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Applications of Big Data Analytics in Traffic Management in Intelligent Transportation Systems

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***Abstract*— Big Data technology is emerging as a mass technology that can be applied to many industries in life. Decisions in a wide range of fields may benefit greatly from the information provided by Big Data and Analytics research. One of the areas that have benefited the most from this technology is transportation, which is known as an important field in the development of each nation and possesses a huge treasure of data that traditional technologies cannot handle. Indeed, many countries have applied Big Data-based intelligent transportation systems because it is a traffic system that interacts with vehicles and people on the road, thereby reducing traffic congestion and traffic accidents year by year in many countries. The article presents the applications of Big Data technology in smart traffic systems, thereby providing the perspective of a smart city with a smart traffic system as a critical factor. This paper's analysis indicated that smart cities could be born and further developed through the linkage of Big Data technology and smart traffic systems with smart traffic systems as the core. In addition, the results also showed that the obstacle that needs to be studied at this time is the policy and legal framework for Big Data technology. Therefore, a system managed by the state or shared between the state and the private sector should be studied in the future, aiming to harmonize interests and develop the system extensively.**

***Keywords*— Intelligent transportation systems; big data; smart city; traffic congestion; management strategy.**

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I. INTRODUCTION

In recent years, big data technologies' strong and rapid development has supplied many ideas and equipment that support facilitating effective management and decision-making [1], [2]. In order to study complex simulation systems and decision-making support, data exploitation has been widely adopted [3], [4]. Almost all systems operations were recorded by big data technique, from then demonstrated the ability to model, prognostication, and optimization of the system [5]–[7]. In the field of transportation, an increase in the construction of the road transport network has quite far been lag compared to the development of the number of vehicles [8]–[11]. Many traffic issues such as traffic jams, traffic accidents, resource squandering, and environmental pollution, economic damage have appeared [12]–[14]. Many studies have been done to improve the impact of the transport system on the environment and the economy. These studies have shown that transportation activities were one of the main causes of increased environmental pollution [15], [16]. Therefore, there is also a lot of research involved to reduce the impact of transportation activities on the environment such as applying new techniques to modify the engine aiming to increase the performance and reduce emission [17]–[23], using electric vehicles, proper design, and energy storage [24]–[32], using alternative fuels [33]–[38]. Simultaneously, efficient energy management and policy applied to support the use of clean energy have been paid much attention [39]–[43]. In addition, with a huge number of vehicles participating in traffic in one day, traffic accidents are continuously increasing. About 8 million traffic accidents, 7 million injured people, and 1.3 million dead people were statistics each year in the United States. Around 90 billion hours were lost due to traffic issues (accidents, gridlock), resulting in a 2% decline in worldwide total domestic output. Furthermore, the vehicles created around 220 million carbon footprint metric tons [44], [45]. Moreover, 3 trillion USD was considered transportation costs by the individual car that excepted commercial and public transport. In this number, parking, collision, pollution, and traffic service accounted for about 40% [45]–[47].

The notion of the intelligent transportation system (ITS) appeared to enhance the output of traffic systems, improve road traffic safety and protect the environment [48]–[50]. The advancement of sensing and broadcasting technologies, as well as the development of efficient incorporation of networked information systems, decision-making, and infrastructure of physics, all contributed significantly to the appearance of ITS [47], [51]–[53]. However, with increasing traffic density, especially in developing countries, an intelligent transportation system needs an auxiliary system to control and increase the safety and sustainability of the transport system, and Big Data can meet these requirements. Indeed, many regions of the globe use a hybrid of these two systems. The equipment such as cameras, roadside, and wireless networks sensor have been installed to observe traffic flow and traffic safety impetus. These tools have collected huge data. This allows traffic departments to have a better overview of the traffic stream in the corresponding region. In addition, transportation data for this study is derived from global positioning systems (GPS), mobile phones, car data, and individuals on the road. The data from the sources above are merged with information on human activity (social media, public transport, etc.) [54], [55]. Historical and online data analysis is accepted by the traffic data availability, thanks to analyzing traffic data that can create the transport model, identify bottlenecks, and help to find out the cause of the accidents. The different analytics and methods used in Big Data, such as machine learning, may be used to filter through massive amounts of traffic data and extract valuable information, enabling the transportation authority to take preventative action and make suitable choices. When the number of connected means of transport and information exchange with other appliances inside them or with the infrastructure of the road or with other nearby vehicles significantly increases, the traffic data volume increase together [56].

