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Desarrollos Tecnológicos en el Sistema Inteligente de Transporte. Una revisión sistemática

Technological Developments in the Intelligent Transportation System. A Systematic Review

Desenvolvimentos tecnológicos no Sistema de Transporte Inteligente. Uma Revisão Sistemática

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Resumen

Este artículo revisa sistemáticamente la literatura sobre el desarrollo tecnológico de los sistemas inteligentes de transporte en los últimos diez años con la metodología PRISMA. La investigación describe el concepto de ITS, su desarrollo y cómo puede mejorar el transporte y contribuir al desarrollo de ciudades inteligentes. También analiza cómo ITS se combina con las TIC y su uso en el sistema de transporte. Además, en la investigación se aborda la importancia de integrar nuevas tecnologías en los sistemas de transporte. Los documentos analizados abordan implementaciones exitosas de ITS para apoyar las tendencias de urbanización y motorización. Por ejemplo, después de más de 20 años de desarrollo en China, ITS ha crecido hasta alcanzar logros notables. Además, el documento también repasa el desarrollo de los vehículos autónomos. Una de las principales razones para promover las tecnologías AV es su potencial para reducir los errores humanos, como la fatiga, la distracción y la conducción enérgica.

Palabras clave: Sistema de transporte inteligente; Ciudad inteligente; Ciudades sostenibles; Inteligencia artificial; Gestión del tráfico.

Abstract

This article systematically reviews the literature on the technological development of intelligent transport systems in the last ten years with the PRISMA methodology. The research describes the concept of ITS, its development and how it can improve transport and contribute to the development of smart cities. It also looks at how ITS is combined with ICT and its use in the transport system. In addition, the research addresses the importance of integrating new technologies into transportation systems. The documents analyzed address successful ITS implementations to support urbanization and motorization trends. For example, after more than 20 years of development in China, ITS has grown to remarkable achievements. In addition, the document also reviews the development of autonomous vehicles. One of the main reasons to promote AV technologies is their potential to reduce human errors such as fatigue, distraction and energetic driving.

Keywords: Intelligent transport system; smart city; Sustainable cities; Artificial intelligence; Traffic management.

Resumo

Este artigo revisa sistematicamente a literatura sobre o desenvolvimento tecnológico de sistemas de transporte inteligentes nos últimos dez anos com a metodologia PRISMA. A pesquisa descreve o conceito de ITS, seu desenvolvimento e como ele pode melhorar o transporte e contribuir para o desenvolvimento de cidades inteligentes. Também analisa como os ITS são combinados com as TIC e seu uso no sistema de transporte. Além disso, a pesquisa aborda a importância da integração de novas tecnologias aos sistemas de transporte. Os documentos analisados abordam implementações bem-sucedidas de ITS para apoiar as tendências de urbanização e motorização. Por exemplo, após mais de 20 anos de desenvolvimento na China, o ITS cresceu para conquistas notáveis. Além disso, o documento também analisa o desenvolvimento de veículos autônomos. Uma das principais razões para promover tecnologias AV é seu potencial para reduzir erros humanos, como fadiga, distração e direção enérgica.

Palavras-chave: Sistema de transporte inteligente; cidade inteligente; cidades sustentáveis; Inteligência artificial; Gestão de tráfego.

Introduction

The volume and density of traffic have increased significantly over the last few decades and contributed to the rise of accidents, traffic congestion, and pollution. These problems arose because of the considerable growth in demand for various transportation, including public transport, private cars, and freight trains (Sumalee & Ho, 2018). This phenomenon has been detrimental to the environment, economy and the quality of life. Alam, Ferreira, & Fonseca reported that road accidents were the leading cause of fatality for youth under 29 in 2015, according to WHO. The study also predicted that road accidents will be the seventh leading mortality cause for people of all ages by the year 2030 worldwide (Alam, Ferreira, & Fonseca, 2016).

Even though traffic laws and regulations and traffic management mechanisms such as traffic lights and signs can be found in almost every country, these instruments need to be updated and capable of dealing with the increase in traffic. This predicament is worse in developing countries. While building and widening roads could alleviate some of the problems, these actions do not solve the fundamental issues. Moreover, they are not sustainable because they need significant financing and use up valuable land.

Therefore, governments need other solutions to improve traffic problems (Alam, Ferreira, & Fonseca, 2016). In order to resolve these problems, scientists and governments have developed an intelligent transportation system (ITS) that can integrate various elements such as communication, sensing, traffic control, and information distribution (Sumalee & Ho, 2018). This article will systematically review the literature concerning the technological development of intelligent transportation systems over the last ten years with the PRISMA methodology. First, it discusses the concept and development of ITS, its components, categories, and functions. Second, it reviews articles about artificial intelligence and technological application contribution to improving transportation in cities. Finally, it analyzes ITS contribution to reducing pollution, economic development, smart city, and future issues.

Methodology

The systematic review was conducted using the PRISMA methodology.

Research questions

The study asks the following research question:

Intelligent transportation (ITS) system definition

The increase in traffic density results in more congestion, air pollution, and accidents.

How ITS improves the transportation system in cities.

How ITS has developed and led to intelligent and sustainable cities.

How ITS can help the economic development of cities.

Criteria

The following criteria were used to evaluate whether to include the paper in this review:

a. Describe the concept of ITS, its development, and how it can improve transportation and contribute to the development of smart cities.
b. English-language journal articles and conference proceedings, book sections.
c. Published between 2012 and 2022.
d. Not a dissertation or thesis

e. Using five scientific databases: Google Scholar, Web of Science, Scopus, Sage, and ScienceDirect.
f. Must have DOI
g. The search strategy included keywords like "intelligent transportation system," “smart city," "sustainable cities," "artificial intelligence," "traffic management," and "pollution" combined via the “AND” Boolean operator.

The search has obtained a list of 20 papers applicable to the study, as in Table 1.

Development

Intelligence Transportation System Development and Concept

The early ITS concept was initiated in the US in the 1970s. Nevertheless, it has become an area of interest for R&D, especially in Japan, the EU, and the US. While ITS refers to all means of transport, the EU has defined its meaning to focus on land transportation only. ITS combines the ICT and employs them in the transportation system. ITS collects data from equipment and sensors in vehicles and infrastructures and utilizes it to improve the transportation system. ITS contributes to a safer, more efficient, sustainable, and friendly environment. For example, nowadays, ITS such as Advanced Driver Assistance Systems (ADAS) are used for cars, electronic tolling systems, and traffic information systems.

At the early stage, ITS is developed as a standalone system, incapable of sharing data and collaborating. However, newer development of ITS called cooperative ITS sees an approach to increase communication and sharing information to improve safety, efficiency, and sustainability. For example, C-ITS can share information such as accidents, traffic jams, and other road hazards. To exchange information, C-ITS utilizes vehicle-to-vehicle, infrastructure-to-infrastructure, infrastructure-to-vehicle, and vehicle-to-infrastructure communications with dedicated devices (Alam, Ferreira, & Fonseca, 2016).

ITS has been viewed as an efficient and effective solution for easing transportation problems in China. Successful implementation of ITS is expected to support the trends of urbanization and motorization(Huang et al., 2017). Wang et al. reported that ITS was incorporated into the infrastructure when China started major road-building projects in the 1990s. The authorities have

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recognized the importance of integrating new technologies into transportation systems, especially ITS (Wang et al., 2017).

Components of ITS

ITS must have three crucial parts to function: data collection, analysis, and transmission. In the data-collection stage, the components collect information such as average travel time, traffic flow, and the number of passengers boarding for further analysis. After the data analysis stage, the data transmission components communicate the information to management, travelers, and infrastructures with various means, such as optical fibers and wireless networks. The methods have progressed from traditional traffic signs and radio broadcasting to mobile applications, flexible message signs, and in-vehicle information (Sumalee & Ho, 2018).

ITS Categories and Functions

According to Sumalee & Ho, ITSs can be divided into two categories by functions; Advanced Traveler Information Systems (ATIS) and Advanced Management Systems (AMS). ATISs function is to assist travelers in making decisions about mode of transport, route, and departure time by giving information such as expected travel time, available parking, and route suggestions. AMS's function is to control or manage various transportation infrastructures and operators to guarantee the safety and efficiency of the system. Further real-time and detailed management is possible with developed data sources and information dissemination systems. (Sumalee & Ho, 2018).

Results

How AI can improve transportation in cities

Artificial intelligence (AI) is a wide-ranging part of computer science that styles a machine's function to imitate a human to overcome problems that are hard to solve using traditional computational methods. For example, user behavior in transportation is too complicated to model and predict their traveling pattern using traditional computation. AI can overcome the problems of growing traffic congestion, safety, and pollution. It can gather traffic data to help reduce traffic congestion and improve public transport schedules. (Khan et. al., 2022). Lendel et al. suggest that

ITS can be built with less time and money by applying artificial intelligence (AI) (Lendel et al., 2016).

Abduljabbar gave three examples of how AI applications can be used in transportation. First, it can be used in corporate decision-making, planning, and managing to overcome the problem of increasing traffic demand with limited road infrastructure. AI can provide a more accurate forecast of traffic volume, conditions, and accidents. Second, AI can improve public transportation services, a more sustainable mode of transport. Finally, AI applications can increase efficiency by reducing the number of accidents with connected and autonomous vehicles. Although autonomous cars and buses are still in the experimental stage, it has the potential to be an intelligent solution for transportation (Abduljabbar et al., 2019).

Not only in developed economies in developing countries, but the use of AI can also contribute to a better transportation system. Developing countries often have transportation problems due to inadequate infrastructure, rising populations, and urbanization. In many developing countries, increasing prosperity has led to increased car ownership, which worsens traffic and pollution. Artificial intelligence can contribute to reducing traffic problems by allowing countries to make better decisions on which infrastructure projects to prioritize and allocate investment. There are numerous ways AI can contribute to both advanced and developing economies in terms of the transportation system. (Conde, 2019).

AI-based techniques have been applied to ITS to overcome these issues of processing large amounts of data collected from in-vehicle sensors and network devices. Machin et al. grouped the application into three main areas; (a) Vehicle control, (b) Traffic control and prediction, and (c) Road safety and accident prediction. The study found that combining different AI techniques is more effective in managing and analyzing the large amount of data generated in transportation (Machin et al., 2018).

Tencel & Lentil reported the increased interest among researchers in transportation and practitioners in discovering the feasibility of applying AI models to solve some of the transport problems to improve transportation systems' efficiency, safety, and environmental compatibility (Stencil & Lentil, 2012).

In addition to the physical data that could be gathered from sensors, the data from cyber sources can be used to assess the public perception of the performance of its transportation system. The future ITS must use these data sources to monitor and manage the systems. For example, a natural language processing (NLP) algorithm could be used to detect social events or public comments that may lead to potential traffic congestion. The system must also be able to detect the public attitudes toward the transport system or policy. For example, comments about the delay of train service or disruption could estimate the severity of the problem. (Sumalee & Ho, 2018).

How technological application can improve transportation

The autonomous vehicle navigation system has five major components: perception, Localization and Mapping, Path Planning, Decision Making, and Vehicle Control. Like human vision, perception employs sensors to continuously scan and monitor the environment. Localization and mapping processes calculate vehicles and map the environment from sensor data. Path planning decides the probable safe routes for the vehicle based on perception, localization, and mapping information. The decision-making module calculates the best course based on the possible routes, the present vehicle condition, and environmental factors such as road and weather conditions. Finally, the vehicle control component calculates the proper vehicle command, such as steering wheel angle and speed, to follow the ideal course decision, such as a right and left turn or another movement. The system enables the Avs to effectively perform high-speed driving while avoiding moving objects, such as other cars, motorcycles, and pedestrians (Van Brummelen et al., 2018).

Connected vehicle (CV) systems have been a core focus of the ITS program for quite some time because of their capability to support various ITS applications and integrate infrastructures and vehicle components into an effective transportation system. AV systems have been experimented with earlier with mixed results. However, Google’s involvement in the research has sparked renewed interest in the AV system. Shadower suggests that an AV system with a combination of CV elements can improve the system’s effectiveness (Shladover, 2017).

AV technology was initially introduced to drivers through advanced driver assistance systems (ADAS). The system’s objectives are to decrease the number and severity of accidents, assist people with disabilities and the elderly, decrease emissions, and increase infrastructure efficiency. One of the main reasons for promoting AV technologies is its potential to reduce human-related errors, such as fatigue, distraction, and spirited driving (Van Brummelen et al., 2018).

The transportation authorities have adopted the international standard for automation levels which describes autonomous vehicle categories. The vehicles in which the human driver has

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complete control are categorized as level 0, while entirely automated AV that drives itself is categorized as level 5.

Because of cost constraints, most commercial Avs are only rated at Level 1 to Level 2, which still require continual driver monitoring and control. These vehicles, in general, can perform an emergency stop, detect blind spots and change lanes. While level 3 features are included in the Tesla Model X and S, recent accidents have caused alarms regarding the drivers' knowledge and competence in using the technology safely. For autonomous features to have essential effects in improving safety, mobility, and efficiency, the general public must understand the capabilities of the technology, such as the limitations, application for the technology, and the appropriate scenarios to rely on the technology (Van Brummelen et al., 2018).

AI technology can improve the transportation system's operation by allowing communication between the vehicle, the infrastructure, and the driver. More traffic information data has become more feasible recently because of the advancement in surveillance technology. This system can improve decision-making by transport network managers and other users (Miles & Walker, 2006).

ITS contribution to reducing pollution, economic development, and smart city

ITS can encourage the urban economy by improving the efficiency of the transportation industry, reducing transportation costs, and assisting in developing other related industries. Guam & Zhang found that ITS contributed to the economic growth in cities in China from 2007 to 2017. They found that ITS in Shenzhen, Hangzhou, and Shanghai have contributed to urban transportation operation efficiency and related industries (Guam & Zhang, 2020). Stawiarska & Sobczak found that using the ITS concept for regional public transportation rail lines contributes to an increase in passenger and bulk transport, consequently contributing to the region's economic development." (Stawiarska & