Una revisión a los sistemas de transporte inteligente*

A review of intelligent transportation systems

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Abstract

Intelligent Transportation systems are essential because of the rapid expansion in new machine learning methods and the emergence of new data sources, ITS has made it possible to check and forecast traffic conditions faster and more accurately. Although this type of transport has been widely studied, a literature review that covers the main areas has not yet been built to date. The objective is to carry out this review using the tree of science through a Scopus query. The results showed three approaches: deep learning of transport systems, the importance of data for these transport systems, and traffic flow prediction. In practical terms, this article is important because it improves the effect of limiting the use of private vehicles in the contemporary world, and can help different countries to use fossil fuels more efficiently and maintain a healthy environment for the current generation.

Keywords: IoT, VANET, ITS, ICT.

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Resumen

Los sistemas de transporte inteligentes son esenciales debido a la rápida expansión de nuevos métodos de aprendizaje automático y la aparición de nuevas fuentes de datos. Los ITS han hecho posible verificar y pronosticar las condiciones del tráfico de manera más rápida y precisa. Si bien este tipo de transporte ha sido ampliamente estudiado, hasta la fecha aún no se ha construido una revisión de la literatura que cubra las principales áreas. El objetivo es realizar esta revisión utilizando el árbol de la ciencia mediante una consulta Scopus. Los resultados mostraron tres enfoques: aprendizaje profundo de los sistemas de transporte, la importancia de los datos para estos sistemas de transporte y predicción del flujo de tráfico. En términos prácticos, este artículo es importante porque mejora el efecto de limitar el uso de vehículos privados en el mundo contemporáneo y puede ayudar a diferentes países a utilizar los combustibles fósiles de manera más eficiente y mantener un medio ambiente saludable para la generación actual.

Palabras clave: Internet de las Cosas, Red ad-hoc vehicular, Sistemas de transporte inteligente, Tecnologías de la Información y las comunicaciones.

1. Introducción

The importance of Intelligent Transportation Systems (ITS) lies in being able to predict high demand requests to increase their efficiency. The global ITS market size was valued at USD 25,378.2 million in 2020 and is expected to expand at an annual growth rate of 7.0% from 2021 to 2028. Stawiarska & Sobczak [1] mentioned that some of the benefits are the increase in road safety (reduction of traffic accidents by 40-80%), an increase in street traffic by 20-25%, and the improvement of travel comfort.

The solutions offered by the key market players can combine data processing technology with sensing and telecommunications technologies to ensure on-time management. However, due to the growing number of inhabitants and vehicles, an advanced traffic management system is required that can solve problems such as travel time, rapid response to accidents, and road infrastructure reliability. Finally, it cannot be ignored that the loss of time in road congestion affects the economic and socioeconomic growth of a country and that the great powers are betting on the implementation of traffic management systems as part of the efforts to reduce the financial burden of governments.

Chen & Chen [2] mention that traffic flow prediction is one of the key problems of ITS. Zhang et al.[3] concluded that during the last two decades, ITS has emerged as an efficient way to increase the performance of transport systems, improving travel safety and offering more options to travelers. However, none of these reviews use scientometric tools to identify the evolution of the ITS, therefore, there is a need in the academic literature to write a review about ITS.

Scopus query on ITSs was first conducted to develop this study and the results were uploaded to the Tree of Science web platform [4]. Finally, the main articles were identified according to the position in the tree, the classic articles in the root, the structural articles in the trunk, and finally, the articles of the branches show the different subfields of the ITS.

The tree visualization allows us to understand the evolution of the concept and the different contributions over time.

The general research question of this review is: What are the main theoretical contributions of the ITS? In response to this question, we proceeded to map the role of information and communication technologies (ICT) in transport systems at the urban level. This revision allowed to establish of three essential subfields; deep learning of transport systems, the importance of data for these systems, and traffic flow prediction to improve mobility.

This article continues with the methodological part, in which the process of searching and identifying the main articles are explained in detail. Then we show the contributions chronologically until reaching the different subfields identified from the branches. Finally, it concludes that ITS are a fundamental tool to reduce traffic congestion and improve road capacity.

