transportation systems. For example, ride-sharing algorithms might prioritize services in wealthier areas, leading to unequal access for lower-income communities. This selective benefit can create a false sense of equity and lead to moral licensing among wealthier users who might feel justified in not supporting broader equity measures [15].
- Accountability and Transparency: The complexity of AI algorithms can make it difficult to understand how decisions are made, leading to a lack of transparency. This is problematic when errors occur or when decisions have significant impacts on individuals' lives. For instance, if an autonomous vehicle is involved in an accident, determining accountability can be challenging [30].
- Moral Licensing and Reduced Personal Responsibility: The adoption of AI and automation in transportation can lead to a perceived reduction in personal responsibility for sustainable behavior. For example, users of autonomous electric vehicles might feel that their transportation choices sufficiently address their environmental impact, leading them to neglect other sustainable practices, such as reducing overall travel or supporting public transportation initiatives [34].
- Ethical Oversights in AI Systems: Ethical dilemmas inherent in AI systems themselves can contribute to moral licensing. For example, if AI systems are designed primarily to maximize efficiency or profit rather than equity and sustainability, they can lead to behaviors that undermine overall environmental and social goals. Users might feel licensed to engage in less sustainable behaviors because they believe the technology itself is inherently green [50].

4.5 Case Study Example: Waymo Autonomous Vehicles

Waymo, a subsidiary of Alphabet Inc. (Google's parent company), operates a fleet of autonomous vehicles in Phoenix, Arizona. While these vehicles are designed to reduce human error and optimize traffic flow, the deployment of Waymo AVs has raised several ethical and moral licensing issues:

4.5.1 Privacy Concerns

Waymo's AVs collect extensive data on users, raising concerns about data privacy and potential misuse. Residents might feel uneasy about the surveillance aspects of these technologies, yet justify increased car usage due to perceived environmental benefits (Waymo 2020).

4.5.2 Reduced Personal Responsibility:

Users of Waymo's AVs might feel that their choice of an autonomous electric vehicle absolves them from other sustainable behaviors, such as reducing travel or supporting public transport. This moral licensing can undermine broader sustainability efforts [6].

The deployment of AI and automation in transportation, while offering significant benefits, can exacerbate moral licensing by reducing personal responsibility, creating illusions of comprehensive solutions, and contributing to privacy and equity issues. Addressing these challenges requires careful consideration of ethical implications and ensuring that these technologies complement broader sustainable efforts.

5 Strategies for Addressing Moral Licensing in Green Transportation

5.1 Frameworks for Ethical AI and Automation

Developing Guidelines and Best Practices: Developing ethical guidelines and best practices for AI and automation in transportation is crucial to ensure these technologies benefit society while minimizing negative impacts. Here are some key components and initiatives that contribute to these guidelines:

5.1.1 Establishing Transparency and Accountability

- Explainability: AI systems should be designed to provide clear, understandable explanations for their decisions and actions. This can help users trust and understand the technology, reducing the risk of ethical oversights [8].
- Accountability: Clear lines of accountability should be established to determine who is responsible when AI systems fail or cause harm. This includes developers, manufacturers, and operators.

5.1.2 Ensuring Privacy and Data Protection

- Data Minimization: AI systems should collect only the data necessary for their functions and implement robust data protection measures to safeguard user privacy (Zhang 2019).
- User Consent: Users should be informed about what data is being collected and how it will be used, and they should provide explicit consent.

5.1.3 Promoting Fairness and Equity

- Bias Mitigation: AI systems should be audited regularly to identify and mitigate biases that could lead to unfair outcomes. This involves using diverse training data and developing algorithms that account for potential disparities [15].
- Inclusive Design: The development of AI systems should involve input from diverse stakeholders to ensure that the needs and perspectives of different communities are considered.

5.1.4 Ensuring Safety and Reliability

- Robust Testing: AI systems should undergo rigorous testing in a variety of conditions to ensure they can operate safely and reliably. This includes both simulated environments and real-world testing [30].
- Continuous Monitoring: Once deployed, AI systems should be continuously monitored to detect and address any issues that arise during their operation.

5.1.5 Regulatory and Policy Frameworks

- Government Regulations: Governments should establish regulations that set clear standards for the development and deployment of AI systems, ensuring they align with societal values and ethical principles. Examples include the European Union's General Data Protection Regulation (GDPR) and proposed AI regulations [10].

- Industry Standards: Industry groups and standards organizations, such as the Institute of Electrical and Electronics Engineers (IEEE), have developed guidelines and standards for ethical AI, including the IEEE's Ethically Aligned Design initiative.

5.2 Integrating Ethical Considerations in Technology Design

Integrating ethical considerations into the design of AI and automation technologies ensures these systems are developed responsibly and with a focus on societal well-being.

5.2.1 Ethical by Design

- Ethics Boards and Review Committees: Organizations developing AI systems should establish ethics boards to review projects and ensure they align with ethical guidelines and best practices. These boards should include ethicists, legal experts, and representatives from diverse communities [13].
- Ethical Impact Assessments: Conducting ethical impact assessments during the design phase can help identify potential ethical issues early and guide the development process towards more ethical outcomes [45].

5.2.2 Human-Centered Design

- User-Centric Approaches: AI systems should be designed with a focus on the end-user, ensuring that they are accessible, usable, and beneficial to a broad range of people. This involves iterative testing with real users and incorporating their feedback into the design process [40].
- Transparency and Explainability: AI systems should provide users with clear and understandable information about how decisions are made, enabling them to trust and effectively use the technology.

5.2.3 Long-Term Sustainability

- Environmental Impact: The design of AI systems should consider their environmental impact, aiming to minimize energy consumption and reduce carbon footprints. This includes optimizing algorithms for efficiency and using sustainable materials in hardware [49].
- Lifecycle Management: Planning for the entire lifecycle of AI systems, from development to deployment and eventual decommissioning, ensures that ethical considerations are maintained throughout their use.

5.2.4 Inclusive and Diverse Design Teams

- Diverse Perspectives: Including individuals from diverse backgrounds in AI development teams helps ensure that the systems are designed to be fair and equitable. This diversity can help identify potential biases and ethical issues that might otherwise be overlooked.
- Cross-Disciplinary Collaboration: Collaborating with experts from various fields, such as sociology, psychology, and law, can provide valuable insights into the ethical implications of AI systems and help develop more comprehensive and responsible solutions [19].

Developing frameworks for ethical AI and automation involves establishing clear guidelines and best practices, ensuring transparency and accountability, promoting fairness and equity, and integrating ethical considerations into technology design. By adopting these approaches, we can ensure that AI and automation technologies are developed and deployed in ways that benefit society and minimize negative impacts.

5.3 Policy Recommendations

To effectively address moral licensing in the context of green transportation and the adoption of AI and automation, policymakers need to implement targeted interventions. These interventions can help ensure that sustainable behaviors are consistently supported and not undermined by compensatory actions.

5.3.1 Comprehensive Environmental Policies

- Holistic Approaches: Develop comprehensive environmental policies that address multiple aspects of sustainability simultaneously. For example, combining incentives for electric vehicle (EV) adoption with measures to promote public transportation, cycling, and walking can prevent compensatory behaviors where individuals justify unsustainable actions in other areas.
- Integrated Policy Frameworks: Encourage collaboration between different governmental departments and agencies to create integrated policy frameworks that address transportation, energy, and urban planning in a coordinated manner [14].

5.3.2 Incentive Structures

- Conditional Incentives: Structure incentives to promote a broad range of sustainable behaviors. For example, provide financial incentives for purchasing EVs only if the recipient also demonstrates a reduction in overall car usage or an increase in the use of public transportation.

- Performance-Based Incentives: Design incentives based on actual environmental performance rather than specific actions. This could involve setting targets for reductions in carbon footprints and rewarding individuals or organizations that meet these targets, encouraging continuous improvement rather than one-off actions [5].

5.3.3 Education and Awareness Campaigns

- Behavioral Insights: Use insights from behavioral science to design public awareness campaigns that address moral licensing. Educate the public on the importance of holistic sustainable behavior and the pitfalls of moral licensing, encouraging consistent and widespread adoption of green practices [24].
- Transparency and Accountability: Promote transparency in environmental impact reporting. Encourage individuals and organizations to publicly share their sustainability efforts and results, creating social accountability and discouraging compensatory behaviors [34].

5.3.4 Regulatory Measures

- Stricter Emissions Standards: Implement stringent emissions standards for all vehicles, not just those in specific zones. This can prevent the displacement of emissions and ensure broader environmental benefits.
- Mandatory Reporting: Require companies to report on their comprehensive sustainability efforts, including both direct and indirect environmental impacts. This can help identify and mitigate instances of moral licensing within corporate practices [10].

5.4 Encouraging Responsible Consumer Behavior

Policymakers can also implement strategies to encourage consumers to adopt and maintain responsible behaviors, avoiding the pitfalls of moral licensing.

5.4.1 Positive Reinforcement

Reward Programs: Establish reward programs that recognize and reward consistent sustainable behaviors. This could include discounts, rebates, or public recognition for individuals who consistently reduce their carbon footprint and engage in a range of sustainable practices [21].

5.4.2 Nudges and Behavioral Interventions

- Default Options: Implement default options that favor sustainable choices. For example, make public transportation passes or carpooling options the default choice in company travel policies, requiring an active decision to opt-out.
- Social Norms: Use social norms to influence behavior by highlighting the sustainable actions of peers and community leaders. Public campaigns can showcase stories of individuals and organizations leading in sustainability, creating a social expectation to follow suit.

5.4.3 Information and Feedback

- Real-Time Feedback: Provide real-time feedback on the environmental impact of consumer choices. For example, smart meters and apps can show users the immediate effects of their energy consumption patterns, encouraging more mindful usage.
- Educational Initiatives: Develop educational programs that teach the principles of sustainable living and the importance of avoiding moral licensing. Schools, workplaces, and community groups can be targeted to foster a culture of sustainability from a young age [37].

5.4.4 Community-Based Approaches

- Local Initiatives: Support local initiatives that promote sustainability within communities. These can include community gardens, local recycling programs, and cooperative renewable energy projects that foster a collective sense of responsibility.
- Peer Support Networks: Encourage the formation of peer support networks where individuals can share tips, experiences, and encouragement for maintaining sustainable behaviors. These networks can help sustain motivation and accountability among participants (Hoffman and Henn 2008).

Effective policy interventions and strategies to mitigate moral licensing and encourage responsible consumer behavior are crucial for achieving sustainable outcomes. By implementing comprehensive policies, designing incentive structures, and fostering a culture of sustainability, policymakers can ensure that the positive impacts of green technologies and AI are not undermined by compensatory behaviors [25].

5.5 *Leveraging AI and Automation for True Sustainability*

Strategies to Ensure AI and Automation Support Sustainable Goals: Leveraging AI and automation for sustainability requires strategic planning and implementation to ensure these technologies contribute effectively to environmental goals. Here are key strategies to achieve this:

5.5.1 Integrating Sustainability Metrics into AI Systems

- Environmental Impact Assessment: Incorporate sustainability metrics into the design and deployment of AI systems. This involves assessing the environmental impact of AI applications throughout their lifecycle, from development to deployment and operation [49].
- Sustainable AI Algorithms: Develop and use algorithms that optimize for energy efficiency and minimize resource usage. This includes creating models that require less computational power and utilizing renewable energy sources for data centers.

5.5.2 Promoting Circular Economy Principles

- Resource Efficiency: Use AI to enhance resource efficiency in various sectors, such as manufacturing, logistics, and energy management. AI can optimize production processes, reduce waste, and improve recycling efforts [27].
- Lifecycle Management: Implement AI systems that monitor and manage the lifecycle of products, ensuring they are reused, refurbished, or recycled at the end of their life, thus reducing waste and promoting a circular economy [48].

5.5.3 Enhancing Energy Efficiency

- Smart Grids: Deploy AI to manage smart grids, which optimize the distribution and use of electricity, integrating renewable energy sources and reducing energy waste. AI can predict demand, manage supply, and detect inefficiencies in the grid (Liu 2020).
- Building Management Systems: Utilize AI in building management systems to control heating, ventilation, air conditioning (HVAC), and lighting, significantly reducing energy consumption in commercial and residential buildings [22].

5.5.4 Facilitating Sustainable Transportation

- Traffic Management: Use AI to optimize traffic flow and reduce congestion, leading to lower emissions and improved air quality. Intelligent transportation

systems (ITS) can dynamically adjust traffic signals, manage incidents, and provide real-time traffic information to drivers (Zhang 2019).
- Autonomous and Electric Vehicles: Promote the development and use of autonomous electric vehicles, which can reduce greenhouse gas emissions and improve energy efficiency. AI can optimize driving patterns, manage fleets, and facilitate the integration of EVs with renewable energy sources [15].

5.5.5 Encouraging Sustainable Consumer Behavior

- Personalized Recommendations: Use AI to provide personalized recommendations that encourage sustainable consumer behavior. For example, AI-powered apps can suggest eco-friendly products, monitor energy usage, and provide tips on reducing carbon footprints.
- Gamification and Incentives: Implement gamification strategies and incentives to motivate individuals and organizations to adopt sustainable practices. AI can track progress and reward sustainable actions, fostering a culture of sustainability.

5.6 Examples of Successful Implementations

5.6.1 Google's Data Centers

Google has successfully implemented AI to manage its data centers, significantly improving energy efficiency. Using DeepMind's AI algorithms, Google has reduced the energy used for cooling its data centers by 40%, leading to a 15% improvement in overall energy efficiency. This initiative not only reduces operational costs but also minimizes the environmental impact of Google's extensive data infrastructure (Google 2016).

5.6.2 Siemens' Smart Grids

Siemens has developed smart grid solutions that integrate AI to manage and optimize energy distribution. In the city of Vienna, Austria, Siemens' smart grid technology has been deployed to balance energy supply and demand, integrate renewable energy sources, and reduce energy losses. This implementation has enhanced the city's energy efficiency and sustainability (Siemens 2020).

5.6.3 Singapore's Intelligent Transport System

Singapore's Intelligent Transport System (ITS) utilizes AI and automation to manage traffic flow, reduce congestion, and improve public transport efficiency. The system includes real-time traffic monitoring, adaptive traffic signals, and automated public transport scheduling. As a result, Singapore has achieved a more efficient and sustainable transportation network, reducing emissions and improving air quality [46].

5.6.4 IBM's Green Horizon Project in China

IBM's Green Horizon project in China leverages AI to address air pollution and improve environmental management. The project uses AI to analyze environmental data, predict pollution levels, and recommend actions to reduce emissions. In cities like Beijing, this initiative has helped to better manage air quality and develop more effective pollution control strategies (IBM 2016).

AI and automation offer immense potential for achieving true sustainability. By integrating sustainability metrics, promoting circular economy principles, enhancing energy efficiency, facilitating sustainable transportation, and encouraging responsible consumer behavior, these technologies can significantly contribute to environmental goals. Successful implementations by companies like Google, Siemens, and initiatives like Singapore's ITS and IBM's Green Horizon project demonstrate the positive impact of leveraging AI and automation for sustainability.

6 Conclusion

Moral licensing can undermine the effectiveness of green transportation initiatives by allowing individuals to justify less sustainable behaviors after performing an environmentally friendly action. AI and automation, while offering significant benefits for sustainability, can exacerbate this issue by creating an illusion of comprehensive solutions and reducing personal responsibility for sustainable practices. Understanding and addressing moral licensing is crucial for maximizing the positive impact of AI and green transportation technologies.

Addressing ethical challenges in the deployment of AI and automation is essential to ensure these technologies contribute to sustainable goals without unintended negative consequences. This includes ensuring transparency and accountability, promoting fairness and equity, protecting privacy, and preventing bias. By integrating ethical considerations into the design and implementation of AI systems, we can mitigate the risks of moral licensing and enhance the overall effectiveness of sustainable transportation initiatives.

Further research is needed to understand the impact of AI on long-term sustainable behavior and how to design these technologies to promote consistent and widespread adoption of green practices. Investigating the psychological mechanisms underlying moral licensing in the context of green transportation and AI can help develop more effective strategies to counteract compensatory behaviors. Additionally, studying the impact of AI and automation on different socioeconomic groups is crucial to ensure these technologies benefit all segments of society. This includes examining how to design and implement AI systems that promote equity and inclusion.

Exploring the development of comprehensive policy and regulatory frameworks that support the ethical deployment of AI and automation in transportation can guide policymakers in creating effective regulations that balance innovation with ethical considerations.

The long-term vision for sustainable transportation with AI and automation includes integrated and intelligent transportation systems that optimize traffic flow, reduce emissions, and enhance public transportation efficiency. These intelligent systems will be adaptive, data-driven, and capable of continuously improving based on real-time feedback. Sustainable mobility solutions, including autonomous electric vehicles, shared mobility services, and smart infrastructure, will prioritize energy efficiency, reduce reliance on fossil fuels, and support the transition to a low-carbon economy.

Adopting holistic approaches that consider the entire lifecycle of transportation technologies, from development to decommissioning, is essential. This includes designing AI systems that minimize environmental impact, promoting circular economy principles, and ensuring that all aspects of transportation contribute to sustainability goals.

Collaborative efforts between governments, industry, academia, and civil society are crucial for developing and implementing AI and automation technologies that support sustainable transportation. By working together, stakeholders can share knowledge, resources, and best practices to achieve common sustainability objectives.

The integration of AI and automation into green transportation presents both opportunities and challenges. By addressing ethical considerations and understanding the impact of moral licensing, we can leverage these technologies to create sustainable, efficient, and equitable transportation systems. Continued research and collaboration will be essential to realizing the long-term vision of sustainable transportation powered by AI and automation.