Among the category of data-intensive applications, traffic management can be considered one of the scripts in transportation and mobility, where data has been a key component of decision-making even before the emergence of Big Data. The advancement of this field of study has been facilitated by the improved spatial-temporal resolution of transport data made possible by the incorporation of additional data sources [57] and the utilization of Big Data technology, which has resulted in the development of novel techniques and extraordinary findings that much beyond those produced by conventional theories and instruments. In this problem, the variations in traffic capacity planning, predicting traffic conditions, and managing traffic demand are mutated clearly by Big Data technology [58], [59]. In general, Big Data has concentrated on some specific fields so far, but it cannot be denied that the potentiality of Big Data in the traffic domain that helped the transportation industry has become more intelligent and more developed [60]–[62]. Although research on Big Data in transportation is growing, most of the systems implemented so far to enable Big Data analytics in ITS systems are based on architectural solutions [63]–[65]. As a result, they are difficult to adapt to new uses and data sources since they are designed to achieve a narrow set of predetermined outcomes. A lack of flexibility in ITS systems leads to a lack of adoption of Big Data technologies [66], [67]. The considered documents are mainly researched for the road mode in this work. So, research gaps in this study as well as direction for the future, are the application of Big Data algorithms to all modes of transport. Especially by sea and air are the two most used methods for transporting goods and passengers. In addition, the cost of building an ITS system with a Big Data application is also considered a gap in this study. This is also considered a future research direction on the comparison between values related to the environment, people, and costs to build the system. It is possible to build ITS models for large, medium, and small urban levels based on population or regional gross domestic product (GDP) [68], [69]. The key goal of this article is to discuss the applications of Big Data in today's intelligent transportation system.

II. Materials and Method

A. *Big Data*

Big data (BD) is an umbrella term for gathering all types of data. It may be organized or unorganized, structured, semi-structured, or unstructured, and BD is so vast and diverse that it is almost difficult to analyze it using conventional data processing methods. Therefore, Provost and Fawcett have defined Big Data as massive data amounts that traditional processing systems cannot handle, leading to necessitating the use of new technologies [70]. Because computers produced most big data, it was often referred to as machine data. Volume, variety, velocity, variety, and value are five pillars of Big Data analytics, and businesses can extract a significant quantity of relevant information from big data using advanced data analytics [71].

The tendencies related to Industry 4.0 were gradually becoming more prevalent, and they were having strong impacts on human life. The auspicious beginning quickly mutated into disadvantages because a huge of data was gathered. That the collected data had a lot of disadvantageous information more than advantageous information. So, purifying the required data from the collected data set was important, especially for producers. In this perspective, the logistics of information was a critical component of this issue: Summarizing, the objective of information logistics was to ensure that the appropriate data is available in the appropriate format at the appropriate time [71]. The supply of relevant data is critical and required in the transportation industry. In 2012, Beyer and Laney circumscribed detailed Big Data [72]. Big Data is a term that refers to information properties that are large in volume, fast in velocity, and/or diverse; it necessitates new kinds of treatments since it enables improved decision-making, comprehensive information discovery, and process optimization. Thus, a data file is known as Big Data if it implements tasks like gathering, storage, distribution, administration, analysis, and pictorial data via modern model technologies [73]. Diversity, particular, real-time, and iteration were affections of the new trend of the Big Data Analytics system. Over time, big data analysis systems have evolved more and more, up to now, according to Alex Bekker, big data analysis systems have developed through 4 stages (1) Descriptive Analysis that data is taken from the past and then analyzed; (2) Diagnostic Analytics that identifies the causes of past events; (3) Predictive Analysis that makes predictions; and (4)

Prescriptive Analytics that assist in making optimal actions [74].

The challenge of Big Data approaches was no longer gathering data but analyzing and extracting valuable information from the data set when the file of data rapidly developed over time. To be sure, academics and practitioners have long considered exploitation of gathered data, but the high velocity, volume, and variety of large streams of real-time data strain existing storage, administration, and processing capacities. It can be seen that Big Data has fabricated a large challenge for classical statistical methods (particularly concerning prejudice). The classical methods cannot adapt to the new data streams detected opportunistically and in crowds. Certain data streams are organized so that they may be utilized for just one specific purpose and cannot be used for other purposes directly. Yet, unstructured data such as situational data [3] from the worldwide web and social media and credit card purchases are developing, and it is unclear if these can be utilized to understand mobility patterns better. As a result, it was critical to creating contemporary system abstractions that effectively handle vast and novel data streams [66]. According to Cybertec [75], building a big data analytics model would usually go through 4 important steps, including (1) Data collection; (2) Data cleaning and merging; (3) Data analysis and modeling processed in step 2; (4) Model development that assist in making optimal actions. Fig .1 below shows the basic process of forming a big data analytics system.

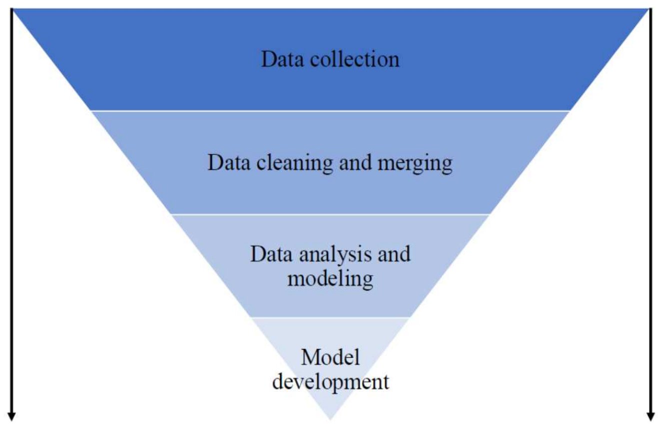

Fig. 1 A big data analytics model [66]

B. *Intelligent Transportation Systems*

Since the early 1970s, Intelligent Transportation Systems have been started to develop, and it was considered the future of the transportation industry. Sensor technologies, data transfer, and sophisticated control technologies were the advanced technologies that have been combined in ITS [76]. The ITS purpose was to enhance the quality of service for the drivers and participants traffic when they were in traffic [48], [77], [78]. In ITS, data may be gathered from a variety of sources, including smart cards, GPS, sensors, video probes, social media, etc. By utilizing precise and efficient data analytics to arrange chaotic data, ITS could offer a higher level of service [79], [80]. Along with the development of ITS, from trillion bytes to Petabyte level was the amount of data created in ITS. And with this huge of data, inefficient and unable to respond were phrases to talk about the traditional data handling system. The rapid development and complication of data were not forecasted by them, which led to the traditional system's overload [69]. ITS is a broad term encompassing a range of instruments, including traffic engineering ideas, software, hardware, and broadcasting technologies, that may be incorporated into the traffic system to increase efficiency and safety [81]. Environment and infrastructure for ITS are factors that the nation worldwide is being paid much effort to supply. Numerous nations, including the United States and Europe, have begun developing and deploying ITS on a ground level [82], [83]. According to Lin et al. [84], defined Intelligent Transportation System (ITS) was an exhaustive traffic service and management system. The birth of this system's goal was to supply advanced transportation management services. The ITS integrates sophisticated technology and advancements in information systems, broadcasting, sensors, controllers, and complex mathematical techniques with traditional transportation infrastructure, which is the ITS's greatest distinguishing characteristic [85]. When incorporated with the traffic system's vehicles and background, these technologies alleviate congestion, increase safety, and boost production [86]. Fig. 2 shows the ITS system development in China according to Huang et al. [13].

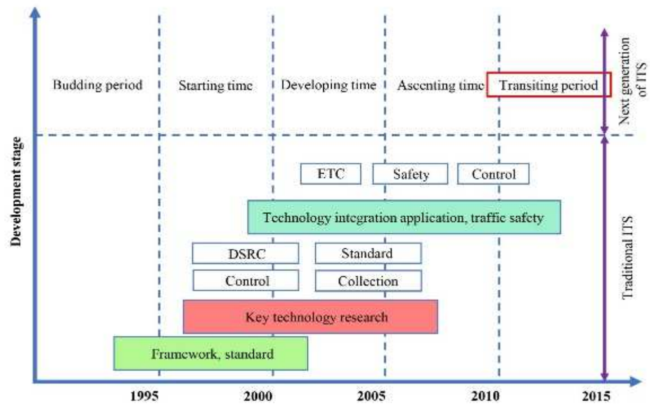

Fig. 2 The development steps of the ITS system in China [13]

The success of ITS is highly dependent on the platform utilized to access, gather, and analyze correct environmental data. Nowadays, there are 2 types of sensors that was known widely. The first type is inside the vehicle, this sensor gathers the vehicle data such as the operating status and condition of the car, another type is known as the urban sensing platform, this category was utilized for collecting the traffic condition, and traffic flow. The information exchange relationship between Vehicle-to-Vehicle (V2V) will create a huge data as well as in the relationship between Vehicle to Infrastructure (V2I), so that, the sensor technology is considered the important part during the data collection. The collected data will be supplied to the traffic management department, from then, this department will handle and analyze data for giving the next decisions. ITS engages it will help to deal with problems such as rising fuel costs, excessive carbon dioxide emissions, long traffic jams, and enhanced roads system [45], [87], [88]. For making it easier to visualize an ITS system, Fig. 3 will systematize with a diagram of the parties involved in an intelligent transportation system.