2. Methodology

We searched ITS in Scopus and uploaded the data to the ToS platform. Scopus has bibliographic references and citations from the Elsevier company (peer review literature). The following search equation was used: Title=("Intelligent" AND transportation AND system) AND Title-abs-key=("cities" or "city") with a date range from 1999 to the present.

Once these results were obtained, they were uploaded to the Tree of Science (ToS) web platform [4]. ToS enables the construction and practical understanding of the theoretical framework and state of the art from the initial search in WoS [4]. The ToS algorithm is based on graph theory and the new algorithm imitates the sap process [5]. ToS has been applied in different areas like education [6], management [7]–[9], and health [10]. A reference of the diffusion process can be found in the study of Eggers et al. [11]. Table 1 shows some of the selected articles.

Tabla I. ITS Tree of Science

Traffic Learning Systems	Smart Data	Dynamic Control based on Intelligent Networks
Branch 1	**Branch 2**	**Branch 3**
Yuan et al. [12]	Gunes et al. [13]	Liu & Ke [14]
Sharma & Battula [15]	Nguyen et al [16]	Li & Yu [17]
Raja et al. [18]	Ghatee [19]	Li & Wang [20]
Javed et al. [21]	Surnin et al. [22]	Nzouonta et al. [23]
Wang [24]	Xu et al. [25]	Al-Mayouef et al. [26]

Trunk
Ferdowsi et al. [27]
Kumar et al.[28]
Hahn et al. [29]
Sobral et al. [30]

Root
Lv et al.[31]
Guerrero-Ibáñez et al. [32]
Menouar et al.[33]
Hartenstein & Laberteaux [34]
Liu et al. [35]

Source: Own creation

3. Results

The articles located in the root are the support the theory of ITS. The articles describe the availability of a large amount of data that can potentially lead to a revolution in the development of ITS; for example, changing an ITS from a conventional technology-driven system to a more powerful data-driven multifunctional ITS [3]. This is the reason of the adequate use of the information is vital to deploy a successful ITS since the existing traffic flow prediction methods are unsatisfactory. For example, Lv et al.[31] propose a new traffic flow based on deep learning with a prediction method, which considers space and temporal correlations. Due to this problem, ITS have gained special attention and have gained importance in transport systems. Manufacturers have developed a large number of sensors for different applications, ranging from use in vehicles, such as security and traffic management. Guerrero-Ibáñez et al. [32] clarify how the technology can be integrated with transport infrastructure to achieve sustainable ITS and how traffic control and safety applications can benefit. Therefore, these challenges must be addressed to enable a fully operational and cooperative environment.

A smart city without a reliable and efficient transportation system is not possible. ITS is a key component of any smart city concept seeking the effective integration of two technologies: connected and autonomous vehicles. Although, these two emerging technologies are crucial in enabling fully automated transportation systems, there is still a significant need to automate other components in highways and transportation. For example, Menouar et al.[33] talk about unmanned vehicles, due to their mobility, autonomous operation, and communication/processing capabilities, unmanned vehicles are envisioned in many ITS application domains. Likewise, Sjoberg et al. [36] propose a cooperative STI or also known as connected vehicle technology in the United States. This is an application that uses vehicle-to-vehicle and vehicle-to-infrastructure communications to increase the safety and efficiency of road traffic in Europe.

This is why there has been significant interest and progress in the field of vehicular ad hoc networks in recent years. These networks are called VANET (for its acronym in English), they are Ad-hoc networks where its nodes are vehicles. Hartenstein & Laberteaux [34] show these applications with an example of collision warning and local traffic information for drivers, information on rechargeable power sources and in the environment, and vehicular traffic flow patterns.

With the increasing number of traffic jams and vehicles, urban traffic management is becoming a serious problem. Liu et al. [35] propose a novel four-tier architecture for urban traffic management with the convergence of VANET, 5G networks, software-defined networks, and mobile edge computing technologies. The proposed architecture provides better communication and faster response speed in a more distributed and dynamic way. Key technologies are also discussed with respect to the vehicle location, data prefetching, traffic light control, and traffic prediction. The new architecture shows remarkable potential to alleviate traffic congestion and improve the efficiency of urban traffic management.

This is the reason why large cities think of parallel transport control and management systems (PTMS) and their application in the construction of smart cities. Zhu et al.[37] present a general approach and the main ideas in the construction of intelligent transport for smart cities based on ACP (artificial system, computational experiment, and parallel execution). The main components of the proposed architecture include social signal and social traffic, cloud and ITS services, agent-based traffic control, and transport awareness automation.

IoT an transparently and seamlessly incorporate a large number of heterogeneous systems, while providing open access to selected subsets of data for the development of countless digital services. Building a general architecture for IoT is therefore a very complex task, mainly due to the wide variety of devices, technologies, and services that may be involved in such a system. Zanella et al. [38] focus specifically on an urban IoT system which, while still a fairly broad category, is characterized by its specific application domain. Urban IoT, in fact, is designed to support the smart city vision, which aims to exploit the most advanced communication technologies to support value-added services for the city administration and for citizens.

Trunk

The articles in the trunk begin to shape the ITS theory. They are more specific articles on this topic and over time they have become references. The disproportionate increase in the vehicle fleet and therefore in the traffic of all cities, has become a matter of concern since the traffic control systems have become inefficient. However, an ITS can provide safety, efficiency, and sustainability for large-scale vehicular traffic. Nama et al.[39] showed remarkable work in the programming and deployment of traffic agents, using various optimization algorithms forming a three-level solution taxonomy. Currently, ITS generates a large amount of data with which the dynamics of people can be analyzed in a better way and resolve situations or paradigms that arise in smart cities.

ITSs are an important component of the future of smart citie. However, identifying the true potential of ITS requires reliable real-time data analysis and a heterogeneous mix of data from the ITS network and its environment. Such data analysis capabilities cannot be provided by conventional cloud-centric data processing techniques, whose computing and communication latency can be high. Instead, solutions must be developed that are tailored to the unique ITS environment. Ferdowsi et al. [27] present an edge analytics architecture for ITS in which data is processed at the roadside or vehicle smart sensor level to overcome latency and reliability challenges.

Kumar et al.[28] mention that ITS have become an important and widely adopted component for smart cities, as it overcomes the limitations of the traditional transport system and solves problems such as fuel waste and increased carbon emissions. These aim to integrate sensing, control, analytics, and communication technologies into travel and transportation infrastructure to improve mobility, comfort, safety, and efficiency. Smarter vehicles are continually being created, and advances in roads and infrastructure are changing the feel of travel. Travel is becoming more efficient and reliable with a variety of new technologies and research and development in ITS. However, there is a vector to consider, Hahn et al. [29] speak of attacks by malicious actors. Smart cities with connected public transportation systems introduce new privacy concerns with data collected about passengers and their travel habits. The article provides a comprehensive classification of security and privacy vulnerabilities in STI. In addition, the challenges to address security and privacy issues in STI are discussed and possible mitigation techniques are considered.

Sobral et al. [30] mention that data visualization provides multiple perspectives supporting the analytical tasks of domain experts and highlights research opportunities based on their findings. Additionally, Gohar & Nencioni [40] propose that the fifth generation (5G) of wireless mobile communications allows a new type of network to connect everyone and everything. 5G technologies will profoundly impact economies and societies as they will provide the necessary communication infrastructure required by many for city applications.

VANETs have been a fairly vibrant area of research over the last decade. It has been successfully used for the intelligent transportation system. However, intermittent connectivity, high routing overhead, inflexible communication infrastructure, non-scalable networks, and high packet collision are the key challenges hindering the wide application of vehicular ad hoc network. The severity of these challenges is further intensified when implemented in urban areas. To overcome these obstacles, Raza et al.[41] mention the integration of micro unmanned aerial vehicles (UAV) with an ad hoc vehicular network as a viable solution. In this article, a vehicular ad hoc network communication architecture assisted by UAVs is proposed in which they fly over a deployed area and provide communication services to the coverage area. The unmanned aerial vehicle-assisted vehicular ad hoc network takes advantage of line-of-sight communication, which is a flexible and cost-effective implementation.

Fast and timely travel depends on making good decisions on ITS, and this relies on a wealth of data to back it up. However, due to the limited resources of UAVs, they cannot collect data directly from all storage devices, resulting in inaccurate data collection. Therefore, Li et al. [42] propose a fairness data collection scheme based on the UAV speed control (USCFDC) in this way improve the fairness of data collection and maximize the amount of data collected by each node.