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Transformative Impact of Generative Artificial Intelligence (Gen AI) on Smart Transportation System

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Abstract Transportation, the backbone of our contemporary society, teeters on the edge of an era of digital transformation. Generative Artificial Intelligence (Gen AI), a robust division of artificial intelligence, is emerging as a pivotal catalyst for this revolution, offering the potential to redefine vehicle design, enhance traffic management, and cultivate a safer, more environmentally friendly transportation ecosystem. AI technology in transportation has the potential to transform traffic control by forecasting and alleviating immediate congestion. Picture AI-driven mechanisms that can adapt traffic signals on the fly, redirect vehicles, and anticipate accidents in advance, resulting in a more efficient and secure traffic flow for all. AI technology in the transportation sector enables manufacturers to provide unprecedented levels of personalized vehicle customization. By utilizing Gen AI algorithms that take into account individual preferences, driving behaviors, and lifestyle choices, unique design proposals can be created. This high degree of customization not only meets consumer preferences but also fosters a stronger bond between drivers and their vehicles.

Keywords Artificial intelligence · Generative artificial intelligence · Internet of things · Green transportation · AI algorithms · Environmentally friendly · Smart transportation

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1 Introduction

Any nation's progress depends heavily on the transport industry. Public transit is especially important because of its cost and accessibility. If public transit were to cease even for a day, many individuals would struggle to afford private means of transport, potentially causing a standstill in the city. A well-functioning transport system is imperative for a thriving economy. As industrialization progresses and the demand for private transportation rises, along with traffic congestion, ensuring the sustainability of the transportation industry becomes increasingly urgent. In response to growing environmental and climate change concerns worldwide, there is a necessity to establish eco-friendly transportation infrastructure to address these issues.

Urbanization has been a key driver of global demographic changes in recent decades. The percentage of the world's population living in urban areas has increased significantly, from 34% in 1960 to 56% in 2019. Projections suggest that by 2050, 5 billion people will be living in urban areas out of an estimated global population of 8.2 billion. This shift has also impacted the economic landscape, with the agricultural sector's contribution to GDP decreasing from 27 to 10%, while the industrial sector's share has risen from 32 to 43%, driven by the demand for urbanization [29].

Green transportation refers to any form of travel that has a minimal negative impact on the environment. This can include private options such as high-speed electric bikes, as well as public transportation like electric city buses. Walking is also recognized as an eco-friendly mode of transportation. The key characteristic of green transportation is its sustainability, as it relies on resources that can be replenished and utilized by future generations. There are three types of sustainable vehicles (Green) vehicles as listed below [21].

1.1 All Electric Vehicles

All-electric vehicles utilize electric motors, which sets them apart from vehicles powered by combustion engines. These vehicles can be powered by various sources such as solar cells, electric batteries, or electric generators that convert fuel into electricity. One of the key advantages of all-electric vehicles is their environmental friendliness compared to combustion engine vehicles. Unlike their counterparts, they do not consume fossil fuels, which are non-renewable resources. Additionally, they do not emit harmful exhaust gases that contribute to environmental pollution. It is worth mentioning that the adoption of electric-powered engines is not limited to prominent car manufacturers like Tesla. Public transportation systems, including buses, light rail commuter trains, and intercity trains, are also transitioning to electric motors, further promoting sustainable transportation options.

1.2 Hybrid Vehicles

Hybrid vehicles combine the strengths of an electric motor and a traditional combustion engine. Electric motors are known for their power generation capabilities, while combustion engines excel at maintaining high speeds. The concept behind hybrid vehicles is to leverage the unique advantages of each power source. While not as environmentally friendly as all-electric vehicles, hybrids still emit fewer greenhouse gases than vehicles powered solely by a combustion engine, contributing to a greener environment. When driven efficiently, hybrid cars can reduce emissions by 26–90% compared to conventional vehicles. Like all electric vehicles, hybrids are utilized in both private and public transportation systems.

1.3 Electric Bikes

Electric bicycles, commonly known as e-bikes, are essentially traditional bicycles with an electric motor. These batteries can last for hours, allowing riders to reach speeds between 15 and 25 mph. Some e-bikes are capable of going even faster. There are various models of electric bicycles available, with the most environmentally friendly option being the pedal-assist bike. This type requires the rider to pedal before the motor kicks in. On the other hand, some models continuously use the motor as well.

Electric bikes are considered efficient forms of green transportation for several reasons. They require fewer resources during production compared to full-sized vehicles and consume less energy as well. While e-bikes are gaining popularity in the United States, they are already widely used in Europe and Asia as a sustainable mode of transportation. In urban areas, e-bikes are particularly favored by couriers and commuters due to their ease of navigation through the cityscape.

Transitioning to green transportation is crucial in safeguarding our planet for future generations. By decreasing our reliance on fossil fuels, which are both limited in supply and contribute to global pollution, we can make a significant impact on reducing greenhouse gas emissions. Embracing a green transportation culture not only benefits the environment by reducing AI pollution and promoting better health but also helps individuals save on energy costs and reduces governments' dependence on fossil fuel providers.

Making this shift will bring us closer to achieving a sustainable society [3]. The transport sector accounts for approximately 20% of global carbon emissions, a figure that is on the rise according to the United Nations. Failure to take immediate action could have severe consequences not only for the environment but also for public health and overall well-being. Green transportation is poised to play a significant role in driving economic growth and social progress in various countries.

The World Bank projects that transitioning to sustainable transport options could result in savings of up to $70 trillion by the year 2050. Improved access to transportation infrastructure can enhance mobility, productivity, and opportunities for millions of individuals, particularly in low- and middle-income nations. Beyond environmental benefits, green transportation can also contribute to improving the quality of life and health outcomes for individuals and communities. By reducing AI pollution, noise levels, and traffic congestion, sustainable transport solutions can help create more livable and appealing urban environments. Furthermore, promoting physical activity and social connections through green transportation options can have positive impacts on both mental and physical well-being [36].

Generative Artificial Intelligence (Gen AI) is a groundbreaking advancement in artificial intelligence that shifts the focus from analyzing existing data to creating new data. Unlike conventional AI which is limited to tasks like classification and prediction using pre-existing data, Gen AI can produce fresh content like text, images, music, and intricate data structures. This innovation has wide-ranging applications in diverse fields, from creative sectors to scientific endeavors, and carries significant implications for the future of technology and society.

Gen AI is a groundbreaking technology that has the potential to completely transform smart transportation systems. With the ongoing urbanization and population growth, there is a growing need for transportation solutions that are efficient, sustainable, and intelligent. Gen AI's unique ability to generate new data and forecast outcomes using existing data can lead to significant advancements in optimizing transportation networks, predictive maintenance, and personalized travel experiences [22].

Gen AI is centered on utilizing algorithms to analyze patterns within a dataset and leveraging this knowledge to generate fresh, comparable data. Key methods within Gen AI include various models like Generative Adversarial Networks (GANs), Variational Autoencoders (VAEs), and Transformer-based models, each utilizing distinct methods to facilitate generative capabilities. GANs were first introduced in 2014 by Ian Goodfellow and his team, comprising two neural networks: the generator and the discriminator.

The generator is responsible for producing new data samples, whereas the discriminator assesses these samples by contrasting them with real data samples. This adversarial process enables the generator to enhance its capacity to produce lifelike data progressively. GANs have achieved remarkable success in generating top-notch images and finding applications in image synthesis, video generation, and the creation of authentic deepfakes [37].

Gen AI has the potential to revolutionize smart transportation systems by offering innovative solutions to enhance urban mobility. Unlike traditional AI, Gen AI goes beyond its capabilities and utilizes advanced algorithms to generate new data, predict future scenarios, and optimize complex systems. This makes it a powerful tool for addressing the multifaceted challenges faced by modern transportation networks, such as efficiency, safety, and sustainability. One of the key applications of Gen AI in smart transportation is optimizing traffic management.

Traffic congestion is a persistent problem in urban areas, leading to increased travel time, fuel consumption, and AI pollution. By analyzing vast amounts of real-time traffic data, including vehicle counts, speeds, and patterns, Gen AI can predict traffic flow and identify potential bottlenecks. It can then simulate various traffic scenarios to provide actionable insights for city planners and traffic control centers. These insights can be used to dynamically adjust traffic signals, implement adaptive traffic management strategies, and optimize the allocation of road space.

For example, AI-generated models can recommend alternate routes to alleviate congestion and reduce travel time, significantly improving the overall efficiency of the transportation system. With Gen AI's capabilities, smart transportation systems can become more efficient, safer, and more sustainable, ultimately transforming the way we move in urban areas [31].

The incorporation of Gen AI into autonomous vehicles (AVs) marks a significant advancement in smart transportation. AVs heavily rely on AI to maneuver through intricate urban settings, make split-second decisions, and interact safely with other drivers. Gen AI can create lifelike driving scenarios to train AVs, AI helps them in adapting to various traffic scenarios, even those that are rare or unexpected. Through simulating diverse environmental conditions and traffic patterns, Gen AI can bolster the resilience and safety of autonomous driving systems.

AI-powered fleet management solutions can streamline the deployment and routing of AVs, ensuring optimal resource utilization and minimizing downtime [33]. Gen AI provides revolutionary features for intelligent transportation systems, tackling issues concerning traffic control, enhancing public transit efficiency, managing autonomous vehicles, optimizing logistics, promoting environmental sustainability, ensuring safety, improving user experience, and facilitating urban planning.

Through leveraging the capabilities of Gen AI, municipalities can establish more effective, eco-friendly, and robust transportation infrastructures that cater to the changing requirements of their inhabitants and enhance the general welfare of urban societies. The incorporation of Gen AI in smart transportation signifies not only a technological progression but also a stride towards a smarter and more flexible urban landscape.

2 Research Questions

- How does Gen AI impact the smart transportation system?
- What are the various factors in which Gen AI would influence smart transportation systems?

3 Research Objectives

- To understand the various factors in which Gen AI would affect smart transportation systems.
- To add to the body of knowledge the impact of Gen AI on the Smart Transportation system.

4 Using Gen AI to Transform Predictive Maintenance in Smart Transportation

Predictive maintenance leverages data analysis to identify operational abnormalities and potential equipment problems, allowing for timely repairs before any failures. The objective is to minimize the frequency of maintenance, thus preventing unexpected downtime and reducing excessive costs associated with preventative maintenance.

The effectiveness of predictive maintenance heavily relies on advanced technology and software, specifically the integration of IoT, AI, and integrated systems. These interconnected systems enable the sharing of data, analysis, and actionable insights across various assets. Data is collected through sensors, industrial controls, and enterprise resource planning (ERP) software. Subsequently, this data is carefully examined to identify areas that require attention, utilizing techniques such as vibration analysis, oil analysis, thermal imaging, and equipment observation [1].

Predictive Maintenance Gen AI and IoT Devices enable transport systems. Gen AI uses biometric data to monitor train operators' health and performance, enabling predictive maintenance by analyzing their physical state and alerting them to any irregularities that might compromise their ability to operate safely. The application of AI algorithms in Gen AI enables the analysis of massive volumes of data generated from IoT devices.

Using AI, the system can identify prospective maintenance difficulties based on patterns and trends in the data, allowing for proactive maintenance procedures to be implemented before catastrophic failures occur. IoT devices play an important role in monitoring various components of transportation networks in real time. These devices capture data on the status of wagons, railway lines, and trains, allowing for continual monitoring of abnormalities. Transportation businesses may use IoT devices and Gen AI to build predictive maintenance plans that solve issues quickly and prevent unexpected failures.

Gen AI detects irregularities in the operation of transport systems by combining biometric data, AI algorithms, and IoT devices. By continually monitoring data from sensors and devices, the system may detect deviations from normal operating conditions and notify maintenance teams to take remedial action, maintaining the safety and efficiency of the transportation network [23]. Gen AI which combines AI and

Big Data, allows enhanced predictive maintenance (PdM) solutions for transportation systems. This integration enables the analysis of massive volumes of sensor data, such as pressure, temperature, current, vibration, and other factors, to detect patterns and anomalies that suggest possible problems.

Transportation systems may use Gen AI to discover concerns before they become failures. AI algorithms can analyze past data to identify early warning signals of equipment problems, allowing for prompt maintenance interventions to avert breakdowns and save downtime. Gen AI helps anticipate the remaining usable life (RUL) of transportation equipment. AI can anticipate how long a component or system will work efficiently using machine learning models and predictive analytics, allowing maintenance staff to schedule repairs or replacements ahead of time, hence optimizing asset performance and lifetime.

Gen AI solutions give exact insights into the health and performance of transport assets, allowing maintenance operations to be carried out with accuracy and efficiency. By integrating AI analytical skills with real-time sensor data, maintenance procedures may be adapted to individual equipment conditions, increasing operational dependability and cost-effectiveness [38]. Gen AI uses powerful machine learning techniques to improve predictive maintenance in transportation systems.

Gen AI enhances predictive maintenance model accuracy by using machine learning models such as multilayer perceptron (MLP) and radial basis function (RBF) neural networks. Gen AI improves the accuracy of predictive maintenance models by using surface deflection data from falling weight deflectometer (FWD) tests to forecast pavement condition index (PCI). Hybrid prediction models, such as Levenberg–Marquardt (MLP-LM), scaled conjugate gradient (MLP-SCG), imperialist competitive (RBF-ICA), and genetic algorithms (RBF-GA), play a crucial role in enhancing maintenance prediction accuracy. Gen AI utilizes the Combined Model Integration System (CMIS) to consolidate outcomes from diverse machine learning models, resulting in improved predictive maintenance precision. The CMIS model exhibits superiority compared to other models, supported by metrics like average percent relative error (APRE), average absolute percent relative error (AAPRE), root mean square error (RMSE), and standard error (SD) [14].

Gen AI, is the application of machine learning techniques for predictive maintenance in public vehicles. Real-time vehicle health monitoring entails gathering immediate data from IoT sensors put in cars to analyze their present condition and detect probable faults before they occur. The monitoring system uses machine learning to analyze data and predict whether cars are normal or malfunctioning.

Maintenance planning becomes more efficient with Gen AI since the system can give real-time estimations for maintenance speed based on fuzzy outputs from categorization models. The integration of Gen AI with smart transportation allows for preventive maintenance scheduling, reducing the danger of failures, delays, and accidents in public transit vehicles. Gen AI enables the creation of a high-performing smart maintenance forecasting model, which contributes to the improvement of smart city infrastructure and ensures the uninterrupted operation of public transport systems [26].

Gen AI can increase system availability by proactively detecting maintenance needs before breakdowns. This technique avoids downtime and ensures that transport systems are functioning when needed. Furthermore, by estimating maintenance requirements, expenditures related to emergency repairs and unforeseen downtime are reduced, resulting in cost savings for transportation businesses. Machine Learning algorithms may analyze data from a variety of sources, including error logs, maintenance history, and failure history, to give insights for decision-making. Gen AI may use these technologies to evaluate the best time and actions for maintenance interventions, allowing informed decisions that improve operational performance and safety in transportation systems [7].

Robust data collection and integration form the basis of predictive maintenance. In today's transportation systems, there is a wide range of sensors and IoT devices that constantly monitor the condition and efficiency of various components, including engines, brakes, tires, and other crucial systems. These sensors gather data on parameters such as temperature, vibration, pressure, and patterns of usage. By integrating data from multiple sources, advanced AI systems can create a comprehensive dataset that is crucial for precise predictive maintenance [30].

Gen AI utilizes sophisticated data analytics to process and examine the gathered data. Machine learning algorithms, which are a subset of AI, excel in detecting patterns and trends that signify possible malfunctions or maintenance requirements. By learning from past data, these algorithms can identify early indications of component deterioration, anomalies, and other signs that indicate imminent failures. For example, a gradual rise in vibration levels could indicate the deterioration of a mechanical part, signaling the need for maintenance shortly [4].

The transportation sector is already making significant investments in artificial intelligence. In 2017, the worldwide AI market in this area was $1.4 billion, and it is predicted to grow to $3.5 billion by 2023. It's also reassuring to know that transport and logistics are among the businesses that gain the most from AI and machine learning solutions as shown in Fig. 1. The previous method of fleet management was to remove cars from service every 4000 miles (roughly) for routine maintenance, which was frequently unnecessary. AI-enabled predictive maintenance enables owners to make repair decisions based on the vehicle's present state rather than on predetermined time intervals. It's no surprise that predictive maintenance is gaining traction in the transportation business [2].

Gen AI is reshaping predictive maintenance in smart transportation systems through real-time monitoring, advanced data analytics, and proactive maintenance strategies. By anticipating failures and optimizing maintenance schedules, Gen AI boosts transportation networks' reliability, safety, and efficiency, all while reducing operational costs. As AI technologies advance, their impact on predictive maintenance will continue to grow, paving the way for a future where transportation systems are more intelligent, efficient, and resilient.

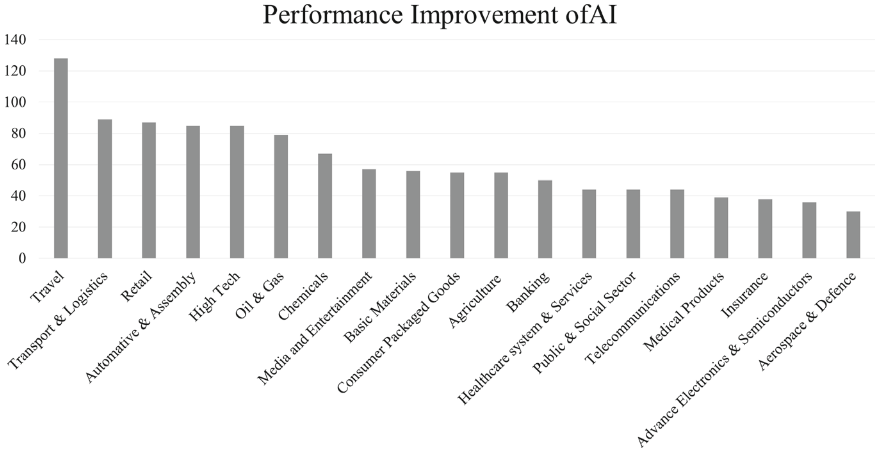

Fig. 1 Performance improvement of AI. *Source*: https://www.softeq.com/blog/ai-in-the-transportation-industry-what-does-predictive-maintenance-have-in-store

5 Incident Detection and Response Using Gen AI in Smart Transportation Systems

Efficient automatic incident detection is a well-known problem in the transportation industry. Non-recurring occurrences, such as traffic accidents, automobile breakdowns, and unexpected congestion, can considerably influence travel times, safety, and the environment, with socioeconomic implications [10]. Gen AI is instrumental in revolutionizing incident detection and accident prevention in smart transportation systems. Through harnessing the power of Gen AI these systems greatly improve the safety, effectiveness, and dependability of transportation networks.