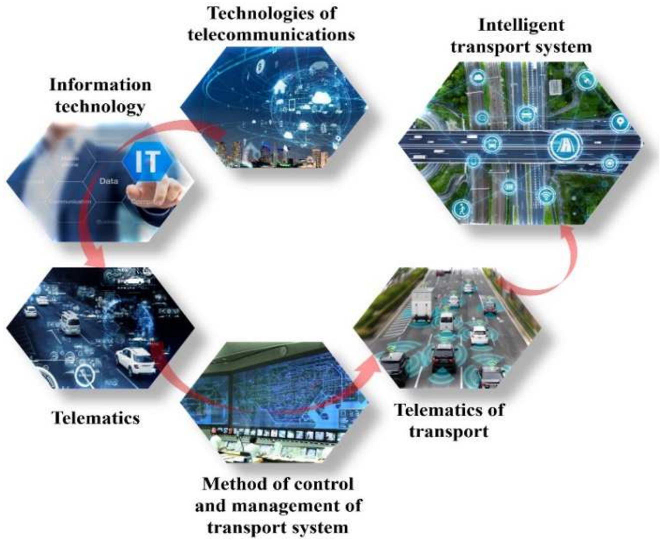

Fig. 3 Diagram of parties involved in ITS [89]

Many parts of the world have applied ITS to their national transportation system, typically in Singapore. The ITS has been applied in strategy traffic and set of systems by Singapore. It was one of the least traffic congestion big cities, with a middling vehicle speed of 27 kilometers per hour on key routes, this speed faster than if compared to the different big cities in the world. In particular, in London, the average vehicle speed was merely 16 km/h and in Tokyo was 11 km/h. This country utilized the Electronic Road Pricing system, and it allowed toll pricing based on traffic stream. The Expressway Monitoring and Advisory System has been installed to help drivers and traffic accident warnings on main roads. Additionally, the city cabs were equipped with a GPS that monitored and reported on traffic situations across the city. The ITS Operations Control Centre would receive data from all of these systems and integrate them in order to provide real-time information on traffic flow to the community [90].

C. The Data Sources

The diversity in size and structure of traffic data is one of the main goals of promoting the application of Big Data in the ITS system. The size of the data was the first thing that needed to take care of them. The amount of data created and handled is continuously increasing. The primary sources of data were social media, online financial transactions, and car sensors. A reliable and highly scalable storage system was proposed due to the volume of data increasing more and more. The exponential growth in the number of cars opens the door for data to be processed using Big Data analytics, which will affect the Internet of Things (IoT) that could be applied in many areas [91], [92]. Data was stored in a variety of forms, including structured, semi-structured, and unstructured. The data was presented in rows and columns formed in the Table called structured data. The association between structured and unstructured data created semi-structured data. Extensible Markup Language (XML) data was considered semi-structured, meaning it was not suitable for the tables and included tags that arranged the data's fields. The data had no specified structure called unstructured data, such as vehicle sensor data. The velocity and different parametric structures of vehicle data were evaluated, estimated, and analyzed, facilitating the organization and execution of smart transportation [90]. In Table I, the main data sources in the operational process of the transport sector are classified based on resource, category, and format.

TABLE I
MAJOR DATA SOURCE IN THE TRANSPORTATION INDUSTRY [61]

	Resource	Category	Format	Ref
Traditional	ITS	Structured	CSV, XML,	[93]
resource	Inheritance	Structured	etc.	[94]
	system		ERM, XLM,	
	(RDBMS)	Semi-	JSON	[95]
	GIS data	Structured		[95]
	Maps	Semi-	GIS	
		Structured	GIS	
Potential	Open Data	Nil-	Text, CSV	[96]
data	Link Data	Structured	RFD	[96]
source	Sensor Data	Semi-	Text, CSV,	[97]
	Social Media	Structured	sensor	[98]
		Raw Data	Text, CSV,	
		Semi-	XML,RDF,	
		Structured	etc.	

III. RESULTS AND DISCUSSION

A. Application of Big Data in ITS

Along with the increase of motor vehicles, pressure is being placed on the transportation system of each country in the world. Especially in the current 4.0 era, keeping the supply flow of materials always smooth has made the previously planned transport system unable to withstand the frequency of operation of vehicles. The weakness of the transportation system is becoming more and more obvious, a lot of problems occurred on a regular and repeated basis of the transportation system. The most common can be said is traffic congestion. This has led to many consequences for a country's transport system, such as high maintenance costs, high fuel consumption, or concerns about the current environment. To improve this problem, many countries around the world have started to apply the ITS model to forecast, minimize the impacts of the transport system and move toward a sustainable transport system. Mobility, sustainable transportation, and convenience are the goals of ITS. Mobility emphasizes the efficiency and capability of the transportation system. Sustainable transportation focuses on traffic safety and environmental-friendly development. Convenience aims to provide accessible service to the traveler. In this section, the article will mention the applications of big data analysis in the ITS system.

This type of ITS application was proposed to enhance traffic flow on highways and in urban areas. Observation applications may be classified into two types: fixed monitoring systems, which utilized permanent stations installed with cameras and sensors for monitoring road statuses, and mobile surveillance systems, which utilized portable cameras and sensors. Another category was utilized for monitoring on the road, utilizing attached sensors and cameras in cars to assist with oversight [99], [100]. Traffic management systems were designed to optimize road capacity at high traffic volumes, such as emergency evacuations, accidents, or inclement weather [101]. RADAR, camera, and infrared sensor were utilized by this application to identify vehicles' presence, direction, and speed. Specific event traffic management systems were a subset of lane management systems utilized to manage and reduce traffic congestion at special locations such as stadiums or conference centers. The traffic management department could change the direction of the traffic flow from traffic demands by using sensor technologies (radar and infrared). Applications for traffic control were becoming more essential. However, all of those apps needed to operate as a cohesive and collaborative system in order to facilitate the implementation of ITS. For example, in a city that had a big event, so that, the traffic management department would base on the collected data from the sensor to institute, design, and operate the traffic stream smoothly. In order to maximize arrival at the event, the traffic management program could change the cardinal of lanes in the same route, it depended on traffic flow from different sides. However, the fundamental issue (smoother vehicle flow) has not been resolved since the majority of people would seek parking, and as the flow increased, the time required to locate a parking space became more difficult. This was one of the reasons why a methodical incorporable of all the apps involved was necessary. In this issue, the apps of traffic and parking management would combine and point automatically the parking place without the necessity for a choice to be made on-site [88]. ITS applications were classified into three categories: mobility, safety, and environmental impact, as demonstrated in Table II [102]. In this article, we considered mainly the Mobility applications. Below are some mathematical models, tools, and works that have been researched and published by scientists since 2018. These models are mainly aimed at predicting vehicle flow and traffic flow and are based on making decisions in traffic control.

The necessary in transportation management was information about traffic flow in real-time. In traffic flow forecast, Big Data analytics in ITS would significantly advantage [103]–[105]. Fig. 4 demonstrated the old traffic flow forecast model with a combination of Big Data analytics [48]. In order to have an effective data file, the ITS initial data would be handled. A traffic flow model is built using a data mining or analytic technique of choice with the preprocessed data. In order to alter the model, the traffic flow model would provide and get feedback on the traffic information to the management department; from then, this department could base this to decide diversified model [69].

TABLE II
ITS APPLICATION [102]

Application kind	Application name	Target	Data resource	Data user
Mobility	Transit signal priority	Advancing real-time transit system performance	Transit vehicle traffic signal	Management center of traffic Management center of transit
Safety	Vehicle safety management	Detecting critical elements of the vehicle Notifying the motorist of any potential hazards	Vehicle onboard system	Vehicle safety monitoring system
Environmental	Environmental probe surveillance	Obtaining real-time environmental conditions via analyzing data from cars.	Vehicle onboard system	Weather service Maintenance and construction management center

Fig. 4 A typical traffic flow prediction model [69]

Yang et al. [106] have studied an open transport system based on the existing transport system. This research aimed to establish an intelligent transportation system based on next-generation wireless communication technology. In the future, the discussion would be organized to agitate about necessary additional elements such as network, services, user support, function, information, link, and communication. It provides the groundwork for an overview of implementing new generation ITS technology by thoroughly understanding the technical features and evolution of the next generation ITS.

