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A Survey on Public Transport Optimization Strategies Leveraging Real-Time Data Analytics for Enhanced Service Efficiency

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***Abstract*—The growth in urban dwellers and the changing demands in mobility requirements have created more demand on an efficient and sustainable mode of public transport system. Real-time analytics in data has emerged as a key driver to help in the optimization of the public transport service by delivering dynamic information on the position of vehicles, passenger movements, traffic, and service breakdown. In this survey article, a wide range of optimization methods, which utilize continuous data gathering through GPS devices, ticketing systems and intelligent transport systems (ITS), are investigated. Such strategies involve agile route design and planning, predictive maintenance to achieve better fleet reliability, and optimization of energy among electrification and smart routing. The fact of integration of innovative communication technologies, including the Internet of Vegetables (ISV), is used to interact between vehicles and infrastructure, supplementing operational control. Although they offer great promise, difficulties with data quality, standardization, privacy, and security issues prevent these analytics-based techniques from achieving their full potential. These barriers are discussed in the paper, while policy and technological aspects that should be considered to make the broad adoption possible are mentioned. This survey provides a synthesis of the recent researches and practice related to data analytics in the real time to provide the overview of the way, in which real-time data analytics can foster more flexible, reliable, and green public transport systems. Finally, it highlights future research directions focused on improving data interoperability, privacy-preserving analytics, and multi-sector collaboration**

Keywords—Public Transport Optimization, Real-Time Data Analytics, Dynamic Route Planning, Predictive Maintenance, Intelligent Transportation Systems (ITS), Data Privacy and Security, Urban Mobility Efficiency

I. INTRODUCTION

The use of real-time data analytics to enhance public transport is transforming today's urban transportation systems, making them more flexible, efficient, and sustainable [1][2]. PT is the term used to describe the movement of groups of people utilizing public transport along pre-established routes, which are networks of private and public infrastructure such as carts, stagecoaches, ferries, or buses [3]. Timetables, which are signs along roads that provide the location, mode of transportation, and time of a vehicle's stop for passengers to enter and disembark [4]. Three main factors are considered while optimizing public transportation: cost, execution, and passenger perception. Costs include expenditures such as fuel, labor, and vehicle maintenance.

ITS is the use of cutting-edge electronics, information, and communication technology to make transportation networks more dependable, efficient, and secure. Better-informed choices are now possible thanks to ITS, which has made it possible for transport data to be collected automatically and sent efficiently. This is especially true for real-time operations [5]. ITS-generated data tends to be continuous throughout time and large in volume.

The primary source of funding for public transport infrastructure is federal and regional governments; improvements in system investing in public transport infrastructure is mostly the duty of, in particular, relying on accurate data regarding demand, operations, and potential for optimization in public passenger transport systems [6]. There are already many data sources used in the planning and management of public transit [7]. The continuous digitization of public transit has significantly increased both the volume and accessibility of available data. These data are generated in diverse formats and at varying rates, further complicating integration. However, a lack of cohesive and integrated information is the root cause of many present issues in public transportation planning, which restricts the capacity of transportation authorities to fully use the data that is available.

Cities throughout the globe are finding electric buses and other electric transport vehicles more and more appealing due to their advantages, which include fewer emissions, cheaper long-term running costs, and a lessened reliance on fossil fuels [8]. But switching to electric fleets presents unique operational difficulties, especially in areas like energy management and fleet scheduling.

Simultaneously, the development of the Internet of Vehicles (IoV) has enabled seamless communication between vehicles and infrastructure, facilitating real-time traffic control and optimized urban mobility services [9]. A constant network connection is essential for immediate traffic regulation and efficient use of transport services in large urban centres.

In the framework of contemporary urban design, transportation authorities and policymakers are increasingly prioritizing data-driven approaches to improve mobility. In this regard, the Origin Destination (OD) matrix is a crucial tool for analyzing travel behavior and planning sustainable transit solutions. OD matrices assist the agencies in determining the differences in travel requirements according to location, time, and frequency. But in the practical aspect of work, traffic jams, roadworks, and some other nuances may negatively influence the high-precision calculation of transfers and flows of passengers. Such errors could cause insufficient detection of transfers and inaccurate route planning, and ineffective services in the process of ensuring transfers [10].