The incorporation of cutting-edge AI technologies in smart transportation requires gathering, analyzing, and utilizing extensive data from diverse origins, facilitating immediate monitoring and preemptive handling of potential incidents [35]. Gen AI, a branch of artificial intelligence, demonstrates exceptional proficiency in producing information and patterns that can anticipate and avert occurrences before they happen. A key aspect of Gen AI's contribution to incident detection lies in its capacity to scrutinize data obtained from a wide range of sensors and devices integrated into vehicles and infrastructure. These sensors gather data on diverse parameters including vehicle velocity, geographical position, driver conduct, weather circumstances, and road conditions.

Through constant monitoring of these data streams, Gen AI can discern patterns and irregularities that might signify potential hazards or incidents [28]. Computer vision services, such as object recognition and tracking, are used in a variety of AI-related transportation applications. While the most visible AI applications in transportation are well-known to the general public, such as self-driving cars, autonomous

AI taxis, and smart roads, several additional use cases are less spectacular but quite beneficial.

For example, AI systems visually monitor crossings and pedestrian/cyclist pathways to detect traffic accidents and improve safety. AI in transportation investigates traffic patterns to identify the causes of delays or congestion [20]. Gen AI leverages cutting-edge computer vision techniques to analyze video streams, detecting risky behaviors like distracted driving, speeding, lane drifting, and running red lights. By promptly identifying these actions, the system can send instant alerts to the drivers involved, thus averting potential accidents.

Gen AI's capacity to interpret and assess natural language data is crucial in comprehending and addressing incidents. For instance, it can analyze reports from emergency services, social media platforms, and other communication channels to identify accidents or traffic disruptions. By merging this data with real-time sensor information, Gen AI can offer a holistic scenario view, enabling more efficient incident management and response [12].

Gen AI plays a crucial role in smart transportation by focusing on preventive measures, particularly in vehicle maintenance and health monitoring. IoT sensors in vehicles collect a wealth of data on engine performance, brake conditions, tire pressure, and other essential components. By analyzing this data, Gen AI can anticipate potential mechanical issues, schedule maintenance promptly, and ultimately decrease the chances of accidents resulting from vehicle malfunctions.

Gen AI is instrumental in advancing driver assistance systems (ADAS) and autonomous driving technologies. These systems heavily rely on AI to interpret sensor data and make split-second decisions to prevent collisions. For instance, Gen AI can improve adaptive cruise control, lane-keeping assist, and emergency braking systems by offering more precise predictions and responses through continuous learning from new data [6].

The integration of Gen AI in smart transportation also supports optimizing traffic flow and reducing congestion, which are crucial for preventing accidents. By analyzing traffic patterns and predicting congestion points, Gen AI can suggest alternative routes and optimize traffic signal timings to ensure smoother traffic flow. This proactive management reduces the chances of accidents caused by sudden stops, lane changes, or driver frustration due to traffic jams.

Another significant contribution of Gen AI is in the realm of collaborative and connected vehicles. Vehicle-to-everything (V2X) communication allows vehicles to share information with infrastructure. Gen AI processes this information to enhance situational awareness and predict potential incidents. For example, if a vehicle detects an obstacle on the road, it can communicate this information to nearby vehicles through V2X, enabling them to take preventive actions [24]. Gen AI contributes to the improvement of smart transportation systems by boosting their overall resilience and adaptability.

In case of any unforeseen incident or accident, Gen AI in organizing a prompt and efficient response by collaborating with emergency services, redirecting traffic, and delivering real-time updates to those affected. This dynamic ability to respond effectively assists in minimizing the consequences of such incidents and expedites the restoration of normalcy. Gen AI is proficient in handling and evaluating vast amounts of data in real time. This data originates from a variety of sensors and devices integrated into vehicles, infrastructure, and the surroundings. These sensors gather details on factors like vehicle speed, location, driver conduct, weather, and road conditions.

Through continuous monitoring of these data streams, Gen AI can pinpoint trends and irregularities that could signify potential safety hazards or incidents. For example, Gen AI can identify sudden changes in a vehicle's speed or erratic driving behaviors and highlight them as possible risks. By examining past data, Gen AI can forecast areas and times with a higher likelihood of accidents. This predictive feature enables transportation authorities to take pre-emptive actions, such as modifying traffic signal schedules, deploying safety personnel, or sending real-time alerts to drivers regarding dangerous situations [25].

Utilizing advanced computer vision techniques for analyzing video data from surveillance cameras and in-vehicle cameras, Gen AI can effectively identify risky behaviors like distracted driving, speeding, lane drifting, and running red lights. By recognizing these behaviors in real time, the system can promptly alert the drivers involved, thus averting potential accidents. Computer vision AIds in monitoring road conditions and spotting obstacles or hazards.

For instance, Gen AI can spot potholes, debris, or road damage and promptly inform the necessary authorities to address these concerns. This proactive strategy not only helps prevent accidents but also enhances overall road maintenance and safety [32]. Gen AI plays a crucial role in comprehending and addressing incidents by utilizing its capacity to synthesize and evaluate natural language data. It can analyze reports from emergency services, social media platforms, and various communication channels to identify accidents or traffic disturbances.

Through the integration of this data with real-time sensor information, Gen AI can offer a detailed analysis of the scenario, enabling better incident management and response strategies. Gen AI also has a significant impact on the maintenance and monitoring of vehicles. With the integration of IoT sensors, vehicles can generate extensive data regarding engine performance, brake conditions, tire pressure, and other vital components. By analyzing this data, Gen AI can accurately predict potential mechanical failures and efficiently schedule necessary maintenance, ultimately minimizing the risk of accidents resulting from vehicle malfunctions.

Gen AI plays a crucial role in improving incident detection and accident prevention in smart transportation by leveraging its advanced data analysis, predictive abilities, and real-time monitoring. Through the integration of data from diverse sources, analysis of patterns, and anticipation of potential risks, Gen AI empowers proactive management of transportation systems. Its utilization of in-vehicle health monitoring, ADAS, traffic optimization, and V2X communication further enhances the development of safer and more efficient transportation networks. As technology progresses, the role of AI in smart transportation is anticipated to broaden, leading to even more remarkable advancements in road safety and efficiency.

6 Traffic Management and Optimization: Gen AI Impact on Smart Transportation

Traffic management encompasses the coordination, guidance, and regulation of traffic flow, including vehicles, traffic lights, infrastructure, pedestrians, and bicycles. The integration of AI-based video analytics has revolutionized the field, giving rise to Active Traffic Management (ATM) for real-time traffic control.

The global AI in transportation market was valued at USD 4.55 billion in 2023, with a projected CAGR of 12.4% to reach USD 23.11 billion by 2032. This growth reflects the growing reliance on artificial intelligence to improve safety, efficiency, and sustainability in transportation networks globally [27]. By 2050, it is estimated that 68% of the global population will reside in urban areas. The integration of AI-driven smart city transportation networks will play a vital role in managing traffic flow, improving public transportation efficiency, and creating a more sustainable and livable urban environment [16].

The application of artificial intelligence in the transportation sector is essential for enhancing the effectiveness, sustainability, and safety of urban travel. AI technology is utilized to optimize various transportation aspects, including traffic control and public transit services. AI-powered mobility systems contribute to sustainability efforts by reducing greenhouse gas emissions and lessening environmental impact [17].

Through dynamic routing algorithms, travel routes are optimized to minimize fuel consumption and emissions, while AI technology in transportation enhances vehicle performance and efficiency, resulting in reduced fuel consumption and emissions due to mechanical issues and inefficiencies. AI–driven traffic management systems prioritize alternative transportation modes like public transit, cycling, and walking, reducing dependence on single-occupancy vehicles and promoting eco-friendly transportation solutions [11].

AI-driven navigation applications and mobility platforms offer personalized route suggestions and transportation choices that take into account individual preferences and accessibility requirements, empowering individuals with disabilities to navigate urban areas with greater independence and efficiency. AI-driven solutions bolster safety in all modes of transportation by recognizing and addressing potential dangers in real time.

Sophisticated driving assistance systems (ADAS) that leverage AI algorithms can identify risks like pedestrians, bicycles, and other vehicles, issuing warnings or activating autonomous emergency braking to avert accidents. AI-powered traffic control systems optimize signal schedules, lane allocations, and intersection layouts to minimize the risk of collisions and boost overall road safety. For example, Mobileye, which focuses on enhancing road safety through cutting-edge technologies, began with a small team led by Professor Alex Khang, to transform the driver-assistance industry using a single camera and a system-on-chip [15].

Presently, around 170 million EyeQ™ chips are in use worldwide. This serves as a testament to one company's commitment to road safety, underscoring the extensive global initiatives AI aimed at improving road safety [13]. Gen AI is a game-changing technology that is reshaping the landscape of traffic management and optimization. By harnessing the power of advanced data analytics, machine learning, and real-time processing capabilities, Gen AI can tackle persistent issues in urban mobility. These challenges include traffic congestion, inefficient routing, and unpredictable traffic patterns.

Through its ability to dynamically control traffic signals, optimize routes in real time, and predict traffic patterns, Gen AI greatly improves the efficiency and smoothness of transportation systems [35]. The rapid progress of technology has had a profound impact on different industries, and transportation is one of the sectors that has greatly benefited from it. Gen AI has emerged as a potent tool in optimizing traffic management and improving the efficiency of smart transportation systems. By harnessing the capabilities of AI, cities can effectively tackle the increasing challenges of urban mobility, alleviate congestion, enhance safety, and establish more sustainable transportation networks [34].

Gen AI, a subset of artificial intelligence that focuses on generating new data and solutions, plays a crucial role in traffic management by predicting and responding to real-time traffic conditions. Its wide range of applications includes traffic flow prediction and optimization, where AI algorithms analyze data from sensors, cameras, and GPS devices to forecast traffic patterns and recommend alternative routes, ultimately reducing travel times and minimizing congestion.

AI-powered adaptive traffic signal control systems adjust the timing of traffic lights based on current conditions, ensuring smoother traffic flow and decreasing waiting times at intersections. Gen AI also excels in incident detection and management by swiftly identifying accidents, breakdowns, and other incidents through video feed and sensor data analysis, providing authorities with accurate information for quicker responses and minimal traffic disruption.

AI enhances public transportation efficiency by forecasting passenger demand and optimizing routes and schedules, ensuring buses and trains operate at maximum capacity and enhancing service reliability. AI-powered smart parking solutions tackle the challenge of finding parking in bustling urban areas by directing drivers to available spaces using real-time data, thereby reducing search times and easing congestion [9]. This holds great importance as it enhances the safety and efficiency of the traffic system by decreasing emissions, preserving resources, promptly identifying safety–critical incidents to lessen injuries and accidents, and enforcing traffic regulations.

AI algorithms have the capability to examine historical as well as current traffic data, merging this data to gain a deeper insight into traffic flow behaviors and developments. Traffic planners employ predictive analytics to forecast future situations, allowing them to allocate resources more efficiently, streamline routes to alleviate congestion, and modify traffic signal schedules. This forward-thinking strategy improves overall traffic control, guaranteeing smoother and safer transportation systems [8].

AI-powered navigation applications have completely transformed the way people navigate and travel. In addition to providing basic directions to specific destinations, these apps leverage real-time traffic data from multiple sources like GPS signals, traffic sensors, and user-generated information. This valuable data is then used to dynamically reroute vehicles based on the current traffic conditions. An essential aspect of this approach is the implementation of variable speed limits (VSL), which can be adjusted in response to congestion or weather conditions, effectively managing and optimizing the flow of traffic.

Smart traffic management involves a well-coordinated network of interconnected processes, where each process affects the functioning of others. AI plays a crucial role in facilitating this coordination, allowing traffic personnel, drivers, and commuters to optimize their travel routes and save time more efficiently. For instance, during peak traffic hours, a technique called hard shoulder running (HSR) is often employed. This involves utilizing the hard shoulders as additional driving lanes temporarily to increase the capacity of highways [18].

AI-driven approaches can accurately predict changes in traffic demand, enabling staff to prepare more effectively for such scenarios. By enhancing the responsiveness and adaptability of traffic management systems, AI contributes to creating travel experiences that are not only more efficient but also safer [5].

7 Conclusion

The revolutionary influence of Gen AI on Smart Transportation Systems is extensive and significant, ushering in a fresh period of effectiveness, security, and creativity. Positioned at the crossroads of technological progress and urban development, Gen AI provides answers to numerous critical issues encountered by contemporary transportation systems. Gen AI brings significant contributions to smart transportation by enhancing efficiency and optimizing operations.

Unlike traditional transportation systems that often face inefficiencies caused by static scheduling, traffic congestion, and underutilized resources, Gen AI can analyze vast amounts of data and predict patterns. This enables it to optimize traffic flow, alleviate congestion, and improve route planning. By integrating real-time data from various sources like GPS, traffic cameras, and social media, Gen AI can dynamically adjust traffic signals, propose alternative routes, and optimize public transportation schedules.

As a result, travel times are reduced, fuel consumption is lowered, and greenhouse gas emissions are decreased, ultimately contributing to a more sustainable urban environment. Transportation safety is of utmost importance, and Gen AI is instrumental in elevating it. By utilizing sophisticated predictive analytics, Gen AI can detect potential dangers and forecast accidents before they happen. The undeniable impact of Gen AI on Smart Transportation Systems is clear. By boosting efficiency, enhancing safety, customizing user experiences, and bringing about economic and social advantages, Gen AI is set to transform the way we travel in urban areas [19].

To effectively address the challenges and opportunities that come with this technology, it is crucial to embrace a collaborative and forward-looking mindset, guaranteeing that all members of society can benefit from the advancements of Gen AI.

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Declarations

Conflict of Interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this chapter.

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Intelligent Electronic Ticketing Platform in Smart Transportation Ecosystem

Mohit Yadav, Khushwant Singh, Kavita Thukral, Shivani Kwatra, and Dheerdhwaj Barak

Abstract The conductor gives the ticket in the traditional transportation system. The entire process is essentially paper-based and tickets are provided on printed papers. Both the amount of money received and the distance traveled by passengers are manually calculated. The cashless system, which makes use of QR Code, is widely used in several countries. In order to replace the manual fare collecting method and increase the efficiency of fare collection, the Transit Smart Card method, a new and innovative Automatic Fare collecting (AFC) System, is introduced in this work. The bus card or the QR reader can be used by passengers in place of a bus ticket. The QR scanner instructs the travelers on how to create an account, connect their band details to the app, and load funds into their wallet. The allocated and collected ticket fare is based on the user's selected destination. The passenger receives an SMS notification with a confirmation of the ticket payment. When a traveler arrives at their destination, the door will open if they scan their ticket to verify they have a ticket. Additionally, the printed materials will be reduced, and the loss of the card is also eliminated. It would ensure that tedious and financial problems like change are kept to a minimum. The current method of delivering Bus Tickets requires the passenger to wait for a long time before the stage closure and then queue to receive the pass. It also helps India become more digitalize.

Keywords QR code · Automatic fare collection · Online payment · Cashless system · Transit smart card

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1 Introduction

Buses are the most widely used kind of public transit in many places nowadays [2]. Typically, an E-Ticket is referred to as a transit card or a travel card. E-Ticketing is used for public transportation buses in our suggested system [5]. The popularity of E-ticketing systems has spread globally and public transportation will undoubtedly profit from these advancements in technology [12]. The following information will be included on Etickets: ticket number, bus number, place of departure, and place of arrival, price, and the number of tickets [52].

In Smartphones or as an SMS in feature phones, an e-ticket will be generated [11]. The bus routes include stops in between the locations and go from Tirunelveli to Madurai, Thoothukudi to Tirunelveli, Tirunelveli to Kovilpatti, Thoothukudi to Kovilpatti and vice versa. Anyone can select the start point, destination, and fare by clicking generate QR [16]. The process of paying is initiated by scanning the generated QR code [27] Debit/credit cards, UPI, and app wallets are all accepted for the e- ticketing payment process [7]. By utilizing cutting-edge technologies to provide a smooth, effective, and user-friendly experience for both passengers and operators, an Intelligent Electronic Ticketing Platform (IETP) completely transforms the conventional public transportation ticketing systems.

In order to streamline the entire ticketing process from purchase to validation, an IETP fundamentally combines real-time data processing, cloud computing, and mobile applications. The platform provides passengers with an array of convenient payment options, such as contactless payment methods, mobile wallets, and credit/debit cards, thereby expediting and streamlining the purchasing process [36]. Furthermore, easy-to-use mobile apps are frequently available for IETPs, enabling travelers to easily plan multi-modal trips, check schedules, buy and store tickets digitally, and more [26, 49].

The platform's capacity to deliver up-to-date details on seat availability, departure timings, and potential delays further amplifies convenience by enabling travelers to make well-informed travel arrangements [6, 28, 40]. From an operational standpoint, data analytics from IETPs give transit authorities and operators important insights that they can utilize to comprehend passenger flow, peak travel periods, and revenue trends [31, 42, 50].

Better scheduling, more effective resource allocation, and increased overall service efficiency are all made possible by this data-driven approach. Furthermore, intelligent electronic ticketing platforms can work in tandem with other smart city projects, like Internet of Vehicles (IoV) systems for public transportation, to provide a seamless urban mobility experience [13, 45]. With features like unique QR codes or NFC-based validation, they also improve security and prevent fraud by guaranteeing that only legitimate tickets are used for travel [15, 51].

Through waste reduction and the promotion of digital transactions, IETPs lessen the dependency on paper tickets and promote environmental sustainability [21, 30, 37]. Moreover, the automation of ticketing procedures lowers the operational expenses linked to manual ticket sales and validation, enabling more efficient and economical management of public transportation [25]. In summary, an intelligent electronic ticketing platform opens the door for a more intelligent and cohesive urban transportation network by improving passenger convenience and satisfaction while also driving operational efficiencies, cost savings, and sustainability for transit systems.

An integrated network of cutting-edge technologies and systems intended to produce more effective, sustainable, and user-friendly urban mobility solutions is known as a smart transportation ecosystem [9, 44]. The main goal of this ecosystem is to improve the whole transportation experience by integrating different elements like artificial intelligence (AI), big data analytics, Internet of Things (IoT) devices, and advanced communication networks. Real-time data exchange and dynamic decision-making are made possible by the seamless connectivity of users, infrastructure, and vehicles in a smart transportation ecosystem [3, 8, 17].

Traffic flow optimization, congestion reduction, and safety are achieved through the analysis of data collected and transmitted by IoT sensors embedded in roads, traffic lights, and vehicles [14]. Traffic management systems with artificial intelligence (AI) capabilities can modify signal timings to prioritize emergency vehicles or lessen congestion during peak hours. AI-driven algorithms can also forecast traffic patterns and recommend alternate routes.

Within this ecosystem, public transportation becomes more dependable and effective thanks to smart ticketing systems that expedite the payment process, real-time tracking of buses and trains, and predictive maintenance to avoid malfunctions. When electric vehicles (EVs) and autonomous vehicles are combined, sustainability and convenience are further improved. EV charging infrastructure is cleverly managed to maintain availability and balance grid demand.

Furthermore, eco-friendly and flexible transportation options are provided by the seamless integration of shared mobility solutions like bike, car, and ride sharing. Users can plan multi-modal trips, access all transportation services, and get real-time travel conditions updates with the help of mobile applications. Urban planning and policy-making are aided by a smart transportation ecosystem, which gives decision-makers important information about traffic patterns, environmental effects, and infrastructure use.

Making better decisions about infrastructure investments, traffic laws, and sustainability initiatives is made possible by this data-driven approach. Additionally, the ecosystem encourages cooperation and innovation amongst stakeholders, such as governmental organizations, businesses, and academic institutions, which promotes ongoing development and adaptation to changing urban mobility requirements. In conclusion, a smart transportation ecosystem offers an all-encompassing, integrated, and adaptable approach to urban mobility that improves user satisfaction, sustainability, and efficiency. It essentially changes the way cities move.

A key component of the smart transportation ecosystem is an Intelligent Electronic Ticketing Platform (IETP), which seamlessly integrates cutting-edge technologies to revolutionize how passengers access and utilize public transportation systems. This platform provides a streamlined, effective, and extremely user-friendly ticketing experience by utilizing a combination of cloud computing, big data analytics, IoT, and mobile technologies.

An IETP becomes a vital component of a dynamic, interconnected network that improves the general functioning and efficiency of urban mobility in the context of a smart transportation ecosystem, doing much more than just making ticket purchases and validation easier. There is no longer a need for paper tickets or cash transactions because passengers can purchase tickets through a variety of digital channels, including websites, mobile apps, and contactless payment methods. These digital tickets can be conveniently scanned or tapped at entry points, expediting the boarding process and cutting down on lines. They are safely stored on smartphones or smart cards. Passengers can plan their trips more efficiently and spend less time waiting thanks to the integration of IETPs with real-time data systems, which gives them access to the most recent information on schedules, delays, and seat availability.

Other components of the smart transportation ecosystem, like intelligent traffic management and vehicle tracking systems, are also connected, guaranteeing that public transportation services can quickly adjust to changing circumstances and remain on schedule. For instance, the IETP can automatically alert passengers and recommend other routes or forms of transportation if traffic congestion causes a bus to run late. These platforms also allow for the purchase of tickets for multimodal travel, which allows users to purchase tickets for trips that combine buses, trains, bikes, and even ride-sharing services through a single, accessible interface.

Operationally speaking, IETPs produce enormous volumes of data that transit authorities can examine to learn more about passenger behavior, peak travel periods, and revenue patterns. Making more informed decisions about resource allocation, route planning, and service enhancements is made possible by this data-driven methodology. By anticipating demand and streamlining fleet management, predictive analytics can also increase operational efficiency and lower maintenance costs by keeping an eye on the health of vehicles in advance. Another important consideration is security. To prevent fraud and guarantee the security of transactions, IETPs include strong encryption and authentication systems.

In conclusion, an intelligent electronic ticketing platform within a smart transportation ecosystem improves operational efficiency and decision-making for transit authorities in addition to revolutionizing the passenger experience by offering convenience, real-time information, and seamless integration across various modes of transportation. Urban mobility solutions that are more effective, sustainable, and user-centered are ultimately the result of this synergistic relationship between sophisticated ticketing systems and the larger smart transportation infrastructure.

2 Literature Survey

Instead of using the ticket, users can scan the QR reader. Following registration, we link our bank account information to this app and add funds to the wallet. Detect the QR code. Therefore, depending on conductor ID, straight money will transfer from the wallet to the transportation firm [29]. Then, you'll get an SMS notice requesting ticket payment documentation. Using a web application, the administrative side (Transport Corporation) determines the financial information for a certain conductor [4]. Then, you can determine the Transport Corporation's daily amount statistics for buses. This application provides a useful online bus pass system and uses a database to record passenger data. It is incredibly helpful because it lowers paperwork, saves time, and streamlines processes [1]. When a pass expires, the user can renew it by extending the pass's validity. Users may obtain a pass at any time and any location. It creates monthly, annual and daily bus passes.

In order to improve efficiency, convenience, and sustainability, the Smart Transportation Ecosystem's integration of Intelligent Electronic Ticketing Platforms (IETPs) is a major step forward for urban mobility. Aspects like technology integration, user experience, operational benefits, and future potential are all covered in the literature on IETPs. In order to give readers a thorough grasp of the function and significance of IETPs in smart transportation systems, this review summarizes the most recent research [10].

The cornerstone of IETPs is their capacity to make use of numerous cutting-edge technologies, including big data analytics, cloud computing, Internet of Things (IoT), and mobile applications. According to some researchers, cloud computing makes it easier to store and process data in a scalable and reliable manner, which is essential for managing the massive amounts of real-time data and transaction volumes produced by contemporary transportation systems. The seamless communication between passengers, vehicles, and infrastructure made possible by IoT devices, such as smart sensors and NFC-enabled ticketing gates, improves the overall effectiveness of the ticketing process [20].

One major area of concentration for IETP development is user-centric design. With features like digital ticket storage, multimodal journey planning, and real-time updates, mobile applications are essential to enhancing the user experience. With the help of these apps, travelers can buy, store, and validate tickets digitally, doing away with the need for paper tickets and decreasing the possibility of human error. Making more informed travel decisions is made possible by real-time information on schedules, delays, and seat availability, which further improves the passenger experience. There is ample evidence to support the operational advantages of IETPs.

Some researchers point out that by using data-driven insights, IETPs help transit authorities optimize resource allocation and route planning. More effective fleet management and scheduling are made possible by the capacity to examine demand and passenger flow patterns. Predictive analytics can also be used to foresee maintenance requirements and minimize downtime. Fleet management and scheduling can be done more effectively by analyzing demand and passenger flow patterns.

Predictive analytics can also be used to minimize downtime by anticipating maintenance requirements. IETPs have significant negative effects on the environment and economy. Through the automation of ticketing procedures and the reduction of the need for physical infrastructure and labor, these platforms economically lower operating costs. Reducing the use of paper tickets and encouraging public transportation help the environment by lowering carbon emissions and leaving a smaller ecological footprint.

In keeping with international efforts to tackle climate change, the integration of IETPs with electric vehicle (EV) public transportation systems further improves sustainability. Even though IETPs have many advantages, there are certain obstacles to overcome in their implementation. These include the hefty upfront deployment costs, the requirement for strong cybersecurity measures, and the necessity of interoperability across various transportation modes and service providers [18].

The adoption of open standards, improving stakeholder collaboration, and the advancement of cybersecurity technologies should be the main goals of future research and development in order to address these challenges [22]. The body of research makes it abundantly evident that the creation of a smart transportation ecosystem depends on intelligent electronic ticketing platforms [23]. They provide significant advantages in terms of sustainability, operational optimization, user convenience, and efficiency [19]. But in order to fully realize the potential of these systems and overcome the current obstacles, more research and innovation are required. Urban mobility in the future will be significantly shaped by IETPs as they develop and interact with other smart city projects.

Automated Fare Collection (AFC) system's widespread adoption creates a new opportunity. The stations and tap-in and tap-out timestamps for each trip are easily accessible from the AFC system records. A solution that uses only the AFC systems and no other machinery or personnel. Confirming the methodology with a large dataset collected via the Shenzhen metro station. The assessed outcomes offer beneficial inputs for developing for passenger path choice model [32–35].

In order to protect QR code generators and users alike, this article builds a security architecture. The technique is backward compatible with the QR code encoding standard already in use. Utilizing a smartphone application built for Android, the system is developed and evaluated. It was found that the system somewhat increases the amount of time required for integrity verification and content certification.

3 Modules

3.1 Working Principle

The passenger must scan the QR code to obtain information about the journey specifics such as travel from, travel to, and fee. The obtained fare information are sent to the payment module.

3.2 How the Process is Carried Out?

The user confirms the plan by clicking the renew button and the app directs them to the payment screen, where they may complete their online payment using credit or debit card. It simply takes a few seconds to pay for the ticket, after which the app contacts the server and updates the data it has just bought.

3.3 Software and Hardware System Requirements

3.3.1 Software Used

- Language: Java, Android
- Tool Kit: Android SDK Manager.
- IDE: Eclipse/Android Studio
- Frontend: Android
- Database: MySql

3.3.2 Hardware Used

- Processor: i5
- Ram: 4 GB
- Hard Disk: 500 GB
- Sensor: Ultrasonic sensor
- Near Field Communication Reader
- Ticket Vending Machine

3.4 Software Description

3.4.1 Overview of Android

The majority of smartphones, tablets, and other devices around the world run the Linux kernel, which serves as the foundation for Google's open-source and adaptable Android mobile operating system [38, 39]. Since its 2008 launch, Android has expanded quickly to become the most popular mobile operating system, partly because of its open-source design, which promotes user, developer, and manufacturer creativity and customization. With millions of apps and games available, the Google Play Store—Android's official app store—is a thriving center for services and content. Android's UI is designed to be directly manipulated through touch gestures that mimic actions found in the real world, like pinching, tapping, and swiping.

Notifications, system management tools, and strong multitasking capabilities round out this user-friendly interaction model [41, 43]. Furthermore, Android allows rich, context-aware applications by supporting a wide range of hardware setups and sensors, including GPS, cameras, and accelerometers. Android places a high priority on security, as evidenced by features like Google Play Protect, frequent security updates, and a multi-layered security architecture that guards user information and device integrity.

In order to improve productivity and connectivity, the OS also places a strong emphasis on its smooth interaction with the Google suite of services, which includes Gmail, Google Maps, and Google Assistant [46–48]. Furthermore, as demonstrated by features like smart replies, predictive text, and improved image recognition, Android is leading the way in embracing cutting-edge technologies like artificial intelligence and machine learning. Because of its dedication to backward compatibility, a variety of devices—from expensive smartphones to more affordable models—can run the most recent software updates and features.

In conclusion, Android's openness, adaptability, and wide ecosystem support have cemented its standing as the industry's top mobile operating system, spurring innovation and offering a premium user experience on a variety of devices. An operating system, middleware, and essential apps make up the Android mobile software stack. The Java programming interfaces and necessary tools needed to begin developing Android applications are included in the Android SDK. Easily facilitates mobile development; provides a complete phone software stack with applications; to serve as a framework for the creation of software. It is Accessible.

3.4.2 Linux Kernel

- Memory management
- Process management
- Network stack
- Driver model

In addition, the kernel serves as a layer of abstraction between the hardware components and the remainder of the software stack.

3.5 Architecture

Architecture and framework of the model is depicted in Fig. 1.

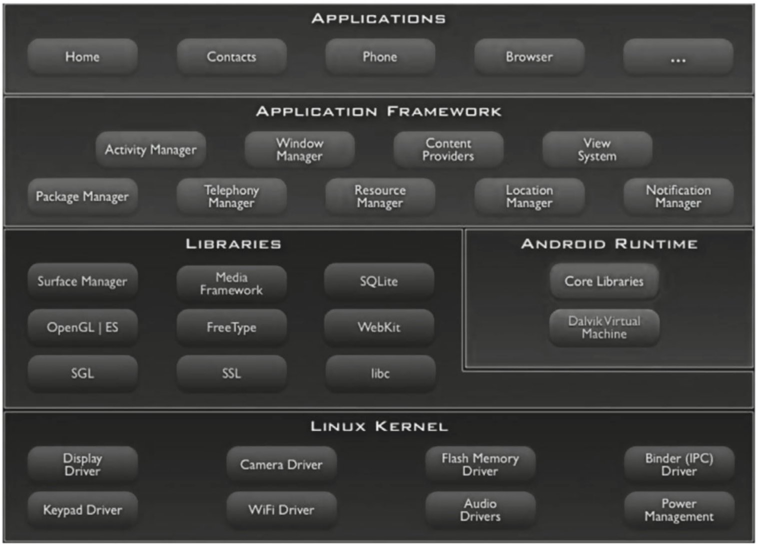

Fig. 1 Architecture and framework of the model

3.6 Development Tools

Various used development tools are such as android emulator and Dalvik Debug Monitor Service (DDMS) as shown in Fig. 2.

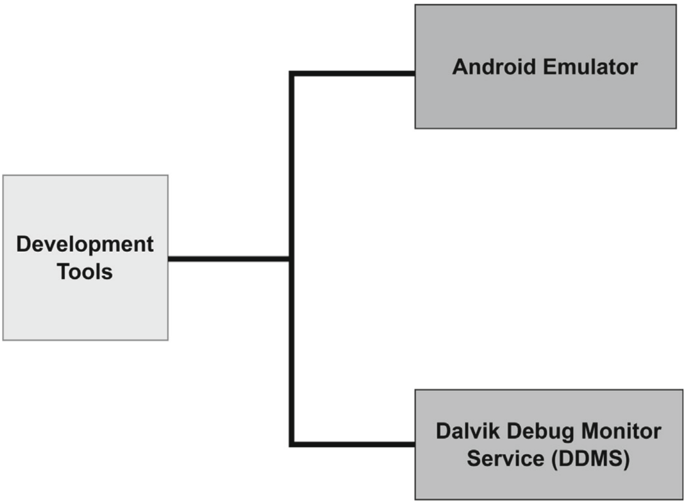

Fig. 2 Development tools of the model

3.6.1 Android Emulator

This computer-based virtual mobile device allows us to develop, test, and debug our apps in a real Android setting. With the help of an Android emulator, developers can test and debug their apps in a virtual environment that closely resembles the hardware and software configurations of actual Android devices on computers. This tool is a crucial component of the Android development process because it offers a flexible and effective means of guaranteeing that applications function properly across a range of Android operating system versions and device specifications.

Many features are supported by the emulator, such as the ability to use the Google Play Store and an entire Android OS experience, as well as the ability to simulate text messages and phone calls and hardware elements like GPS, accelerometers, and cameras. For developers, this feature is essential because it lets them test how their apps react to various scenarios without requiring a number of physical devices.

The official Integrated Development Environment (IDE) for Android development offered by Google is called Android Studio, and it includes the Android Emulator. Android Virtual Devices (AVDs) are virtual devices that developers can create and customize within Android Studio. These devices have distinct features such as screen size, resolution, and Android version. Testing an application's compatibility with the varied Android ecosystem and making sure it runs smoothly on both older and newer devices require this customization.

Advanced features supported by the emulator include integration with the Android Debug Bridge (ADB) for comprehensive inspection and control over the behavior of the app during execution, and network latency simulation, which aids developers in optimizing their apps for varying network conditions. With improvements like hardware acceleration and support for Intel's HAXM (Hardware Accelerated Execution Manager) to speed up emulation on $\times$ 86 systems, performance optimization in the Android Emulator has received a lot of attention.

With these enhancements, the emulator's conventional overhead is greatly reduced, offering testing environments that are more responsive and nearly native in terms of performance. Furthermore, developers can save the current state of the virtual device using the emulator's snapshot and state restoration features, which makes it simpler to resume testing from a particular point without having to restart the emulator altogether.

The Android Emulator's function in pipelines for continuous integration and continuous deployment, or CI/CD, is another important feature. Before deploying to production, automated testing frameworks can use the emulator to run comprehensive test suites on virtual devices to guarantee code stability and quality. By identifying problems early in the development process, this automation shortens the development cycle and improves the application's dependability.

In conclusion, the Android Emulator is a potent and essential tool for Android developers, providing a full range of features that accurately simulate the behavior and configurations of real devices. It is an integral part of the Android app development lifecycle because of its compatibility with Android Studio, capacity to simulate a range of hardware and software conditions, and performance optimizations. The

Android Emulator assists developers in producing reliable, superior applications that function well across the wide range of Android devices by offering a versatile and effective testing environment. The Eclipse unified workspace gains significant improvements from the Android Development Tools Plugin.

3.6.2 Dalvik Debug Monitor Service (DDMS)

This Dalvik-integrated utility helps with debugging and lets us manage processes on an emulator. To make debugging and monitoring Android applications easier, the Dalvik Debug Monitor Service (DDMS) is a strong and adaptable tool that is part of the Android development ecosystem. DDMS, which is a part of the Android SDK, offers developers a full range of tools to monitor and control their apps when they're operating on real devices or emulators. Fundamentally, DDMS gives developers real-time interaction with their apps by providing insights into a range of topics, including thread and heap data, logcat output, network utilization, and process specifics.

The ability of DDMS to monitor an application's heap memory is one of its most important features since it helps developers find memory leaks and optimize memory use. This feature is especially crucial for making sure that apps operate well on hardware with constrained resources. Thread management is another area in which DDMS shines. It offers comprehensive details about every thread operating within the application, including stack traces and thread states. This ability is critical for identifying and resolving concurrency and thread synchronization problems.

The logging mechanism, which is another fantastic feature, is where DDMS shows logcat output, which records system messages, such as warnings, errors, and debug information. For troubleshooting and comprehending the behavior of an application during runtime, this logging is essential. Moreover, DDMS enables video recording and screen capture of the emulator or device, enabling developers to visually record and examine the user interface and interactions.

Developers can track data sent and received by their applications using the network traffic monitoring features of DDMS. This allows for the identification of bottlenecks or excessive data usage, as well as insights into network performance. Apps that heavily rely on network communication can benefit greatly from this feature. Additionally, DDMS comes with a robust file explorer that lets developers upload and download files, browse the file system of the emulator or connected device, and check the contents of shared preferences and databases.

The process of managing app data and testing how apps handle file I/O operations is made easier by this file management features. DDMS is improved by integration with the Android Debug Bridge (ADB), which enables developers to carry out a variety of device actions, including shell commands, application installation and uninstallation, and process start and stop. Because of its close integration, DDMS can be used with other debugging tools and procedures in an efficient manner. Furthermore, DDMS is a crucial tool for debugging complicated problems that might not be readily reproducible due to its capacity to set breakpoints, regulate application execution, and view variables in real-time.

To summarize, the Dalvik Debug Monitor Service (DDMS) is an essential resource for Android developers, providing a stable and all-encompassing setting for tracking, troubleshooting, and optimizing Android apps. Its vast feature set, which includes logging, memory and thread management, network monitoring, file exploration, and smooth integration with ADB, enables developers to identify problems quickly and find effective solutions, which results in the creation of high-caliber, high-performing applications.

DDMS is essential to the Android development process because it gives developers deep insights into the inner workings of applications, enabling them to provide developers' customers with software that is dependable and strong. Android package files (.apk) are created for distribution using the Android Asset Packaging Tool (AAPT). The Android Debug Bridge (ADB) allows you to establish a connection with an emulator that is running right now. You may run commands, install.apk files, and copy files to the emulator.

3.7 Lifecycle of Activity

The lifecycle of activity has been shown in Fig. 3.

3.8 Mysql-Backend

MySQL Enterprise provides extensive services and support. A vast knowledge base library of hundreds of technical articles covering typical database problems like performance, replication, and migration is another feature that MySQL Enterprise provides. An open-source relational database management system (RDBMS) with a high degree of dependability, MySQL is used by many different industries as a dependable backend for their applications.

Originally created by MySQL AB and currently owned by Oracle Corporation, MySQL offers an organized setting for effective data management, retrieval, and archiving. Because of its architecture's capacity to manage massive data operations quickly and reliably, it's a well-liked option for data warehousing, enterprise solutions, and web-based apps. The standard language for database administration, SQL (Structured Query Language), is supported by MySQL and enables sophisticated queries and transactions. Its excellent compatibility with a wide range of programming languages, such as PHP, Python, Java, and C + + , makes it easy to integrate with various software projects.

MySQL's ability to optimize performance is one of its main advantages. Even with high loads, it makes use of sophisticated indexing, partitioning, and caching techniques to guarantee quick query execution and data retrieval. Because of MySQL's architecture, developers can select from a variety of storage engines, such as InnoDB

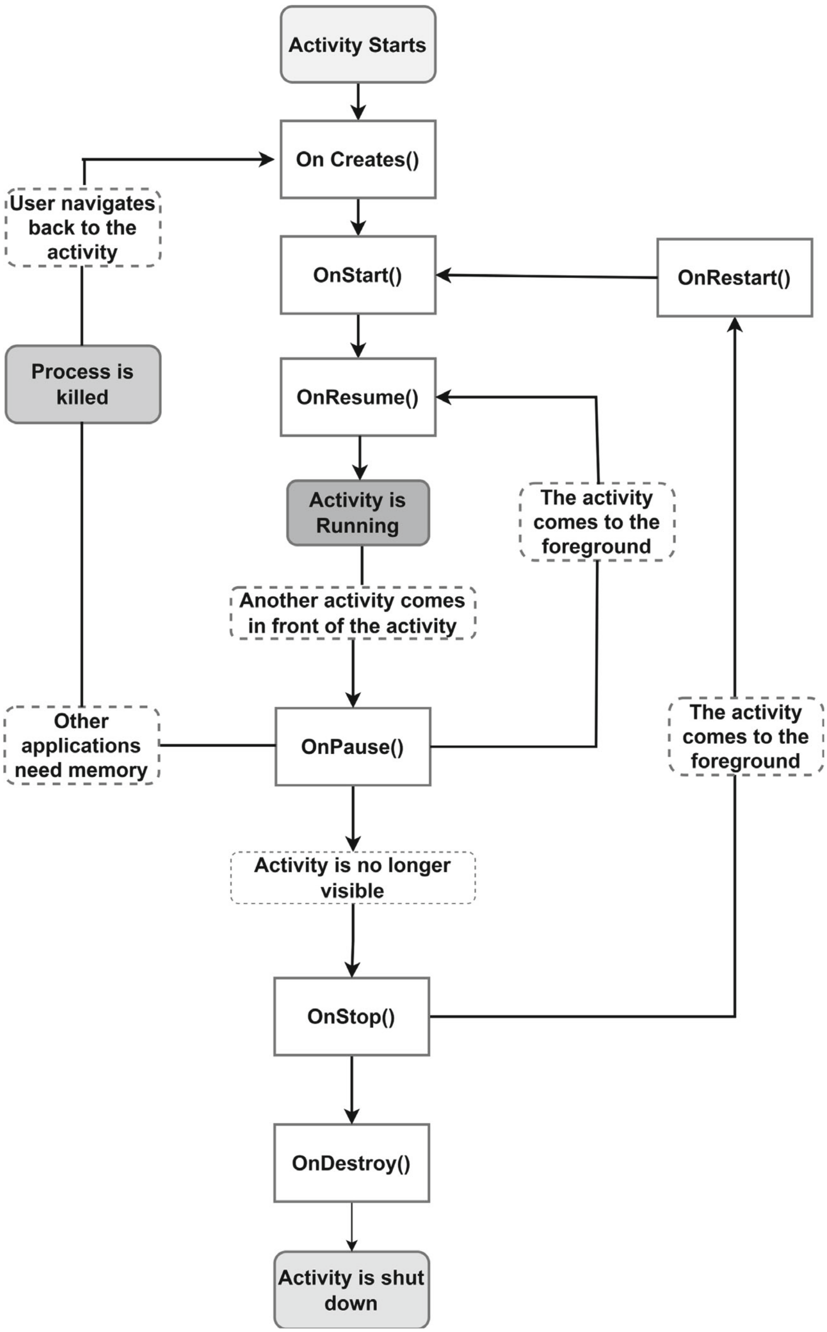

Fig. 3 Lifecycle of activity

and MyISAM, each of which is tailored for a particular set of use cases. For applications needing high data accuracy and security, InnoDB, for example, offers foreign key support and transactions that are compliant with ACID standards, guaranteeing data integrity and reliability.

Strong security features like user authentication, access control, and encryption are also provided by MySQL, shielding private information from online threats and illegal access. Its security resilience is boosted by frequent updates and a robust community support network, which keeps it ready to tackle new threats and vulnerabilities. High availability and scalability are also made possible by MySQL's replication and clustering capabilities, which are crucial for mission-critical services and applications that must continue to function without interruption and expand to meet growing user demands.

Apart from its technical capabilities, MySQL's user-friendliness and administrative tools, like MySQL Workbench, streamline database design, configuration, and administration. Both inexperienced and seasoned database administrators can easily perform tasks like data modeling, SQL development, and performance tuning thanks to these tools' graphical interfaces. Because MySQL is open-source, it also gains from ongoing updates and contributions from a worldwide user and developer community, which promotes creativity and teamwork.

High performance, dependability, security, and scalability all combine to make MySQL a strong and flexible backend option for a variety of applications, ranging from small-scale projects to massive enterprise systems. Its broad adoption and enduring popularity in the tech industry are largely due to its capacity to manage intricate data operations while retaining flexibility and ease of use. MySQL AB develops and manages a range of affordable, high-performance database products. The company's flagship product, "MySQL Enterprise," comes with proactive monitoring tools, production tested software, and first-rate support services. The most popular open source database program worldwide is called MySQL.

4 Methodology

Methodology of the working model includes two components such as coding of E-ticketing process and manual of E-ticketing process.

4.1 Coding of E-Ticketing Process

The coding of E-ticketing process as shown in Fig. 4.

QR Code is generated using visual studio code. After creating the QR Code, the following payment-processing phase is programmed.

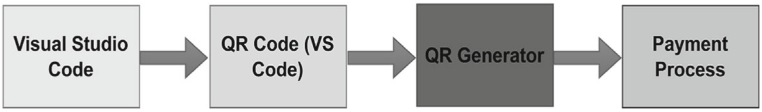

Fig. 4 Coding of E-ticketing process

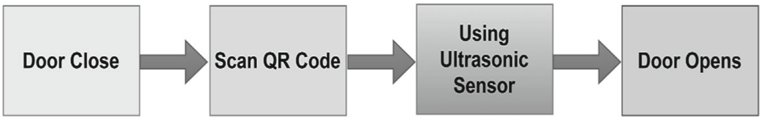

Fig. 5 Manual of E-ticketing process

4.2 *Manual of E-Ticketing Process*

The manual of E-ticketing process as shown in Fig. 5.

The door is initially closed when entering the bus, and then after scanning the generated QR accepting payment, the door is then opened.

5 Results

The start location, destination, and fare must be chosen in order to generate the QR code as shown in Fig. 6.

After that, by clicking Go to Pay, the payment process will begin as depicted in Fig. 7.

After providing the account details, the account data will be confirmed, and the payment confirmation will be displayed as shown in Fig. 8.

6 Conclusions

This module focuses on smartphone-based GPS tracking data. A set of properties, such as GPS mapping, are derived to define the trip state of the Smartphone bearer. In the current method of delivering Bus Ticket, the passenger has to wait for a long time before the stage closure and has to wait in queue to receive the pass. It also aids in the digitalization of India.

In future, E-ticketing systems will be available to everyone, including people with disabilities. One member is assigned to backend development and API integration. Next person is responsible for designing the user interface for mobile application.

Fig. 6 Generated QR code

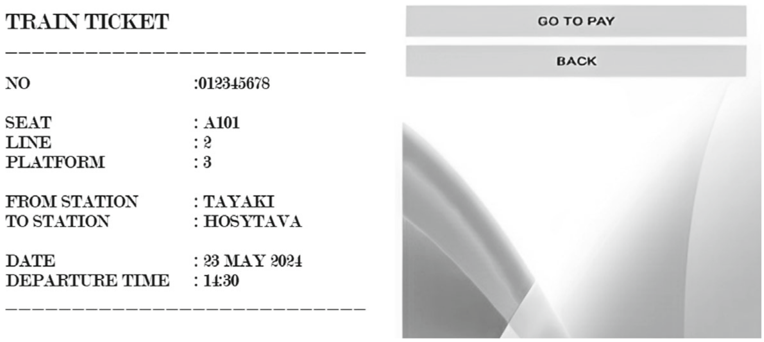

Fig. 7 Order and location

Other one is building the mobile ticketing application. Then the other person is for security specialist [24].

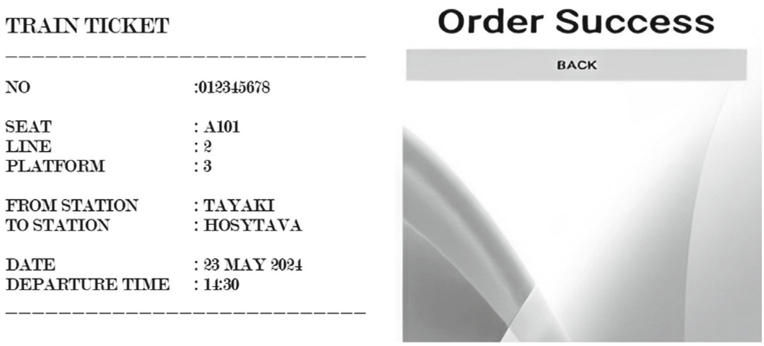

Fig. 8 Order successful and payment

Table 1 depicts the list of abbreviations

1	QR	Quick Response Code
2	AFC	Automatic Fare Collection
3	SMS	Short Message Service
4	ID	Identity Document
5	SDK	Software Development Kit
6	DDMS	Dalvik Debug Monitor Service
7	AAPT	Android Asset Packaging Tool
8	ADB	Android Debug Bridge
9	MySQL	My Structured Query Language
10	GPS	Global Positioning System

7 List of Abbreviations

The collection of abbreviations are presented in Table 1.

Authors Contribution Khushwant Singh: Contributed experiments, conceptualization and methodology. Khushwant Singh, Mohit Yadav, Kavita Thukral, Shivani Kwatra: Contributed Writing and Editing. Khushwant Singh and Mohit Yadav: Contributed Writing – Review & Editing, and Supervision.

Declarations

Conflict of Interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this chapter.

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Enhancing Smart Transportation System: Blockchain Based Integrating Cloud Database Management System

Pankaj Pali, Divya Pandey, and Mahi Yadav

Abstract The World is jumping to the next phase of the Transportation System with rapid development of the Internet of Things (IoT) and Intelligent Transportation System. IoT is the most significant technological advancement allowing smart devices and vehicles to communicate with each other and capable of exchanging information with each other. The Scenario mentioned above, will generate so much data that the ability to handle it appropriately is the foundation of Smart Transportation System and to carry out this action we have two best technologies as of now which are Cloud Database Management System (CDBMS) and Blockchain Technology (BT). In this chapter we explore the Benefits, Challenges and Synergies of CDBMS and Blockchain in Smart Transportation System. The enormous amount of data generated by the Smart Transportation Network requires the technology that is Scalable, Flexible and Efficient which is achieved by CDBMS and Decentralized, Transparent and Secure which is fulfilled by BT. This is particularly true for the pivotal plots, which involve several parties and sensitive data, such as Financial Transactions, owner's information and Vehicles Identification. User's and Service Providers trust is increased because of the Immutable nature of BT, which guarantees that all transactions and data exchanges are Verifiable and Tamper-proof. Moreover, this chapter also projected over to New Developments and Future Enhancements such as using Edge Computing to reduce Latency and role of AI for the Optimized Transportation Networks. This seeks to give Researchers, Practitioners, and Policymakers involved in the creation and implementation of Smart Transportation System useful insights by giving a thorough overview of the current state of Affairs, Technological developments, and implementation techniques. In conclusion, we can justify that the combination of CDBMS and BT stick with notable promise for the enhancement of Reliability, Security and Efficiency of the Smart Transportation System. But in order to realize a genuine Integrated and Intelligent Transportation environment,

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these benefits can only be realized by tackling innate difficulties and encouraging collaboration among diverse stakeholders.

Keywords Smart transportation system · Cloud database management system · Blockchain technology · Internet of things · Intelligent transportation

1 Introduction

We all know that, in the last decade the Internet of Things (IoT) has rapidly increased and use of IoT also increases like an explosion. Due to which the connected devices are also increased as shown in Fig. 1.

As the population increases, the traffic system also changes as more vehicles, more rush and high rate of accidents. So Qilei Ren, et al. [13], proposed an experimental design of Intelligent Traffic System (ITS), which have the following functionalities i.e. monitoring of real time traffic systems, capable of locating traffic emergencies like accidents etc., and managing the use of public transit services. Intelligent Traffic System generates the bulk of data in the traffic flow, which has to be properly managed, secure and easily accessible.

Due to the evolution of Digital Innovation, the convergence of Blockchain and Cloud Computing emerges as a metamorphic force, reshaping Data Security, Data Manageability & Data Leveraging. This union of decentralized ledger enhanced security and operational efficiency but a paradigm shift in digital trust & transparency.

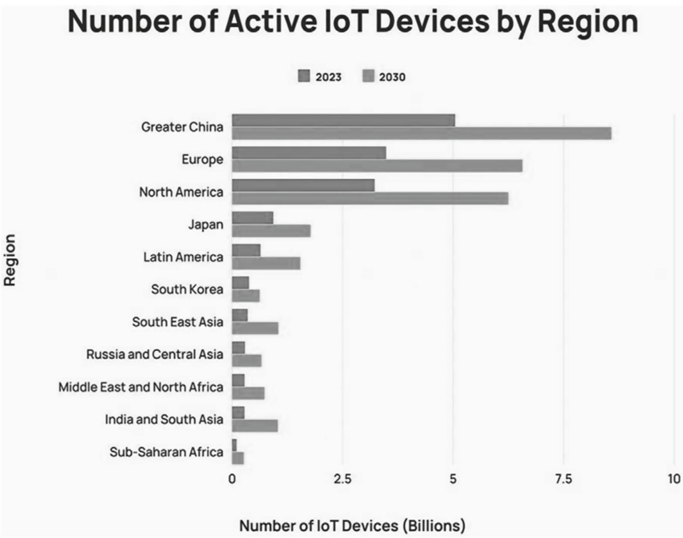

Fig. 1 Active IoT devices worldwide showcasing region wise

Blockchain technology offers a decentralized ledger system where transactions are cryptographically linked and Immutable which ensures that each entry or block is forever carved in a digital fiber, verified by the network of participants rather than a centralized authority.