Branch 1: Traffic Learning Systems

In the part of the branches, the different perspectives that were found are located. The result of the analysis showed that it is important to use real-time transport data to predict the exact demand of vehicles from machine learning methods [2]. ITS emerged as an important and widely used component for smart cities, as they solved problems such as the fixed duration of traffic light control systems, waiting times in traffic lights, and the increase in carbon emissions. For example, Kumar et al. [28] proposes a traffic light control system that takes real-time traffic information as input and dynamically adjusts to the duration of the traffic light.

ITS include a variety of services and applications, such as road traffic management, traveler information systems, public transportation system management, and autonomous vehicles, to name a few. ITS are expected to be an integral part of urban planning and future smart cities, contributing to improving road and traffic safety, transport and transit efficiency, as well as increasing energy efficiency and reducing the environmental pollution. Yuan et al. [12] pose a variety of challenges due to their scalability and diverse QoS needs, as well as the huge amounts of data they will generate.

The widespread use of mobile devices and sensors has motivated data-driven applications that can benefit many aspects of our daily lives, such as health, transportation, the economy, and the environment. In the context of the smart city, ITS, as a main component of modern cities, and edge computing (EC), as an emerging computing service that aims to address the limitations of computing in the cloud, have attracted increasing attention in the research community in recent years. It is believed that the application of CE in ITS will have considerable benefits for transport systems in terms of efficiency, safety, and sustainability [43]

When talking about the pedestrian, the issue of the roads and the places where they travel must be addressed; For this reason, security and infrastructure play an important role in preventing any mishap. That is why Sharma & Battula [15] propose the Internet of Vehicles, whose main challenge is that vehicles can detect pedestrians that cross their path spontaneously and immediately respond to this unexpected interference with minimal delay.

Recent advances in hardware, software, and ICT have culminated in the improvisation of security aspects in vehicular communication networks. VANETs are used to establish a network between the vehicles that cover the road for the STI. Despite the myriad benefits of VANETs, there are a myriad of concerns, such as establishing privacy, monitoring security, reliable connectivity, and high bandwidth. Establishing security services in VANET is the key for any application to be successful in safe driving conditions. Raja et al. [18] state that as part of the intelligence in cognitive systems, Machine Learning algorithms make it possible to constantly extract data and acquire knowledge through advanced analysis. Furthermore, they propose a Cognitive-Intelligent Transport System (C-ITS) model that provides efficient channel utilization and improves accuracy compared to existing classification methods.

The transport system is gradually migrating towards autonomous, electric, and intelligent vehicles. Wireless-enabled vehicles along with roadside infrastructure are connected to traffic management centers that use smart data analytics tools to efficiently manage city traffic [21]. However, such wireless connectivity can make ITS networks vulnerable to security threats; therefore, they impact the reliability of the application. On the other hand, the use of security techniques could hinder the quality of service of the applications. To understand the interplay between these two conflicting requirements, Javed et al. [21] review the quality and safety design challenges in the ITS aspect of smart cities. Using an experimental test, they assess standards-compliant security processing delays, develop an online tool that presents detailed security benchmark results, and study the impact of security on quality using simulation results.

Control and management have been proposed as a new mechanism to carry out operations of complex systems, especially those that involve complex problems of both engineering and social dimensions, such as transportation systems. Wang [24] presents an overview of the background, concepts, basic methods, main problems, and current applications of parallel transportation management systems (PtMS). At its core, parallel control and management is a data-driven approach to modeling, analysis, and decision making that considers both engineering and social complexity in its processes. The developments and applications described here clearly indicate that PtMS is effective for use in complex networked traffic systems and is closely related to emerging technologies in cloud computing, social computing, and social-cyber-physical systems. Finally, this study illustrates and analyzes the experiments and examples of real-world applications.

Light Detection and Ranging (LiDAR) is a remote sensing technology widely used in the manufacture of precise medical equipment. In transportation, LiDAR has predominantly focused on autonomous vehicles, despite their great potential in accurate detection and tracking. For example, Zhao et al. [44] explore the fundamental concepts, solution algorithms, and application guidance associated with using infrastructure-based LiDAR sensors to accurately detect and track pedestrians and vehicles at intersections. The results of the analysis include precise and real-time information on the presence, position, speed, and direction of pedestrians and vehicles.

The ITS is spreading its roots among various smart city experts due to the emergence of a wide range of applications or services, including connected cars. Next generation tourism deliberately relies on its next recommendation services that are powered by dynamic edge intelligence. Benedict [45] proposes an Energy-Aware Edge Intelligence (EAEI) framework to guide tourists or automated vehicles in the selection of air quality-aware tourist locations in an energy efficient manner. EAEI collects the values of air quality parameters through massive sensor networks; opt for an optimal energy prediction service to suggest air quality values and vehicle or tourist guides in cities.

Branch 2: Smart Data

Achieving the development of an efficient public transport system would limit the effect of using the use of private vehicles, would alleviate the exploitation of fossil fuels with more environmentally friendly vehicles, and would maintain a healthy environment for the current generation. Rajkumar & Deborah [46] advocate an intelligent learning system based on long-term memory. This intelligent learning is mainly used to predict the high demands of mass transportation and use it effectively. When the proposed system is implemented, it improves the use of public transport by 87%, as well as the use of taxis and private vehicles would be drastically reduced in the city. The subject of signaling is one of the most neglected in the field of public transport, since a good structure guarantees order and the flow of traffic. For example, Gunes et al. [13] show their design in an effective control system for intersections and signal synchronization.

Smart mobility and transportation are significant elements of smart cities, accounting for more than 25% of total energy consumption. Nguyen et al [16] mention that the transport system can be widely observed, analyzed, and managed through an extensive distribution network of sensors and actuators integrated in an Internet of Things (IoT) system. The paper briefly discusses the benefits that IoT can offer for smart urban transport management using a hierarchical approach to total transport management.

The detection and monitoring of the huge transport network made up of a large number of vehicles and installations are the basic functions of ITS. The transport network is supported by an information-centric network and the tracking function is completed at the application layer. At the same time, a large amount of continuously detected network status information consumes routing space. Wang et al. propose a dynamic naming approach to detect the ITS network. It uses dynamic names to describe the state of modifiable objects in the ITS network detected by the system, and adopts a centralized block storage structure to organize the routing table, reducing redundant information and maximizing storage space. routing and historical routing information for network discovery. This shortens query time, improves network discovery efficiency, and provides a new routing-level solution for discovering and tracking the state of dynamic objects in ITSs.

ITS collect traffic data from various sensors deployed in smart cities. However, such information in real-world transportation systems mainly suffers from irregular spatial and temporal resolution. Consequently, missing or incomplete traffic data is unavoidable as a result of detector and communication malfunctions when collecting ITS information.

Reconstruction of missing values is therefore of great importance but challenging due to the difficulties in capturing traffic patterns. Salehi [47] presents a transport data reconstruction model that leverages Bayesian inference and tensor decomposition/completion to effectively address the missing data problem. The results of the experiments indicate that the proposed Bayesian model can effectively solve the missing traffic data with acceptable accuracy.

ITS are a range of ICT-based transport applications. These systems provide comfortable, efficient, and safe services for transport users. They form a main branch of smart cities and are essential for the development of countries. ITS applications typically use the capabilities of sensor networks, electrical devices, and computer processing units to provide a service; however, they are not limited to hardware devices. Instead, the modeling of transportation problems and their solution are more challenging problems. Ghatee [19] discusses the application of optimization models to the transport context. For this, models of data collection by a network of sensors are needed. Then, to extract this data and extract the necessary knowledge for the transport context, some fundamental models such as regression analysis, frequent pattern mining, clustering, or classification can be applied. This background is used to extend the appropriate ITS models into an integrated architecture. To solve these models, classical combinatorial and network optimization methods, simulation-optimization techniques, and metaheuristic algorithms are explained. Afterwards, the applications of these optimization models in the different subsystems of the ITS architecture are categorized. The result of this research can be used to develop different ITS services for urban and interurban networks.

It is possible to digitally manage, analyze, control, and plan urban public transport based on an ITS. Surnin et al. [22] use intelligent information technologies based on neural networks and Big Data processing methods, allowing real-time adaptation to dynamically changing conditions. Taking into account the results of this research and the technologies related to the transport problem domain, a formal model is presented that describes public transport and helps to reveal the main problems. Using the model, a generalized route network planning algorithm is presented. Xu et al. [25] designed an intelligent wireless urban transport service device by connecting the vehicle terminal composed of various interfaced sensors and modular technologies, providing quality requirements for passengers, cities, and society's development and economy.

Many cities are adopting increasingly advanced ITS. These systems combine connectivity, coordination, adaptability and automated response for the optimization of transport policies, thus increasing "intelligence" and efficiency. However, the control and detection systems of the ITS implemented can open new vulnerabilities, especially to cyber attacks. Currently, vulnerability is managed within the traditional risk assessment framework that assesses potential system failures in response to specific threats. Emerging technologies, by their nature, have threats that are not fully known, therefore resiliency, defined as the system's ability to recover and adapt to known and unknown threats, is an emerging area that promises to assess threats to the ITSs. To illustrate this, Ganin et al. [48] conducted a study of network efficiency and resilience in response to random and specific outages of ITS systems in 10 urban areas. Interruptions were generated to affect intersections or roads controlled by ITSs under different threat scenarios. The modeled worst-case attacks disrupted 20% of intersections and caused an average of 14.6% more additional delays than attacks of the same severity on highways. Also, blocking semaphore states was found to cause more outages than completely disabling semaphores. Therefore, as cities adopt ITS and other smart systems that create potentially unknown vulnerabilities, it is important to consider the resilience of transportation infrastructure affected by potential cyberattacks.

Extracting useful mobility information from big data is crucial to improve decision-making processes in smart cities. Fabbiani et al. [49] describe the application of distributed computing techniques for the analysis of big data information from STI. They present a framework for mobility analysis in smart cities, which includes two algorithms for the efficient processing of big mobility data from public transport in Montevideo, Uruguay.

As the term "smart city" gains more and more currency, there is still confusion about what a smart city is, especially since several similar terms are often used interchangeably. Albino et al. [50] aim to clarify the meaning of the word "smart" in the context of cities through an approach based on a thorough literature review of relevant studies, as well as official documents from international institutions. It also identifies the main dimensions and elements that characterize a smart city. Different urban intelligence metrics are reviewed to show what constitutes a smart city, what its characteristics are, and how it performs compared to traditional cities. In addition, performance measures and initiatives are identified in some smart cities.

Branch 3: Dynamic control based on intelligent networks

Talking about smart cities is talking about ITS since this is one of the keys to the sustainable development of urban transport considering fuel consumption and traffic efficiency. Xiong et al. [51] briefly review the progress of ITS research around the world and outline current challenges, offering a greater understanding of ITS development for all researchers in this area. Recent advances in ITS suggest that roads will gradually fill with autonomous vehicles that can drive themselves while cooperating with each other to form sustainable transport systems [52]. Currently, most smart cities face massive traffic problems every day.

The most important challenge is the traffic control system where the flow of vehicles can be successfully and automatically monitored and managed. For example, Liu & Ke [14] propose a Cloud-Assisted IoT Intelligent Transportation System (CIoT-ITS). This system has integrated IoT sensor cameras installed at each corner and provides traffic flow information. Optimized vehicle flow data is sent to cloud processes and runs an algorithm to detect traffic direction and control traffic lights. Simulation analysis demonstrated that the proposed CIoT-ITS could successfully and automatically monitor and manage vehicle flow.

Overlaying the flow of application data in smart cities can intensify the load of vehicle networks on intelligent transportation systems. Therefore, it becomes important to improve data transmission performance. Li & Yu [17] propose a scheme to determine the state of the network using congestion and routing parameters and compare different amounts of data transmission according to the different states of the network. The experimental simulations show that the proposed scheme exhibits good performance in scenarios of both linear and crossed vehicular networks.

Urban traffic congestion has become a problem facing modern urban management due to relatively backward traffic management methods, inadequate road planning and construction, and the increase in automobiles. STI is gradually becoming the research direction to solve the problem of traffic congestion in various countries of the world. Based on the above background, Zhang & Lu [53] study the vehicular communication network in the IoT-based intelligent transportation system. They use OPNET Modeler software to build a vehicle movement model through a layered network simulation method.

VANET is an emerging technology that integrates ad hoc network, wireless LAN, and cellular technology to achieve intelligent vehicle-to-vehicle communications and road traffic efficiency. These pose many network research challenges. Li & Wang [20] discuss the research challenge of VANET routing and review recent routing protocols and related mobility models for VANET. However, a class of routing protocol called road-based vehicular traffic routing (RBVT) is gaining traction, which outperforms existing routing protocols (VANET). RBVT protocols take advantage of real-time vehicular traffic information to create road-based routes consisting of successions of intersections with network connectivity between them. Nzouonta et al. [23] designed and implemented a reactive RBVT-R protocol and a proactive RBVT-P protocol and compared them with representative mobile ad hoc network and VANET protocols. Simulation results in urban environments show that RBVT-R performs better in terms of average delivery rate, with an increase of up to 40% compared to some existing protocols. In terms of average delay, RBVT-P performs better, with up to 85% decrease compared to the other protocols.

The increase of vehicles on the roads increases the challenges for the authorities regarding the management of road traffic. One consequence of this has been traffic congestion, more accidents and pollution. Accidents remain one of the leading causes of death, despite the development of sophisticated traffic management systems and other vehicle-related technologies. It is then necessary to think of an accident management system. Al-Mayouef et al. [26] seek to establish an accident management system that makes use of ad hoc vehicular networks coupled to systems that use cellular technology in public transport. This system ensures the possibility of real-time communication between vehicles, ambulances, hospitals, road units, and central servers.

Additionally, the accident management system can reduce the amount of time needed to alert an ambulance that is needed at the scene of an accident by using an algorithm. In addition, Saharan et al. [54] propose dynamic pricing in ITS to solve problems such as congestion control, load peak reduction, and mobility management of traditional or electric vehicles (EV) in a profitable way. It also facilitates the construction of a green environment in society through the optimized planning of vehicle routes. However, framing dynamic pricing strategies for STIs has always been a challenging task. An inefficient dynamic pricing technique can lead to poor vehicle management, resulting in an increased vehicle waiting time, increased air and noise pollution, and waste of electricity and other energy sources. In contrast, efficient dynamic pricing strategies can bring satisfaction to all stakeholders, including service providers and service consumers.

Internet of Vehicles (IoV) is an emerging concept in ITS to enhance existing VANET capabilities by integrating with IoT. IoV has dominated transport systems due to many special features such as dynamic topological structures, enormous network scale, reliable Internet connection, compatibility with personal devices, and high processing power. The intelligent transport system involves a large amount of critical dynamic data in real time, so its security is a major concern. Sharma & Kaushik [55] study different security aspects of IoV including security requirements, security challenges, and security attacks. After this, the existing security solutions of all attacks are elaborated and a discussion section is provided to highlight the drawbacks of the implemented security solutions for each attack and emphasizes the attacks for which there are no security solutions available.

Conclusions

This article shows a bibliographic review of the ITS topic. The result of the analysis was shown in the form of a tree (Tree of Science) to visually understand the evolution of this topic. The articles located in the root were cataloged as the basis of the theory. The articles located in the trunk were the ones that gave structure to the topic of intelligent transportation systems and the articles located in the branches were defined as the different perspectives.

In the first branch, topics related to traffic learning systems were addressed. The importance of traffic light control systems and their dynamic adjustment, traveler information systems, and how a trip can be planned efficiently. Internet-based mobile applications for vehicles and how to protect pedestrians at all times. The second branch discussed the importance of data and how to make predictions effectively through a network of sensors and actuators that allow us to structure the signaling system and obtain a hierarchical approach to total transport management. Finally, the third branch was based on the dynamic control of smart networks and how they contribute to the sustainable development of an ITS assisted by the cloud and how to improve data transmission performance.

We can conclude that a smart city is an urban area that collects data using various electronic methods and sensors. Smart cities are based on ICT and aim to improve the quality of services through 5G technologies and; thus, positively impact transport systems, and promote multimodal intelligent transport based on data. This process will reduce the excessive use of private transport and promoting public transport as a way of caring for the environment through renewable energies.

Some limitations in the research was the use of only one database (Scopus) for the selection of scientific articles. Subsequent studies could identify the different perspectives through quantitative methods with case studies to validate the findings of the present investigation. Further study using scientometric techniques such as collaborative scientific analysis or document co-citations to understand the intellectual structure of IST is also suggested. In addition, some redundancies were identified in the information recorded in the databases, which led to discarding some articles where the same topic was addressed in many different ways.

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