A. Structure of the Paper

This paper is prearranged as shown below: Section II discusses the basics of real-time data analytics in the sphere of public transport. Section III covers such optimization measures as dynamic routing, predictive maintenance, and energy efficiency. Section IV undergoes issues such as privacy concerns and information quality. Section V reviews policy support and technology development. Section VI ends with important findings and recommendations on further research.

II. Fundamentals of Real-Time Data Analytics in Public Transport

Improving the efficiency of public transport networks has evolved into a data-driven process, with real-time data analytics playing a pivotal role, reliability and the very passenger satisfaction of the services being offered [11]. With the help of technologies, including GPS tracking, automatized ticketing systems, and ITS, the modern transit system can process a variety of dynamic variables, i.e., travel time, the level of congestion, and positions of vehicles [12]. These sources of information might be used to develop well-informed choices, predictive modelling and mobility-on-demand services. Using real-time analytics in combination with the functioning of the system in the field of public transportation of cities will allow solving the issues of delays and inefficiency, as well as the imbalance of the provision of services, which will give a more sustainable and accessible movement within the city.

A. Definition and Components of Real-Time Data Analytics

The use of public transport is a relevant service whose usefulness is gaining more ground as it helps decongest the roads, air congestion, and use of energy as well as oil [13]. Real-time information (RTI) on the services is one possible way to stimulate switching passengers from private to PT.

GPS data is a vital resource for doing data analytics in the transportation sector and gleaning insightful information. These include for example, GPS data processing methods, and journey time variability analysis of transfer and waiting times for bus topics covered include travel forecasting, investigation of rural-urban migratory populations during the COVID-19 epidemic, traffic monitoring, and the identification of road defects [14]. By integrating complete datasets that represent hourly, daily, seasonal, or event-based fluctuations, present research in the field of transportation modelling and management seeks to attain short-term stability. Improving mobility-on-demand services via analysis and processing of data in real-time is also a key focus [15].

B. Sources of Real-Time Data in Public Transport Systems

Modern cities depend on mobility to enable inhabitants to engage various areas of social and economic life, such as healthcare, education, culture, housing, jobs, trade, and so forth. Everyone, regardless of their location or socioeconomic status, needs access to reliable transportation, and public transit is widely recognized as the most effective and equitable option, access to metropolitan services, including jobs, healthcare, and education [16]. in systems of public transit. Three primary data sources are used in the application of data analysis:

- Open-source ticket sales data, often provided by government agencies and transit providers, with identifying details eliminated to maintain anonymity.
- Accurate position data from GPS systems mounted in cars, often includes private information.
- Open-source information outlining the bus stops, routes, and timetables of the road infrastructure and public transit system.

The associated computationally demanding data processing tasks are then effectively resolved by using parallel-distributed computing methods, utilizing a variety of computing resources, including data centers and supercomputing platforms.

C. Integration with Intelligent Transportation Systems (ITS)

The goals of the ITS include the following: to improve travel times, make roads safer, make better use of available road capacity, boost mobility, decrease energy consumption, and lessen environmental damage through flexible data exchange among users, vehicles, infrastructure, and wildlife [17]. Centralized methods of measurement, analysis, and control are also a part of information communication-based systems. Minimizing mistakes caused by humans is the primary goal of ITS. Additionally, there is a way to avoid air pollution, financial losses, time lost due to traffic accidents (both deadly and nonfatal), and other such problems. Figure 1: The Intersection of Intelligent Transportation Systems and Their Urban Uses.