1.1 Blockchain Technology

Blockchain is a quickly evolving and developing technology that can be compared to as a way of recording all the data in the form of ledger in such a way that it can't be altered or falsified. We can say that this technology acts as an unbreakable digital log. It uses Cryptography based on ethical standards which transform the data and offer decentralized, transparent and safe databases. Blockchain makes it easier for the transmission of money, goods, messages and several other types of data. The databases created by the block chain technology are created with legitimacy that can be checked by the other communities. Due to its distributed nature, allowing for the production of unchangeable accessed and transparent data. This technology has that potential which can make it a favorite tech to everyone and a decentralized global platform.

Blockchain Technology has 3 main elements: Blocks, Nodes & Miners.

1.1.1 Block

Blockchain maintains files are called Blocks in which transaction data is stored permanently. It is distinguished with a unique and specified code called 'Hash'.

1.1.2 Nodes

It represents the computer or system connected with Blockchain through network or internet. It allows all exchanges between the users.

1.1.3 Miners

This element plays an important role in the Blockchain that is to check and verify that the new node which is created following the security standards.

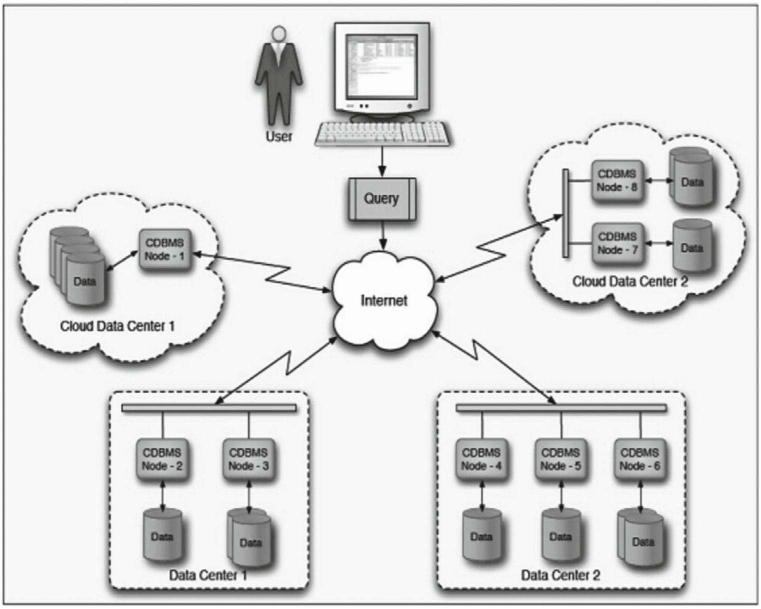

Fig. 2 Cloud structure

1.2 Cloud Database Management System (CDBMS)

Cloud Database Management System (CDBMS) is like a database management system which is accessed by the clients via the internet from the cloud database service provider and is delivered to the user on demand. It makes use of Hardware and Software resources of the cloud computing service providers. As of the survey, 94% of the worldwide companies are deploying their data on the cloud which includes AWS, Google, and Microsoft etc. as shown in Fig. 2.

For storing huge amounts of data CDBMS has become the most adopted technology. It is not like the traditional database which is present on the standalone system, but it needs extra systems or nodes to make it online and helps to increase the performance of the CBMS. Data Availability is the major requirement for this type of architecture to work appropriately as it should be. Data should always be available to the users anywhere and whenever it requests for access.

1.3 Advantages of Cloud Database Management System (CDBMS)

- Flexibility & Scalability: this enables users to modify the resources according to their requirement, free from conventional limitations of standalone systems.

- Cost Efficiency: offers cost-effective solutions to database management unlike with traditional database, you only have to pay-to as per the pricing model of the service provider which is economic.
- Collaborative & Accessibility: it enhances the collaboration as users can access data from any location via. internet, which allows real-time data sharing across geographically boundaries.
- Robust Security & Compliance: huge investment has been done by the service providers for the protection of data from unauthorized access and data breaches. Encryption, Multi-Level Authentication and security audits like features secure the data.
- Performance & Reliability: designed in such a way that provides high performance & is capable of handling huge amounts of data volumes and performing complex queries.

The advancement of the Internet of Things (IoT) has led to the extensive interconnection of IoT devices within networks. These devices continually collect and transmit data to computational nodes for detailed analysis. The rapid progress in deep learning techniques has enabled various applications to utilize these technologies for analyzing collected data, thereby enhancing both "intelligence" and "automation." As a result, integrating data analysis with IoT infrastructure has facilitated the emergence of "Smart Cities," a broad application field that includes smart grids, smart transportation, smart manufacturing, smart buildings, and related areas.

To improve the operational efficiency of transportation systems, it is imperative to more extensively leverage information technology. Intelligent Transportation Systems (ITS), or Smart Transportation, refer to the integration of advanced sensors, computing, electronics, communication technologies, and management strategies to enhance the safety and efficiency of surface transportation systems. These systems aim to optimize traffic flow and safety, thereby reducing travel times and fuel consumption. Effective utilization of IoT infrastructure and seamless integration of information and communication technologies (ICT) are essential for developing a sustainable and intelligent transportation network.

The implementation of advanced communication, electronic, and computing technologies supports information exchange, traffic management, and network administration. Key principles such as sustainability, integration, safety, and responsiveness are crucial when adopting emerging technologies in transportation. These principles are central to achieving the main goals of smart transportation, which include improving access and mobility, promoting environmental sustainability, and fostering economic development.

Smart transportation systems offer significant potential to tackle the issues arising from the increasing urban population, while also improving travel safety. By integrating various traffic control mechanisms across different domains, operating on a large scale, and processing substantial data from diverse sources, these systems can effectively address traffic congestion. Emerging technologies play a critical role in sustaining transportation infrastructures. Innovative techniques for collecting, processing, and disseminating traffic-related information enhance the efficient use of existing transportation networks, facilitating better regulation, control, and management of vehicular traffic. This approach is instrumental in managing congestion and reducing its effects.

2 Literature Review

As we discussed, in the Modern Mobilization System for improving the quality of citizen's life, modern civilization used modern digital technologies which not only reduced the cost of municipal services but also improved the individual life of the people. The way that smart cities are developed is changing as a result of the incorporation of cutting Edge technologies like Blockchain, the Internet of Things (IoT) and Artificial Intelligence (AI). To improve efficiency, security and sustainability, these technologies are being used in a number of industries including Urban Infrastructure, Energy Management and most supremely Transportation System.

With an emphasis on Database Management Transportation System and Cyber Security, this survey of the Literature looks at the current academic contributions that demonstrate how these technologies affect efforts for the creation of Smart Cities. Main challenge with the implementation of the Smart Transportation System in the cities is handling huge amounts of Data generated by the Transportation system in real time. So Bekkali and Essaaidi et al. [2] suggested Blockchain as a perfect technology for Security the data.

A Blockchain based Framework is proposed with the intention of enhancing the cyber security of smart cities. This system protects smart city infrastructure from cyber-attacks by leveraging the fundamental characteristics of Blockchain technology, including decentralization, transparency and immutability. The research emphasizes how important Blockchain technology is lowering risks and protecting data security and integrity in the smart city ecosystem [7].

As technology advances further, our society gains more and more smarter gadgets that improve our day-to-day lives. The Internet of Things (IoT) is one of the most notable of these innovations, it connects a wide range of smart devices including door locks, refrigerators, smart phones, smart watches and fire alarms, allowing for easy data sharing and communication. IoT in Transportation fascinated many researchers, it completely transformed the movement of people and goods. Route optimization, cost effective parking, and accident avoidance are some of the IoT applications in Smart transportation. Exploring the various articles from IEEE Xplore, ACM Digital library, Science Direct and Springer. Oladimeji and Gupta et al. [1], concentrated on the communication mechanisms and framework that supports Intelligent Transport System (ITS).

The examination of the communication protocols such as Bluetooth, Wifi, and Cellular networks, which guarantees smooth data transfer. Until now, we easily identified that carrying out Smart transportation system data plays a vital role in it. As already discussed, huge amounts of data generated, so enhancing data management and security, Kalajdjieski and Raikwar et al. [3], inspects and provides a complete overview whether various databases are compatible with blockchain technology or not. To do this various databases are given a thorough examination of how blockchain might be incorporated into current database systems. This study plays up the necessity of databases that are able to meet up the demands of blockchain technology in order to provide reliable and safe data storage options for applications related to smart cities.

Significant issues are brought on by Urban traffic congestion, such as longer traveling time, fuel costs and pollution. Vadivel and Hussain et al. [14], examines and proposed a promising solution for the above problem, i.e. IoT enabled Wireless Sensor Network. This Sensor network collects all the paramount data in the regular traffic flow like vehicle density, road conditions. The Literature Review highlights how these technologies can be used to build a more adaptable and efficient Urban Transportation System.

We are living in the era where Smart sensors, social networking and cloud computing are all over the people. Most peoples around the world currently reside in cities, many of them follow a predefined route to and from every day, which causes congestion problems as already mentioned above. So Prakash and Murali et al. [12], also proposed a solution i.e. Intelligent Internet-of-Vehicles (IoVs) traffic congestion system. This system is actually a tree-based Machine Learning (ML) predictive model which makes decisions on the basis of some conditions which are generated at runtime of traffic. It detects the congestion in the traffic at minimal costs which make it more suitable for the urban cities as due to its industrial area, it becomes easy to install this system as the Internet is so easily accessed.

This era is called the Digital World because in today's world many of the devices are electronic devices and due to the growth of IoT technology, most of the devices are connected to it. Since devices are generating such a huge pile of data which is to be managed and becomes mandatory for the smooth functioning of the system. So here the best technology to support this is Cloud Data Storage. But cloud databases are very different from traditional databases. So Alam and Shakil et al. [10], shows us a well-defined architecture for cloud data management. Here, a new architectural model for cloud database management system is developed which contains 3 levels Object Oriented database architecture: schema contains Conceptual Level, Internal Level and Physical data organization.

With the advancements of Digital Communication technology, many researchers diverted toward the technology called Digital Twin. Its concept is simple, here there is an entity or system which reflects itself in different platforms and performs bidirectional data accessing. Here Jafari and Fard et al. [11], investigates and proposes how Digital Twin can be originating and developed to fulfill the tasks in the real world. Digital Twin technology can be applied to the multi section technologies like smart transportation system, smart grid, microgrid technology etc. which is more important for the establishment of the smarter cities. Also, the security of the data is discussed which is solved by Machine Learning. Digital Twin can be deployed to various power system applications.

Due to the continuous development of the IoT, a variety of intelligent systems are developed which will improve the daily life routine of the individuals by increasing their effectiveness and security. Particularly, if we talk about the transportation system, this industry goes through a lot of changes from generations. The fastest growing technology in this field is to make a highly Intelligent Traffic System which will improve the fuel efficiency, decrease the traffic congestion and improve the road safety. As per studies, the mail duties of an intelligent traffic system are as follows:

- Real live traffic conditions should be able to be tracked.
- Able to identify traffic emergencies in assigned areas.
- Dynamically monitor and manage ongoing use of public transportation services like shifting of the vehicle to the wrong lane or moving in the wrong direction etc.

The proposed system works on two levels, firstly it captures the changes happening in the transportation and secondly, after the identification it generates a token to that driver or vehicle owner regarding the misuse of the transportation services and not following the rules and policies which are payable, means the driver had been fined. Initially, this works on the simulation scenarios that are described. In real scenarios, a more complex system has to be implemented integrating with other technologies and in terms of security new measures have to be considered.

3 Problem Statement

Until now, it can be seen that this research paper is mainly focused on 'how to secure and optimize the huge amount of data which is generated by the different devices used in smart traffic systems. The problem with this type of system is that the data is not properly handled not only in terms of Data Accessibility, but also other important characteristics of data which are more important for the efficient and effective fulfillment of its tasks or purposes. The characteristics are mainly data Security, Integrity, Confidentiality, Scalability and Availability.

While standard encryption might not offer complete data confidentiality to cloud data, as noted Kumar and Bhatia et al. [9]. The encryption keys can become the weak point of these techniques and managing these becomes very difficult. So maintaining security while appropriate data processing and analysis is quite a difficult task. So new emerging techniques like Homomorphic Encryption and Multi party computation researched more before applying it to the real world.

3.1 Data Security

Smart and Intelligent transport systems handle or generate some sensitive data like vehicle information and location, owner's personal information and its details. So this type of crucial information should be taken care of as a priority.

3.2 Data Availability

Data Availability guarantees that customers can always access cloud services and data from the cloud. So situations like operational interruption, downtime of server can cause financial losses. Also, Data Availability to work perfectly should also deal with some other tech problems like Denial of Services (DDos Attack), Hardware failure and Network interruption.

Kumar and Bhatia et al. [9], traditional techniques which commit data availability are not able to effectively manage the complexity of the cloud when data is stored in different locations. Creating durable infrastructure and adaptation approaches is able to react quickly to these attacks in order to maintain continuous accessing of data.

3.3 Data Integrity

From these types of Implementation in the urban cities, the integrity and transparency of the data are mandatory. Tempering of the data creates a mesh which emerges from ambiguity problems, inconsistency and compromising confidentiality.

3.4 Data Confidentiality

Data Confidentiality ensures that the data can be accessed only by the authorized persons and entities. Due to the nature of Cloud, it increases the data breach risk and unauthorized accessing through which data can be tempered. As mentioned above, how encryption keys themselves become a point of vulnerability and managing the key is a difficult task. So ensuring confidentiality while making the data available for processing and analysis is a unique challenge. Kumar and Bhatia et al. [9], focused on emerging security providing techniques like Homomorphic Encryption which can solve the above problem.

4 Proposed Methodology

4.1 System Architecture

The three main components of the proposed system are combined to achieve the security, scalability and effectiveness of the data.

4.1.1 Data Collection Layer

This layer is responsible for the collection of data from various sources like sensors, vehicles GPS devices & cars built-in sensors. The data obtained contained a variety of traits such as user's behavior, traffic conditions, coordinates of the vehicle position, speed of the vehicle, etc. This comprehensive analysis of data promises an effective dataset for further processing and investigations.

4.1.2 Blockchain Layer

For the intent of safeguarding and documenting each transaction and information updates, the block chain layer is crucial. This layer ensures the details integrity and immutability by utilizing cryptography techniques. Every transaction is encrypted and connected to earlier entries by using unique and specific code called 'Hash' already discussed above [6].

4.1.3 Cloud DBMS Layer

Scalable and adaptable data storage options are offered by CDBMS. It ensures the enormous amount of data received is effectively stored and instantly accessible. As cloud architecture is dynamically scalable, the system can handle different data loads and carry out complex evaluations without dropping the performance of the system.

4.2 Security Measures

In the Cloud DBMS, it is crucial for ensuring the security and integrity of the data, particularly when dealing with sensitive and important data. This proposed methodology describes an effective approach for data security using Audit traits, Access control and Encryption- all of which are added to complete the security framework.

4.3 Encryption

Data Encryption is the fundamental approach of our proposed methodology for providing security. While dealing with encryption, the important concept is to ensure that at what stage of the data encryption should be performed. Crucial time for performing the encryption is when data is being transmitted and when it is being stored. By default, the Network or the Internet provides End-to-End Encryption technologies such as Transport Layer Security (TLS) used to protect data when it is transmitted between users and the cloud database.

By doing this, it is impossible for the attacker to attack the data or to get intercepted by the attackers. When data is at rest, i.e. on the cloud DBMS, it is encrypted by the Advanced Encryption Standard (AES) or by other encryption techniques to encrypt data present at rest. In today's era, Maximus techniques used for encryption are AES because of its strong security and effectiveness. AES protects the data like a shield even from the data breaches or unwanted access. As AES uses different keys for the encryption, a separate Key Management System is preferred to manage all the keys which guarantees restricted and watchful key access.

5 Implementation Details

5.1 Data Gathering

5.1.1 Deployment of Sensors and GPS Devices

First step for the implementation of such a system is deploying a vast network of Sensors and GPS devices as many vehicles from today's worlds have inbuilt GPS (works perfectly with this one also). The devices deployed strategically so that we can collect the real time data on different traffic condition, vehicles positions and environmental element. The sensors which are deployed record the information about flow rates, density of the traffic and the speed. The GPS unit which is installed gives the exact vehicle geolocation data. For the smooth working of Smart Transportation System fast and correct data collection is essential.

5.1.2 User Inputs

Smart Transportation System doesn't only depend on the traffic data collected from GPS and other sensor devices installed as discussed above. But also the data from other devices like mobile. Mobile Applications and other interfaces also generated some data which can be beneficial for the improvement of the proposed system. So, data from user inputs are also taken care of and also collected automatically. This data includes preferences of the user, event warnings and traffic reports etc. User interacts with the system with some interface like mobile application which provokes submission of the real time data, feedback and retrieval of necessary information. This two-pronged strategy guarantees a thorough framework for collecting data that incorporates both automatically generated data and user provided data.

5.2 *Blockchain Technology Implementation*

5.2.1 Smart Contracts

To automate the recordings and validations of transactions, the block chain layer uses smart contracts. Self-executing contracts, or smart contracts, have the conditions of the contract completely encoded in the code. They eliminate the need for mediators by facilitating, confirming and enforcing contract negotiation or execution. Smart contracts are utilized in the context of Smart Transportation System to handle various types of transactions, including user interactions, data updates and system triggers. This ensures that every transaction is safely and openly documented on the block chain.

5.2.2 Consensus Mechanism in Blockchain

To maintain the blockchain's security and integrity, a consensus method is introduced. The consensus technique used by the system, Proof of Stake (POS), validates the transaction by enrolling the participation of stakeholders. Validators in Proof of Stake (POS) are chosen according to the quantity of tokens they own and are prepared to "stake" as collateral. Compared to Proof of Work (POW), this method uses less energy and provides robust protection against malicious attacks. POS ensures that all of the network's nodes agree on the blockchain's current state, preserving a reliable ledger [4].

5.3 *Cloud Database Management System (CDBMS)*

5.3.1 Designing of the Database

To meet the dynamic data which is needed by the smarter transportation systems, the cloud database is implemented for providing both scalability and flexibility. To manage a wide range of data types and relationships between them, the database schema is precisely organized, guaranteeing effective storage and retrieval of data. Scalability is important as it allows the system to handle growing data quantities without sacrificing efficiency. Redundancy and backup plans are also included in the design to ensure the dependability and availability of the data.

5.3.2 Indexing of the Data

State of the art data searching techniques are used to provide real-time access to the data and optimize query performance. By generating pointers to the recorded data, indexing speeds up the process of retrieving data and cuts down on the amount of time needed to retrieve the frequently requested data. Strategies like hash indexing, composite indexing and B-trees are used to improve database performance. This ensures that the system can efficiently handle real-time data updates and responds to user demands in an efficient manner.

5.4 Integrated System and System Testing

At this phase, in-depth testing is done to ensure that the data flows smoothly and that both layers are Blockchain and Cloud Database operates in pairs. Integrity testing focuses to make sure that each part works properly together, data sending and receiving correctly working, and system operations run as per planned.

6 Conclusion

This study introduces a sophisticated methodology for designing a cutting-edge smart transportation system that integrates blockchain technology with a cloud database management system (CDBMS), aiming to enhance data security, scalability, and overall system efficiency. The proposed architecture has three crucial components, which are the Data Collection Layer, the Blockchain Layer, and the Cloud DBMS Layer.

The Data Collection Layer is responsible for aggregating comprehensive data from various sources, including sensors, GPS devices, and user inputs. Effective data analysis and decision-making is based on this diverse dataset that includes traffic conditions, vehicle locations, and user preferences. Through cryptographic methods and smart contracts, the Blockchain Layer ensures the integrity and immutability of data by recording all transactions transparently and protecting them from unauthorized changes [8].

The Cloud DBMS Layer offers scalable and flexible storage solutions, allowing for efficient management and real-time access to vast amounts of data. The system can handle fluctuating data volumes and perform complex operations without degrading performance thanks to its dynamic scalability. Enhanced security measures, like encryption, access controls, and audit trails, are crucial for safeguarding sensitive information.

The implementation process, including the strategic deployment of sensors, user input collection, and blockchain application via smart contracts and a Proof of STake consensus mechanism, is critical to achieving the system's goals. The cloud database's design and indexing techniques ensure data management and retrieval are optimized to meet real-time demands.

Smart Transportation systems can be advanced with a robust framework provided by the proposed methodology that merges blockchain and cloud technologies. The focus for future research should be on improving scalability, establishing interoperability standards, and exploring advanced techniques to preserve privacy. This method promises to make significant advancements in managing and optimizing complex transportation systems, offering practical solutions to modern challenges in the field of transportation [5].

7 Future of Work

7.1 Scalability Enhancement

More research is necessary to address the scalability issues with blockchain technology in large scale smart transportation systems. The current system faced difficulties at some point to handle huge amounts of data due to throughput and latency. Further study should be done on blockchain to enhance its productivity by splitting blockchain into chunks which are definitely efficient in the allocation of processing load.

7.2 Data Privacy

The major concern with data is its privacy. Protecting the data from unauthorized access maintains transparency at the same time. Future research should focus on advanced preservation of data, methods or algorithms to tackle this issue more smoothly and effectively.

7.3 Enhancement in Analytics

Future research should focus on advanced predictive analytics, anomaly detection and optimization techniques or algorithms to enhance decision making and system performance. Integrating Machine Learning models for analyzing traffic patterns, predicting maintenance needs, and improving route planning.

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Cyber Security for Smart Transportation System

Roheen Qamar, Saima Siraj, and Baqar Ali Zardari

Abstract Modern transportation infrastructure is starting to include more and more intelligent transportation systems (ITSs), which provide towns and cities safe, effective transportation options. However, ITSs' dependence on networked technology also raises the possibility of security flaws that hackers may take advantage of. This chapter examines the several kinds of cyber security assaults that may be directed at Information and Communication Technology Systems (ICTSs), including malware, phishing, remote access, denial of service (DoS), physical, insider threat, and social engineering attacks. It also covers the possible fallout from these attacks, which can include everything from bodily harm to fatalities to service interruptions. Intelligent transportation systems (ITS) are intricate, time-sensitive systems where the availability of cyber security directly affects both the effectiveness of transportation services and the physical safety of road users. While ITS standards are being developed, neither the formation of a security strategy nor the implementation of a complete standard have yet to occur. It is necessary to carefully analyze and evaluate the compatibility between the different ITS standards and the interactions with the outside world (Smart Cities, IoT). Intelligent Transportation Systems (ITS) have been created and implemented during the past few decades with the goal of increasing productivity, promoting sustainable transportation development, lowering environmental impact, and improving safety and mobility. ITS blends cutting-edge technology with the traditional realm of transportation infrastructure, using advancements in information systems, communication, sensors, controllers, and sophisticated mathematical techniques. For a rookie researcher, it might be challenging to get a comprehensive view of the entire system because this is an inter-disciplinary subject of study.

Keywords Internet of things · Intelligent transportation systems · Information and communication technology · Denial of service · Cyber security · Cyber-attacks · Security challenges · Vehicular ad-hoc networks · Vehicle network attack

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1 Introduction

Intelligent transportation systems (ITS) employ a variety of technologies to monitor, assess, and manage transportation networks, therefore improving safety and efficiency. They use information and communication technology to connect transportation infrastructure and vehicles.

Intelligent transportation systems ITS strives to deliver new services for diverse types of transportation and traffic management. The ITS business is expanding rapidly, driven by technological improvements and increased demand for smarter, more efficient transportation networks. In this article, we'll look at the top companies driving the industry's growth, as well as their strategies and contributions to the developing business.

The concept of intelligent transportation systems, or ITS, is new and is defined by dynamics, stringent deadlines, and complicated data models. Transportation efficiency and safety rely on the difficult challenge of ensuring cyber security in ITS. One important stage in the advancement of IT'S is the enforcement of standards for a complete architecture and particular security criteria. The study looks at security concerns and the broad contours of the ITS architecture. The goal of this study is to present an overview of the issues related to ITS security and potential remedies for stopping or overcoming security breaches. Additionally, we offer suggestions for putting better security measures and initiatives into place to safeguard ITS.

The Internet of Things (IoT) is a result of the convergence of various technologies, including real-time analytics, machine learning, embedded systems, wireless networks, control systems, and home and building automation. Consumers associate IoT with items related to the notion of the intelligent home, intelligent healthcare, intelligent city, and so on. Many of these locations share traits and confront comparable issues. Borrowing technology from IoT sub-areas is widespread, but it must be carefully evaluated and investigated in reality. Despite their commonalities, the requirements for communication range and bit rate, real-time operation, dependability, and security differ even within the same field [20].

As a sub-area of smart cities many of the characteristics of IoT apply to Intelligent Transportation Systems (ITS). Their distinguishing qualities include severe time constraints, dynamic behavior, and massive amounts of data. One of the most distinguishing features of the ITS is the increased requirement for cyber security. Transportation safety, road traffic efficiency, and entertainment are three categories of ITS applications. Road safety apps must meet stringent cyber security standards while operating under tight real-time constraints. Although road traffic efficiency and entertainment applications are not directly tied to road users' physical safety, cyber security standards remain high, as a breach in any of them might have an impact on the overall effectiveness of the ITS [11]. ITS structure shown in Fig. 1.

Vehicular ad-hoc networks (VANET) play an important role in all recent ITS projects. In VANET, nodes (vehicles) exchange brief messages known as beacons at specific intervals. The beacons store critical information about cars and the surroundings, such as direction, acceleration, speed, road conditions, weather conditions, and

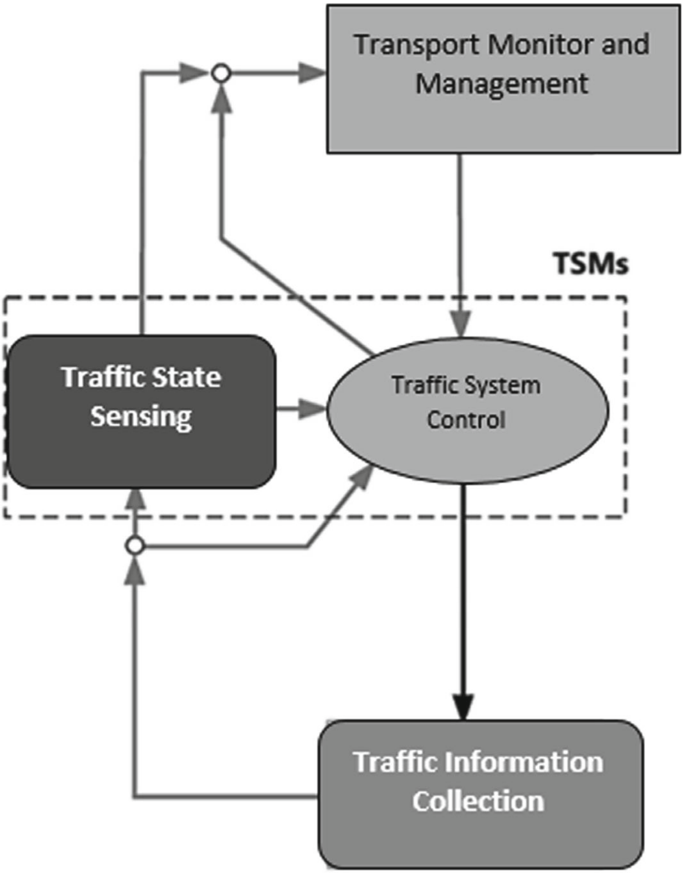

Fig. 1 Intelligent transportation systems (ITS)

so on. Connecting vehicles in wireless one hop communication presents numerous challenges, including authentication of newly joined vehicles, the need to protect the user's identity, interruptions, multi hop communication, and high heterogeneity (depending on whether the cars are congested in a big city or a suburban area). Much of the study on ITS cyber security is focused on network security [8].

2 Architecture and Security Challenges

ITS may be viewed as a subset of IoT, and hence it can be constructed utilizing comparable methodologies and structures. Figure 2 shows the architectural outlines of most IoT advances. It may also be used in ITS [15].

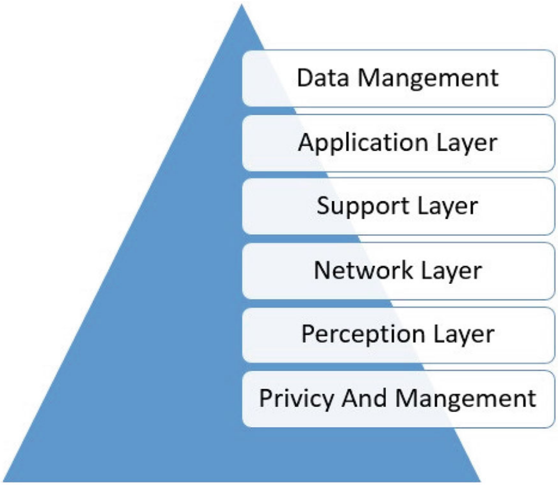

Fig. 2 Architecture and security challenges

2.1 The Data Management

ITSs are data-driven systems that incorporate information and communication technology into transportation infrastructure, vehicles, and management systems.

2.2 Privacy and Management

ITS privacy involves safeguarding sensitive data while leveraging technologies like block chain and biometrics to enhance transportation systems.

2.3 The Perception Layer

Intelligent Transportation Systems (ITS) includes users' cellphones, in-vehicle sensors, and infrastructure equipment. Many security vulnerabilities at the perception layer are focused with the setup and activation of the devices during production and internal vehicular network design, as in most cases they are not meant for connected automobiles.

2.4 The Network Layer

It is a complicated combination of wired and wireless technology. One of the most pressing cyber security issues at this layer is node authentication in VANET. Due to the necessity to secure personal data, authentication must be anonymous. The limited variety of nodes and the severe timing restrictions present further obstacles [22].

2.5 The Support Layer

Data is processed in the fog or cloud, depending on its temporal and geographical characteristics, as well as security concerns. As an emerging technology, fog-based structures provide new security issues since the operating environments of dispersed fog systems are more difficult to defend than a centralized cloud. The present security and privacy measures for cloud computing cannot be immediately applied to fog computing because to its properties, such as mobility, heterogeneity, and large-scale geo-distribution [14].

2.6 The Application Layer

It represents the final interface with the user, which might take the form of information, warnings, or even the activation of a specific system in the vehicle (with unmanned vehicles). Before reaching the user, the data collected in the sensor layer might be processed in several locations. Depending on data semantics, security needs, and time restrictions, computations can be performed locally, in the car, at roadside units (RSU), in the fog, or in the cloud. The data in ITS meets all of the requirements for Big Data, which is a prerequisite for using Artificial Intelligence (AI). Its deployment into security-critical systems such as ITS must be carefully examined, as it is extremely vulnerable to a multitude of assaults [23] (Table 1).

2.7 Cybercrime

As technology becomes more prevalent in people's daily lives, cybercrimes may also rise.

Cybercrime refers to crimes committed via a computer, such as robbery or commission. The US Department of Justice has expanded the definition of cybercrime to include any offense involving technology. A device for storing evidence. Cybercrime now encompasses both computer-based crimes like network intrusions

Table 1 shows the architecture of ITS, as well as cyber security challenges and attacks

Sr. No	Architecture layer	Security issue	Cyber attack
1	Perception layer	Device configuration and initialization during production, as well as designing an internal vehicle network	Threats include denial-of-service, spoofing, and internal vehicle network attacks
2	Network layer	Anonymous authentication in the VANET;	Sybil Attacks; Denial-of-Service; Man-in-the-Middle; Eavesdropping; Routing attacks; Identity attack; Timing attack;
3	Support layer	Cloud protection	Attack over fog
4	Application layer	Complicated data model and AI protection	Data poisoning, environmental disruptions, and policy manipulation [23].

and computer viruses, as well as traditional crimes like stealing, stalking, intimidation, and coercion. Cybercrime refers to the use of a computer and the internet to perform crimes such as identity theft, smuggling, stalking, and disrupting operations using harmful programs.

A cybercrime, often known as a computer-oriented crime, is a crime committed using a computer and a network. The computer might have been used to commit a crime, or it could be the target. Cybercrime is the use of a computer as a weapon to perpetrate crimes such as fraud, identity theft, or privacy violations. Cybercrime, particularly on the Internet, has expanded in prominence as computers have become vital to all fields, including business, entertainment, and government [17] as shown in Fig. 3.

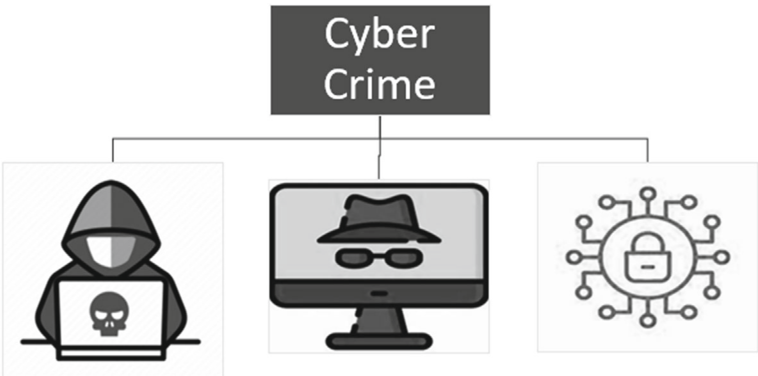

Fig. 3 Cyber crime attacks

3 Cyber Security

Companies prioritize privacy and information protection as their major security measures. In today's digital environment where all data is kept, we favor square measures. While social networking sites offer a safe space to connect with loved ones, cyber thieves may also utilize them to steal personal information. Cyber security is the collection of technologies, methods, and practices that safeguard networks, devices, programs, and data against attack, theft, damage, alteration, or illegal access. This involves utilizing specific applications to detect malicious malware and learning how to identify and avoid online frauds. By practicing proper cyber security, you can keep your data private and your online interactions secure. It is often referred to as Information Security (INFOSEC), Information Assurance (IA), or System Security [16].

Cyber security is the process of securing your systems, digital devices, networks, and all data stored on such devices from cyber assaults. We can protect and defend ourselves from various cyber threats, such as phishing and DDoS attacks, by learning about them. It protects your devices from hackers and viruses by using techniques such as firewalls and antivirus software.

Encryption is a technology that helps to keep your personal information private; only you can read it. Cyber security also teaches you how to recognize techniques such as phishing, in which bad men try to steal your information by seeming to be someone you trust. In brief, cybersecurity ensures that your online environment is safe and secure [21].

4 ITS Cyber Attacks

The diversity of ITS complicates the challenge of categorizing and recognizing cyber-attacks. This section covers ITS-specific attacks that will subsequently be linked to the architectural layers:

4.1 VANET Man-in-The-Middle Attack

The man-in-the-middle attack is a common sort of cyber-attack in which the attacking party intercepts messages between two communicating parties and passes changed material. In the event of a man-in-the-middle assault on the physical and data connection levels in VANET, the attacking party takes into consideration the fact that the nodes have a certain range. They must either attenuate the signal or change the location information if they intend to exploit a circumstance in which the attacked nodes are out of range but the attacking party is within range of both nodes. Example of a man-in-the-middle VANET attack: the attacking party disrupts communication between two or more cars and alters their position data [6].

4.2 Routing Attacks

The physical and data connection levels of VANET define one-hop communication. Routing protocols enable multi-hop communication. Routing attacks occur when there is a break in VANET's routing protocols and a rogue node prevents data from reaching its intended destination. A black hole attack is a type of routing attack in which a hostile node discreetly drops all packets that are intended to be re-transmitted. Gray whole attack is another sub-type of routing attack in which dropping is executed selectively on selected packets [10].