In 2020, Mena et al. [107] investigated and developed traffic flow forecast equipment in real-time accurately and in a timely manner. Traffic data has grown rapidly in recent decades, and they have shifted toward big data ideas for transportation. Existing traffic flow prediction techniques use certain traffic prediction models but remain inadequate for handling real-world applications. In this study, machine learning, genetic, and deep learning algorithms have been planned to utilize by Meena et al.; the purpose was data analytics for traffic systems with the complexity of the data was greatly reduced. Additionally, image processing techniques were used to recognize traffic signs, which helped in the proper training of autonomous cars. In the same year, Lian et al. [108] researched using Big Data to analyze traffic safety in ITS and Connected Automated Vehicle (CAV) environments. The specific subjects covered include accident detection and prediction, the identification of crash-related variables, driving behavior analysis, and the identification of collision hotspots. According to the research examined, using sophisticated analytics for Big Data offered significant potential for comprehending and improving traffic safety. Applying Big Data in traffic safety combined and analyzing large amounts of data from many resources overcame conventional data analytics limits and identified and resolved issues that could not be resolved by standard safety analytics. By utilizing the deep learning algorithm, also in 2020, Zhihan et al. [109] have investigated and researched for handling the safety issues of ITS with the main purpose was simulated the enhanced system, improved data transmission performance, enhanced accuracy of forecast performance, and the system's route changing method were statistically evaluated. The findings established that when the system's data transfer performance was analyzed, the likelihood of successful propagation was determined to be 100%. When lambda was from 0.01 to 0.05, the outcome was nearest to reality and the lowest data delay.

In 2020, Chang et al. [110] have presented a predictive backward shockwave analysis (PSA) method for achieving the RT-ASD depending on analytics studies about PSA MA (macroscopic traffic shockwave) and PSA MI (microscopic car-following). PSA has contributed some aspects related to safe proactive driving: 1) anticipating and estimating high-risk hazard backward shockwaves by using collected Big Data from vehicle driving condition information, 2) Through the 3-tier mechanism cloud computing method, communicating the estimated danger signals to the cars in high-threat regions, 3) reducing the risk of accidents for the driver, 4) Self-driving or human-driving vehicles could achieve maximum safety with PSA_MA and PSA_MI. The numerical findings demonstrated that the PSA has beaten other relative error rate forecast methods, backward shockwave detection accuracy, average vehicle speed, average movement duration, number of circulated vehicles, time, and distance-to-collision**.** The same year, Hao et al. [111] developed an efficient computing architecture for massive traffic video data management depended on cloud computing, which was incorporated by a distributed file system and computing system for solving issues like as flexible server expansion or contraction, load balancing, and dynamic storage expansion or contraction, calculating power and enhancement in storage efficiency. Based on this technological architecture, the system employed algorithms based on BP neural networks to extract static traffic indicators from road footage. Then, to extract moving objects from road transportation videos, the author utilized an interframe difference algorithm and a method of Gaussian mixture model (GMM) integration. The ITS video handling system, which depends on the environment of Big Data, has been demonstrated successful. The design plan of this system had strong practical application value after the tests have been performed about network pressure, calculating ability, identification ability, and other examination. Fig. 5 depicts the physical structure of the ITS.

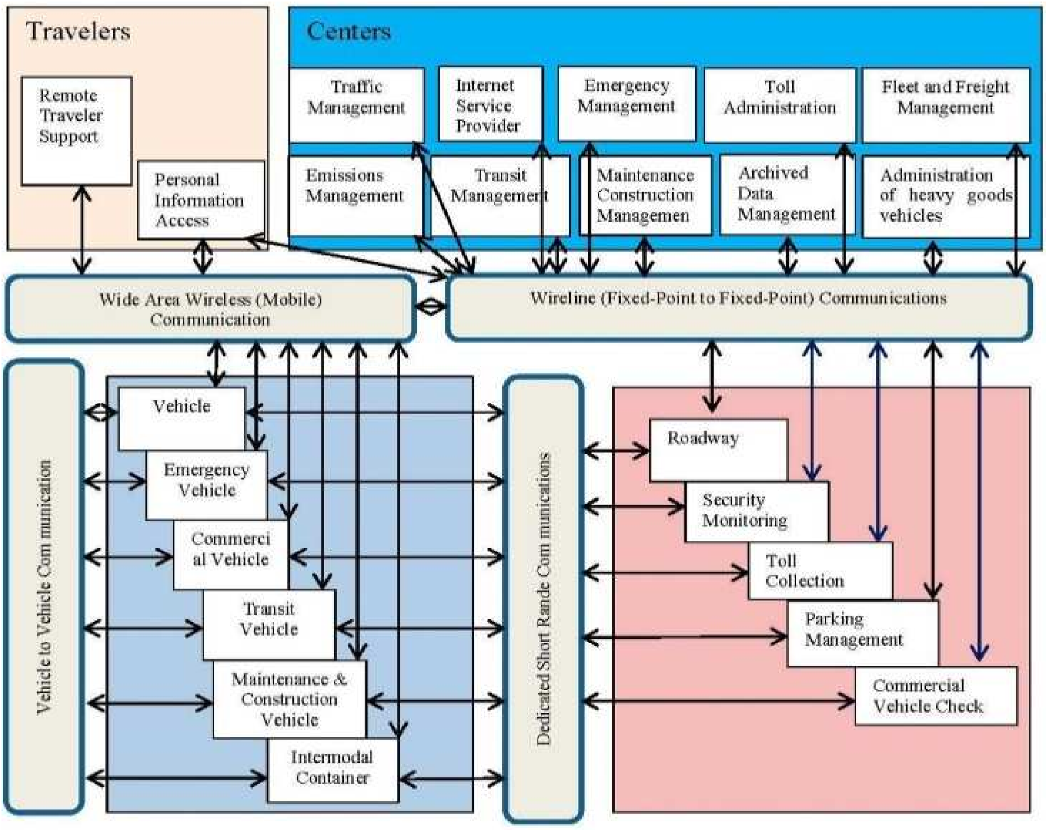

Fig. 5 Physical ITS architecture [112]

With so many applications offered, to apply them in practice, a legal framework is needed. In fact, at present, there are very few studies on building appropriate legal frameworks that can bring applications into practice. Ding et al. [113] researched and concluded that complex network theory has yet to be applied to urban planning from a theoretical or methodological standpoint for creating an application framework. The lack of technical standards for each ITS application is also a difficulty that makes application frameworks not focused on research. Therefore, building applications with a set of criteria are prerequisites for the application of these systems in the future. Accordingly, many models have been introduced with detailed application frameworks for each application. Iqbal et al. [114] proposed a framework that allowed on-site data processing and making decisions based on cloud computing. Zhu et al. [69] discussed a framework for applying Big Data in ITS as well as the problems of Big Data analytics in ITS in the future Mousavi et al. [115] investigated a fully expanded big data framework, and this framework could use with any Botnet detection method. It can be seen that recent studies on the application of Big Data in ITS have all proposed their own application frameworks. However, for each different country, the applicability of this system is also different. Therefore, the introduction of a common legal framework for the whole world or a certain region will have certain implications for these applications.

B. ITS and Smart City

In recent decades, the ITS in the smart mobility category under smart cities has been concerned a lot. There was currently no agreement in the literature on what defines a smart city, and there were many notions [116], [117]. For instance, Hall et al [118] proposed that a smart city could manage its ingredient (e.g., roads, buildings, etc.) in order to better manage its resources, schedule preventative maintenance operations, and manage the protection, all while providing the best possible service to its people. On the other hand, Lombardi et al. [119] defined smart cities the city that utilize information and communication technology (ICT), and care for and solve human, social, relationship, and environmental pollution problems. The notions above were also based on government development focus. A clear example of this problem is that researchers considered the focus of smart city development to improve people's lives while private development companies put efficiency and economy first [120]. Despite the diversity of concepts, they all had one thing in common: the intervention of the information technology system into the city's infrastructure. The goal was to transform the city's hardware into smart [121].

The deployment of the ITS entails ensuring that the planned system accomplishes smart transportation via localization and traffic avoidance through certain Big Data methods. Using Big Data analytics technology, the multivariable data would be provided instead of univariate data in the transportation system. The multivariate analysis evaluated more than two variables simultaneously, resulting in more meaningful findings in less time. With the Big Data technique applied in the ITS, finding the best routes would become fast. This helped to avoid the traffic congestion and arrive at the destination earlier. This entails applying the time element and the utilization of a route map depending on the user's location [90]**.**

As previously stated, the basis of smart cities was the hardware that was installed in ICT (information and communication technology), such as sensors and mobile devices. This equipment was equipped to make the hardware smarter by the gathered information [122]–[126]. Though many data have been supplied, the data would be of no value if it were not pre-handled and pre-analyzed [127]–[129]. Thus, in addition to the hardware infrastructure and applications that created and stored data, an analytical framework was critical to developing an intelligent smart city [130]. This was called Big Data analytics, and the goal was to derive meaning from massive amounts of data. Thus, from the viewpoint of Big Data, a smart city must monitor, process, and regulate real-time data via the use of information and communication technology [131]. The massive quantities of data generated by smart cities may be utilized to better depict city operations [132], such as item movement patterns through trajectory mining [20], and from then, give recommendations for future development [133]–[135]. Transportation is the nervous system in urban areas since it is utilized by the public to go to and from work and to move commodities. There have been a variety of applications supported by ITS over the last two decades to improve mobility, decrease CO_2 emissions, achieve fuel economy, increase safety, and enhance energy management [136]. However, one difficulty to be able to applying technologies to smart cities is a legal framework. Governments need an effective legal framework to manage this problem to apply new technologies such as Big Data into the current transport system. Based on the features and characteristics of Big Data technology today, there are 2 streams of opinions debated on this issue. One side said that new technologies should not be applied to the transport system because of great potential risks are. The other side said that the application of new technologies to the transport system is completely reasonable with the current development progress of countries. Applying new technology in traffic is a steppingstone towards an intelligent transportation system and smart city. To be able to satisfy these two problems, a legal framework for system adoption is essential. The legal framework will help ensure that technology is properly applied and managed, avoiding potential risks that may occur in technology. Depending on each country's capacity and transportation system, the legal framework for this application will be different. In developing countries, the potential risk is high; the legal framework must be put in place and managed strictly. This is because, in these countries, the transportation system is often incomplete, combined with poor management infrastructure. Therefore, the application of Big Data technology to the transport system of this country will face many difficulties, and management resources will also increase higher. In contrast, in developed countries, this application is said to be quite easy because of the complete infrastructure combined with the network and transportation system. Therefore, it can be seen that the development of traffic is necessary, in which the application of new technology in management is very important to move towards a smart city. However, although a lot of technologies have been born for this, in order to apply these technologies, the order of application and the management of these technologies after being applied will have to depend a lot on managers.

In the combination of ITS and smart city, a current global trend is also concerned with the management and operation of smart cities in a sustainable way. In fact, research on sustainable operation is becoming an inevitable trend today. Aspects that are of great interest in sustainable development today can be mentioned as clean and renewable fuels and energy management [137], [138]. Sonali et al. [139] discussed

Big Data, smart cities, and the need for sustainability in technology operations. In the study, the authors found the intersection between the three factors above to provide direction for further research. From there, design a smart ecosystem. In the context of smart cities, Anthony et al. [140] investigate the function of application programming interfaces (APIs) in handling real-time, online, and historical energy data. Additionally, layered architecture for district energy management that uses APIs in big data is built to provide energy information intelligence. Finally, in this study, the author wants to improve energy consumption by creating renewable energy sources in a smart city system with a Big Data application. However, determining the sustainability in the operation of a smart city with the application of big data technology is also difficult. A report by Dixon et al. [141] showed this in big data initiatives in the built environment face four primary challenges: (1) There was a lack of agreement in the definitions and measurement of built environment big data; (2) A lack of commercial involvement in the built environment sector; (3) Because various datasets were not compatible with one another. (4) It was currently lacking a "bottom-up" and demand-focused strategy in the smart cities movement. The above four issues could open future research directions on smart cities' sustainable development with big data applications. In addition, one of the aims of developing intelligent transportation systems is to reduce pollutant emissions; thus, the policy for clean and renewable energy development should be focused on reducing the dependence on fossil fuels [142], [143].

IV. CONCLUSIONS

In this article, the authors have highlighted the role of Big Data technology in intelligent transportation systems through published research and applications. With the current rapid development of science, the application of this technology to the transportation system is becoming more and more necessary. With a large amount of data being collected, processed, and analyzed, the intelligent transportation system is predicted to be an effective solution to reduce traffic accidents, as well as reducing harmful effects on the environment. With smart traffic systems as the core, smart cities can be born and further develop through the linkage of Big Data technology and smart traffic systems. However, the obstacle that needs to be studied at this time is the policy and legal framework for Big Data technology. The managers of this system for the transport system are also an issue to be studied. A system managed by the state or shared between the state and the private sector is also a matter of research to be able to harmonize interests and develop the system extensively. Although there are many factors that need to be researched, the benefits of the combination of Big Data technology and smart traffic systems are undeniable and bring many positive things to a country or region. To be able to move towards smart cities, this combination is the core element. In addition, the study on the cost of building an ITS system for large, medium, and small urban levels based on population is the target for further studies.

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