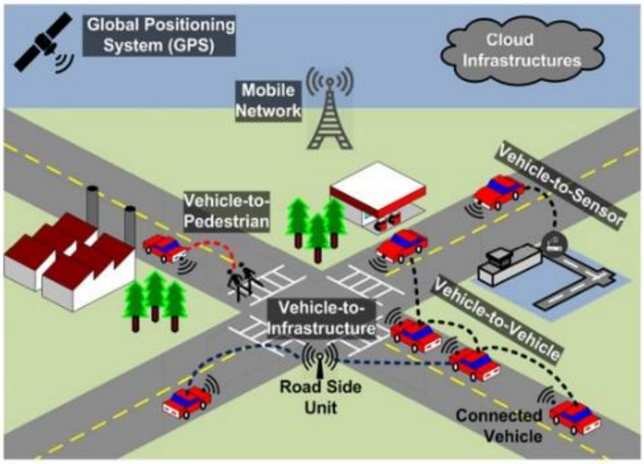

Fig. 1. Intelligent Transportation System

In order to address transportation issues and promote safety, mobility, and efficiency, ITS components are being employed efficiently all over the globe. ITS as the ITS architecture that supports it [18], using topologies and technologies for self-healing communications networks that are fit for military use to guarantee the safe and dependable functioning of complex control systems. While ITS implementation differs from country to country, the overarching objective is the same: to alleviate congestion and enhance the efficiency of transport networks, the enhancement of safety, and the enhancement of passenger convenience.

III. Optimization Strategies In Public Transport Using Real-Time Data

Data analytics in real-time is changing the game public transport optimization through dynamic route planning [19], predictive maintenance, and energy-efficient strategies. By leveraging real-time vehicle locations, traffic conditions, and passenger demand, transit systems can dynamically adjust schedules to enhance service reliability and reduce operational costs. Predictive maintenance enabled by continuous monitoring minimizes breakdowns and improves fleet uptime. Additionally, optimization strategies targeting energy efficiency and emission reduction, through electrification, alternative fuels, and intelligent routing, promote sustainable urban mobility. Collectively, these strategies demonstrate how real-time data empowers smarter, safer, and greener public transport systems, aligning with broader goals of operational excellence and environmental stewardship.

A. Route Optimization and Dynamic Scheduling

Transporting goods and people over land, air, and sea is made possible via multimodal networks in today's transportation system. A major change has occurred with the introduction of the idea of dynamic rerouting, which allows for the rapid modification of transport routes and modes in reaction to evolving circumstances by reflecting both existing conditions and unexpected events [20]. It has become technically possible to monitor the vehicles in real time, and manage and schedule vehicles dynamically. Based on With the help of these technological resources, the control centre can get up-to-the-minute information on the whereabouts of vehicles, the current state of traffic, the number of passengers, and any other pertinent details in order to quickly and affordably revise vehicle routing plans to make public transportation more appealing and dependable.

Dynamic rerouting is another important feature provided availability of transport network adaptability enabled by real-time data, predictive analytics, and adaptable algorithms [21]. The history of route planning in the transportation network has turned to be impressive, as calculating driving directions is possible in milliseconds, even over continental distances.

B. Predictive Maintenance and Incident Management

Development of technology aims at enhanced productivity in production, maintenance and quality within firms. Such factors like unproductive periods which might arise as a result of failure in the production and defected goods have an impact on the productivity of the company [22]. Improving productivity greatly depends on having a well-planned maintenance strategy that is executed at the right times.

Maintenance policies, which are also referred to as maintenance strategies, entail maintenance activities that need to be undertaken in relation to the parts replacements, renewal and fixing that is necessary to continue the state health of the assets in the business during its lifetime and to carry out its operational tasks. Maintenance techniques have been categorized differently by several studies. This discusses four primary approaches to maintenance: predictive, corrective, prescriptive, and preventative. Figure 2 provides a visual overview on the working methods of various forms of maintenance.

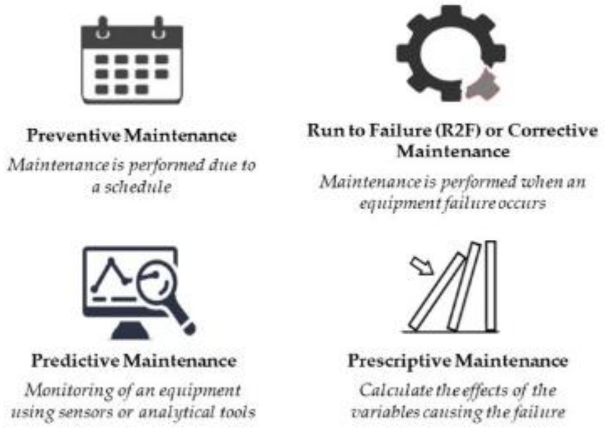

Fig. 2. Different Types of Maintenance

IM is envisaged as all the measures the aim of which is to swiftly remove traffic from the affected area after an event, ensure the safety of emergency services and road users, and control the extent of the damage. Since road networks are an essential part of every nation's infrastructure, they are subject to the same safety regulations and rules that apply to other modes of transportation [23].

C. Energy and Emissions Optimization

Transport or movement and logistic processes are among the major pillars of global economic development. Transport contribution contributions to GDP have been rather substantial throughout the last ten years [24]. The transportation sector is among the greatest consumers of energy in the world today in terms of global share in the energy used by the various sectors and contributes up to 24% of the global CO22Emissions. Emissions and Energy use is mainly dependent on several aspects [25], such including fuels, technology, vehicle operation, demand, population makeup, and roadway layout. Existing optimization actions may be broadly divided into two:

- Enhancement of energy conservation.
- The use of electricity and renewable energy.
- Arrangement of transport modalities for maximum efficiency.

Reducing pollution and sustainably managing mobility are two areas where Operations Research is having a significant impact.

IV. Challenges And Future Directions

Despite the transformative possibilities for optimizing public transportation with real-time data analytics, several challenges hinder its widespread implementation. Key concerns include data quality, availability, and standardization, which are critical for deriving reliable insights from increasingly complex datasets. Privacy, security, and ethical issues further complicate data sharing and storage, demanding robust safeguards. Moreover, successful integration of real-time analytics relies heavily on supportive policies and technological infrastructure. Future directions should focus on harmonizing data standards, enhancing privacy-preserving techniques, and fostering cross-sector collaboration to ensure scalable, secure, and equitable improvements in public transport systems driven by intelligent, real-time decision-making.

A. Data Quality, Availability, and Standardization

The importance of public transit is becoming more acknowledged as a vital service it offers. True, it aids in lessening the impact of traffic jams, air pollution, and energy and oil use. It is becoming more difficult to sustain the public daily commute network due to rapid urbanization and the accompanying population increases, particularly in developing countries. A new field that has opened up new possibilities for public transport system improvement is big data, which has been growing in popularity in recent years.

Massive data sets may now be used in public transit due to the availability of this data and sophisticated methods of data analysis. In light of this, it is now generally believed that public transport issues may be better addressed by using big data in a way that conventional methods of transport data and analysis cannot [13]. Consequently, there has been a noticeable uptick in the public transport community's calls for the creation of more robust analytical tools and more widely used data sources about public transit. To fully take use of transit data, however, there are several rising concerns associated with managing them, such as validating them, due to the enormous growth in data availability.

B. Privacy, Security, and Ethical Concerns

The term "transport security" encompasses a wide variety of ideas and practices. The decision will include defining the realm of transport security. There is a connection between ethics and the law with relation to the three interconnected concepts of privacy, security, and trust. The word "data privacy" refers to the guidelines for the secure gathering, processing, and dissemination of information in light of individuals' legal rights. In contrast [26], ethics refers to those duties, which may sometimes turn into a duty [27].

While there are many advantages to researchers from data storage and exchange, there are also many challenges, including security concerns. Given the current state of data, the conventional privacy and security measures are unable to deal with the deluge of information.

C. Policy Support and Technological Advancements

A policy-supported optimization strategy for public transport, using real-time data [28], involves leveraging real-time data analysis to improve service planning, scheduling, and operational control [29], while also addressing policy-related objectives like improving accessibility, increasing efficiency, and reducing congestion. This approach can involve using data to optimize route planning, adjust schedules based on demand, and implement real-time interventions like holding or skipping stops to improve transfer connections.

The intensive evolution of technologies and the creativity of the search of solutions that would transform the transport sector into one that is not only friendlier towards the environment but a much less susceptible to shocks, be it a pandemic that hits the world in the future or any other global crisis. Modern transport is also moving in such directions as electromobility, improvement of the transport infrastructure, ITS, as well as fresh solutions to the organization of logistics and public transport [30]. Nevertheless, such solutions require different factors to come into play and in this case, there are issues like government policies, availability of technology as well as international collaboration. It is quite important to make sure that these innovations are capable of effective implementation and their practice.

V. Literature Review

It provides a literature review of recent articles on the optimization of public transport with the help of real-time data analytics, electric vehicle scheduling, policy frameworks, AI-powered systems, and IoT integration, as well as multimodal mobility. The innovations as pointed up in the studies are in services, efficiency and sustainability.

Wang et al. (2025) provided a comparative summary of BEV timetabling and planning, that was structured into three key contributions. On the one hand, it empirically traces the development of the problem of timetabling of electric vehicles within the framework of a comprehensive evaluation of alternative methodological solutions to the field. Second, it provides a critical overview of the essential advances in the field of scheduling of electric vehicles alongside longer perspectives of research (involving the combination of personnel scheduling) and the execution of these plans. Their third point is that it investigates the possibility of integrating BEV scheduling and timetabling, and combines the advantages and drawbacks of existing techniques with a sketch of the future research directions that take them to the next level [31].

Fatorachian and Kazemi (2025) poses a threat to conventional public transport, and its viability is in doubt as concerns sustainability and energy consumption. This study will analyze these issues by exploring a literature review, which will look into operational efficiency, energy transition, and the policy implications. The analysis of existing literature enables the study to unearth on-demand transportation insights, offer insight into difficulties, potential solutions, and avenues for further study. Urban transport planners and policymakers may find the study's theoretical and practical framework useful for informing policymaking and policy implementation [32].

El Amrani et al. (2024) research reveals a preference towards specific forms of research, use of different modes of transport, under-researched too and increased focus on transhipment activities. In cities, logistics is becoming more complex as urban areas look to sustainable avenues to development; one of them is combining freight transportation with public transport. This research is aimed at assessing current practices, gaps, and opportunities in the growth of this area. Interaction between freight and city transport is known to be an evolving fields that are constantly evolving and has great promise for promoting sustainable urban development [33].

Vemuri, Tatikonda and Thaneeru (2024) is a dynamic solution that also intends to deliver more responsive services that eventually decrease wait times and increase overall user satisfaction. The passenger information systems are discussed as a key element, demonstrating how AI and IoT technologies can be used to improve the experience of the passengers. Mobile apps, digital displays and other communication media in real-time will keep the passengers updated with the correct information on arrival time, delays, and alternative routes to empower them to make informed decisions [34].

Panigrahy and Emany (2023) the applications include, but are not limited to, ITS when weighed against other developments, network optimization, the IoT discourses, as well as the classification of the algorithms. The next trend of IoT is the Io. ITS can be constructed using Io. But, the overloads imposed on the Io network are because of a huge amount of information relayed by the devices interconnected in Io. The network connection to which one of the units of an Io belongs is one such overhead. To create an efficient ITS with the help of Io, it is necessary to optimize the network connection [35].

Enescu et al. (2022). Discussions focused on the public transport system's most important subsystems, including their respective challenges and potential solutions transport development of the city with great demographics, to find a solution concerning the blockchain technology to develop in future the contemporary managerial tools. In Web of Science, Scopus, and Science Direct, more than 2000 research papers have been reviewed since 2018 to date. Technology, services, management, EV usage, and environmental impact are all keywords that were considered for this analysis of blockchain integration as a solution in the public transportation sector [36].

Guillermo, Orozco and Alessandretti (2021) the locating of various forms of transportation together has become very important in large urban centers as a way of ensuring that high levels of people movement are made fast and sustainable. Multilayer networks are a good fit for representing multimodal transport systems using a network science approach, where the networks that represent the various transport modes are not apprehended as an independent entity, but as a structure composed of layers. Although multimodality is considered an essential concept in contemporary cities, there is a lack of a cohesive view of the subject matter. In this section, they survey in detail the field of multilayer transport networks and transportation options in urban areas in regard to multidisciplinary advancements in the fields of complex systems, city data science, and city science [37].

Table I summarizes key studies on real-time data-driven public transport optimization, highlighting their focus areas, methodological approaches, primary findings, identified challenges, and proposed future research directions

TABLE I. COMPARATIVE ANALYSIS OF RECENT STUDIES ON REAL-TIME DATA-DRIVEN OPTIMIZATION STRATEGIES IN PUBLIC TRANSPORT SYSTEMS

Reference	Study On	Approach	Key Findings	Challenges	Future Direction
Wang et al. (2025)	BEV Timetabling & Scheduling	Systematic Review	Identified key trends in timetabling and scheduling, and proposed integration strategies	Coordination complexity and methodological limitations	Develop unified, integrated scheduling systems for electric fleets
Fatorachian and Kazemi (2025)	Public Transportation Sustainability	Explorative Literature Review	Highlights energy transition and policy issues in urban mobility	Policy gaps and lack of practical frameworks	Develop theoretical-operational frameworks for sustainable planning
El Amrani et al. (2024)	Urban Freight and Transit Integration	Empirical Analysis	Shows opportunities in integrating freight with transit for sustainability	Limited intermodal focus, fragmented systems	Advance integration models and study transshipment efficiency
Vemuri et al. (2024)	Passenger Information Systems	Technology Evaluation	Demonstrates AI and IoT enhancing user satisfaction via real-time data	Infrastructure and interoperability issues	Strengthen real-time digital communication and adaptive routing systems
Panigrahy and Emany (2023)	IoV-based ITS	Comparative Technological Review	IoV enables smarter transportation through data exchange	High data overhead and connectivity bottlenecks	Optimize IoV networks for scalable, efficient ITS deployment
Enescu et al. (2022)	Blockchain in Public Transport	Large-scale Literature Review	Blockchain enhances transparency and trust in transit management	Complexity in deployment and system compatibility	Develop blockchain-integrated platforms with EV and service coordination
Guillermo et al. (2021)	Multimodal Transport Networks	Network Science Approach	Multilayer network models support integrated, sustainable mobility	Lack of unified modeling frameworks	Foster interdisciplinary research on multilayer mobility systems

VI. CONCLUSION AND FUTURE WORK

Advancements in real-time data analytics are driving significant improvements in public transport optimization and service efficiency. Continuous data flow enables dynamic scheduling, predictive maintenance, and energy-efficient operations, resulting in enhanced reliability and sustainability within urban mobility systems. Data-driven strategies contribute to reduced operational costs, better passenger experiences, and lowered environmental impact. Challenges such as data quality issues, privacy risks, and technological constraints remain critical barriers to widespread adoption. Addressing these requires strong policy support, innovation in technology, and collaboration across different sectors. Future focus on harmonizing data standards and developing privacy-preserving techniques will be essential to unlock full potential. Embracing these approaches promises smarter, more adaptive, and resilient transport networks capable of meeting evolving urban demands.

Future efforts should focus on standardizing data formats to improve system integration and interoperability. Strengthening privacy-preserving methods is vital to protect sensitive information. Advancing predictive analytics with machine learning can enhance maintenance and demand forecasting. Expanding real-time data use across multimodal transport will enable comprehensive optimization. Close collaboration among policymakers, technologists, and transit agencies is necessary to develop scalable, efficient, and sustainable public transport solutions.

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