4.3 Timing Attacks

Timing attacks induce communication delays, disrupting the functioning of applications with real-time needs. For example, with a cooperative adaptive cruise control system, an emergency message is delivered to the surrounding car to avoid a collision. If the attacking party succeeds to induce a delay (for example, by overloading the network traffic), despite the accurate reception of the data, the reaction in the braking system will delay and the accident will not be avoided.

4.4 Spoofing

Spoofing attacks include broadcasting faulty data to trigger incorrect reactions in the system. Example: The attacking party sends fake GPS coordinates, interrupting the functionality of the navigation system. As shown in Fig. 4

4.5 Denial of Service Attacks (DoS)

DoS is a common cyber-attack that disrupts the availability of system components. It is particularly risky in IT'S when a safety–critical feature is involved. Sybil is a common VANET DoS attack in which a malicious vehicle impersonates numerous identities and sends false broadcast messages throughout the network. This disturbs the regular flow of information [12].as shown in Fig. 5.

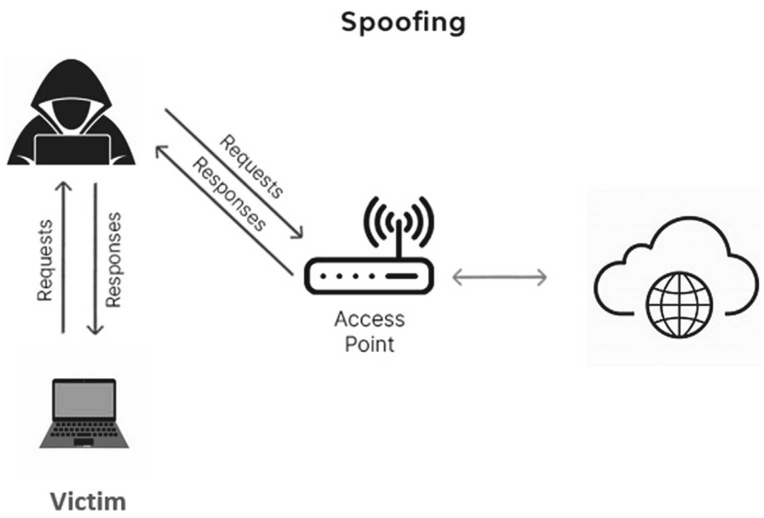

Fig. 4 Spoofing attack by victim

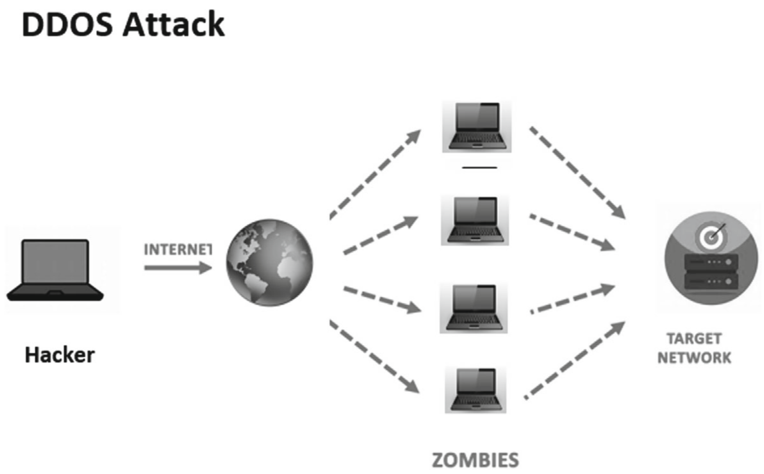

Fig. 5 DDoS attack

4.6 Internal Vehicle Network Attack

Most internal vehicle networks are vulnerable to assaults because they were created before automobiles were linked. For example, the attacker can easily get access to the internal network via the CAN (Controller Area Network) protocol and so manage to operate the airbag control system.as shown in Fig. 6.

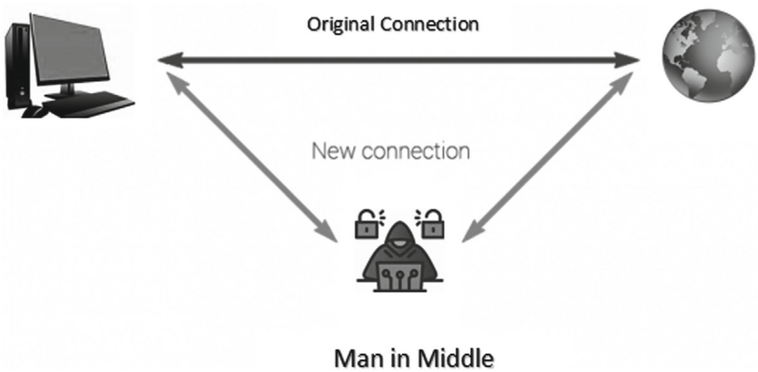

Fig. 6 Vehicle network attack

4.7 Identity Attack

Identity privacy ITS might apply to the privacy of a motorist, passenger, pedestrian, and so on. The attacking party may attempt to get personal information such as location, behaviors, and habits. An example of an identity assault is when the attacking party gets to gain information on how nicknames are assigned in VANET and therefore track the whereabouts of a vehicle.

4.8 Eavesdropping

Eavesdropping is a classic passive attack in which the attacker does not disrupt communication but gains unauthorized access to information. For example, the hostile party may eavesdrop on the communication between the car and the road infrastructure during the payment of the toll, gaining access to the user's bank account information.

4.9 Attack Against Fog

Because of their physical qualities (typically physically accessible) and limited resources in compared to the Cloud, ITS's fog components are difficult to defend and vulnerable to a variety of threats. Example: The fog node aggregates and filters data from sound and vibration sensors. By modifying the aggregated information, the malicious actor immediately influences the data analysis algorithm for planning and organizing road traffic [28].

4.10 AI Attacks

Attacks on AI might be based on data manipulation (data poisoning), environmental perturbations, or policy manipulation. Example: To mislead the machine learning algorithm, the attacking party may pick and submit data to produce misleading trends in the model [3].

5 Related Work

This article provides a brief overview of the key security challenges and various assaults that impede Intelligent Transportation Systems [18]. To allow secure and safe ITS applications, this paper conducts a thorough review of existing systems, highlighting their strengths and limitations. Finally, this study covers major field issues and current developments that academics, implementers, and automobile manufacturers must consider in order to improve ITS security.

With the growth of embedded electronics and wireless capabilities, modern automobiles are no longer isolated mechanical devices. They form part of a hyper-connected system called Intelligent Transportation Systems (ITS), which has the potential to support many degrees of autonomy and intelligence, significantly enhancing the safety, efficiency, and sustainability of transportation networks. However, this poses additional security challenges, making the whole system vulnerable to cybersecurity assaults that risk both the safety and privacy of all road users [9].

ITSs are gaining a lot of interest from business, academia, and the government as they stage the next generation of transportation [25]. Meanwhile, cyber security worries are increasing as cyberattacks become more common and complicated. Recently, game theory has been utilized to describe and predict the behavior of these complicated attacks. In this article, we provide an overview of how game theory might be utilized to secure ITSs against assaults, weighing the benefits and drawbacks in terms of security level and needed cost. Furthermore, we present a new cyber security Stackelberg game-based framework for identifying significant attack traits and therefore improving detection efficiency.

Because of advancements in information technology, the world is evolving toward a more connected environment; smart cities are one example of this trend [4]. Smart transportation is one of the key technologies receiving a lot of attention in the context of smart cities. Smart transportation, often known as the ITS, has solved several transportation-related difficulties. On the other side, it poses several security and privacy concerns. As a result, the purpose of this research is to look at security challenges, privacy concerns, and solutions for smart mobility. The importance of this research rests in introducing the researchers to the many sorts of security and privacy.

Automobiles are becoming increasingly connected, with the capacity to sync with cellular phones, provide atmospheric and navigational alerts for car occupants, and even broadcast safety alerts to all other vehicles and adjacent infrastructures [27]. Although automotive connection or digitalization delivers clear benefits to passenger comfort, including accident avoidance, it has also expanded the ability for attackers to take control autos, endangering the lives of either the driver or pedestrian. Because the attackers can hack vehicle communications, numerous well-known automotive assaults become effective. This study builds on previous debates regarding cyber security issues, including cyber security difficulties and mitigation techniques in intelligent transportation systems and vehicle communications.

To respond to constantly expanding vulnerabilities in software products and cyber threats that exploit them, security experts are actively collaborating with software developers to create more secure systems [26]. Agile approaches are being used in important software projects where security threats are a major concern. This popularity is due to the fact that agile techniques are highly iterative and enable providing services and products in smaller batches, allowing security professionals to effectively combine software development and security operations with agile processes.

Furthermore, the iterative nature of agile software development promotes regular inspections, tests, and patching of software systems to reduce cyber security risks and vulnerabilities. Given the tremendous rise of IoT and ITS goods, the issue of software development while addressing these devices' security and safety concerns will only intensify. This article provides a thorough and exhaustive examination of agile software development in the context of IoT, ITS, and related cybersecurity and risk issues. Furthermore, we present a systematic comparison of the evaluated literature using a set of stated criteria. Finally, we present a larger perspective and a framework for developing future secure agile software development solutions for IoT and ITS systems.

This article first explains prerequisite knowledge before presenting a Hyperledger Fabric-based data architecture for a safe, trustworthy, smart transportation system [11]. The simulation findings reveal a balance between block chain mining time and the amount of blocks generated. We also utilize the average transaction delay assessment model to assess the model's performance and that of the proposed system. The technology will solve people' and authorities' security concerns about the transportation system in smart, sustainable communities, resulting in improved governance.

This paper presents a federated deep learning-based intrusion detection system (FED-IDS) that may detect assaults more effectively by outsourcing the learning process from servers to dispersed vehicle edge nodes [1]. FED-IDS uses a context-aware transformer network to learn spatial–temporal representations of vehicle traffic flows, which are required for identifying various types of assaults. Block chain-managed federated training is demonstrated, allowing numerous edge nodes to provide safe, distributed, and dependable training without the need for centralized authority. Miners on the block chain confirm distributed local updates from participating cars to prevent unreliable updates from being submitted. The studies on two public datasets (Car-Hacking and TON_IoT) showed that FED-IDS outperformed cutting-edge techniques. It demonstrates the legitimacy of protecting networks of intelligent transportation systems against cyber-attacks.

This paper seeks to propose a method for resolving authentication and security challenges in ITS utilizing lightweight cryptography and graph-based machine learning [9]. Our system provides authentication and security to the smart vehicle in ITS by combining identity-based authentication techniques with graph-based machine learning. By authenticating smart cars in ITS and recognizing different cyber risks, our suggested solution significantly helps to the establishment of an intelligent transportation communication ecosystem.

ITS is a new technology that will dramatically transform the driving experience. In these systems, smart cars and Road-Side Units (RSUs) connect via the VANET. Safety applications use this information to detect and avoid harmful situations in real time. Detecting malicious nodes and attack traffic in ITS is an ongoing research topic. Recently, researchers have proposed graph-based machine learning algorithms for identifying rogue users in the ITS environment, making it easier to monitor network data and detect harmful devices. As a result, graph-based machine learning algorithms might be effective in detecting rogue nodes in the ITS system.

This research proposes a cyber-security system that uses existing encryption technologies to construct a safe real-time double hybrid encryption algorithm [24]. As an example, the suggested system is used to a Smart autonomous bike prototype to secure data transit between the bike and the various objects in its surroundings.

The Internet of Things (IoT) applications have received a lot of attention in recent years due to a variety of causes, most notably technological advances in hardware and software. Nonetheless, IoT devices remain vulnerable to assaults due to their characteristics, such as limited compute, storage, and network capacity. IoT is regarded as the cornerstone of the smart city paradigm. ITS-Intelligent Transportation Systems is a key component of a smart city, and Smart Bikes have emerged as an inescapable ecologically beneficial mode of transportation inside ITS. The way various entities in an ITS interact and how those conversations are protected is a major challenge that academics are addressing in a variety of ways.

Authors propose an on-demand DTaaS architecture that fully utilizes ITS sensing capabilities as well as DT's macro viewpoint [19]. Second, a double-auction model and a price adjustment algorithm are suggested to provide optimal DT matching for ITS requesters while also ensuring participants' advantages. Third, a permissioned block chain and a new DT-DPoS consensus mechanism are implemented to improve the security and efficiency of DTaaS. Simulations demonstrate that the suggested DTaaS and double-auction methods may effectively stimulate and facilitate DT transactions. The suggested DT-DPoS has clear advantages.

6 Security Challenges

Identifying potential threats is crucial for Intelligent Transportation Systems. Potential ITS attackers include foreign intelligence, criminal gangs, hackers, cyber terrorists, insiders, unethical operators, and natural calamities. Nation governments utilize specialized software and viruses to acquire intelligence. These attacks aim to steal intellectual property or acquire a competitive edge.

During battle, another nation might undermine a country's ITS infrastructure.

Hacking teams and resources can be directly controlled by the state or outsourced to third parties for plausible deniability. Criminal gangs employ various ITS hacking tactics to generate unlawful cash.

Hacktivists utilize ITS infrastructure to promote political causes. Hackers can exploit message boards on roadways to promote political causes as shown in Fig. 7.

Cyber terrorists target ITS to cause property damage, loss of life, and fear. Insiders may criticize their current or former organization, which may have an indirect impact on their own interests. There are several motivations for these attacks. Unscrupulous operators may target IT'S to evade penalties and fees, avoid traffic, and destroy rivals,

Fig. 7 Cybersecurity attacks

among other reasons. Natural calamities may potentially pose a hazard to ITS. Natural occurrences can cause system failures, possibly crippling the ITS infrastructure [13].

The vast majority of cyber-attacks are motivated by money. Attacks on ITS systems have a significant impact because of their high visibility. This exposure may be a powerful incentive. Possible reasons include ransom, data theft, information warfare, system gaming and theft, retribution, and terrorism. The information can be obtained by physical, wireless, or network assaults. Attacks can occur through one or numerous avenues. Ransom ware assaults encrypt data and systems. Decryption keys are not provided until a ransom has been paid. Attackers can deactivate a connected automobile and demand a ransom to restore functionality. Safety of these autos may be impacted[2].

Stolen data can be utilized for a variety of purposes. Data theft is most commonly carried out by nation governments and unscrupulous rivals. Personal gain is the motivation behind data theft. Information warfare includes denial-of-service attacks on ITS infrastructure. This creates system crashes and pandemonium on the roads. It may also be used to share political messages, demonstrations, and pranks. This might damage the company's reputation and cause financial loss. Fake V2V messages can cause traffic congestion. This attack may cause V2V information poisoning. Map hacking may compromise location transmitters, GPS receivers, and fake GPS signals.

System gaming and theft include taking stuff from inside automobiles or the entire vehicle. ITS systems are often used to avoid paying fees and levies. Autonomous cars may be hacked and redirected to remote locations, or utilized to convey contraband covertly. Autonomous automobiles may be hacked and sent to a remote location, allowing for theft of goods, vehicle components, or even kidnapping [5].

Using an ITS system allows you to avoid paying service charges. MIRT technology enables remote activation of a computer-controlled traffic signal. Hacking a competitor's automobile can disrupt competitiveness and render vehicles unavailable.

Revenge and terrorism are among the most devastating assault vectors against ITS. Driving functions can be hacked and utilized as weapons. Predicting and protecting against these sorts of attacks is challenging. Dumping sensitive data online can disrupt traffic flow control, deactivate ITS safety systems, activate roadside emergency alerts, and jeopardize a company's operations and employee privacy. Hackers typically target ITS systems to get access to the ITS ecosystem. A successful attack on the ITS system allows access to the entire ecosystem via internet or VPN.

ITS infrastructure is vulnerable to physical threats because of its exposed location on highways. Exposed ports can be physically linked. Devices can be accessed by brute force or guessing credentials. To learn topology, scan a secure or closed network. Deleting files may jeopardize an ITS device or system.

Firmware can be used to restore passwords and settings. Man-in-the-middle attacks use exposed wire or connections to intercept traffic and relay fake information to backend systems. Devices can be tampered with to steal or jeopardize data. Malware on removable storage devices can be installed. Incorrect commands may be delivered to the backend servers and controller.

Wireless assaults are a significant IT security hazard to and ITS infrastructure. Spoofing messages, sniffing wireless transmissions, remotely installing malicious firmware, jamming wireless transmissions and vehicle safety systems, man-in-the-middle attacks, exploiting vulnerabilities, and using Wi-Fi to gain access to the controller area network (CAN) bus and on-board diagnostics, infotainment, and can all be done. Remote hijacking can compromise the CAN bus and allow harmful third-party software to be deployed [7].

7 Conclusions and Future of Work

Intelligent Transportation Systems ITS are complicated, time-critical systems that rely heavily on cyber security to ensure the physical safety of road users and the efficiency of transportation services. Although ITS standards are being developed, the implementation of a complete standard and the formulation of a security plan have yet to occur. The interoperability of the different standards within the ITS and their interface with the outside world (Smart Cities, IoT) must be carefully planned and tested. Some of the stated technologies, such as block chain, lightweight cryptographic techniques, network segmentation, and sensor fusion, will undoubtedly find a place in the appearance of ITS. However, further experimental findings, as well as testing on how they will fit into the overall [16].

Another portion of the listed technology is in the early stages of research into their application in ITS. AI and Machine Learning are cited in several publications as crucial technologies that will shape the future of ITS. The benefits of using such technologies are well recognized, but the security concerns of integrating them with ITS have not been thoroughly examined.

On the other hand, experimental findings from using these technologies in ITS security systems are required. Game theory and security-by-contract are two further technologies that are expected to be developed within the ITS sector. They have been effectively employed in IoT cyber security solutions and are expected to find a position in ITS cyber security. The purpose of this research is to provide an overview of the difficulties surrounding ITS security and viable solutions for preventing or overcoming security breaches. Furthermore, we give solutions for putting stronger security procedures and activities in place to protect ITS.

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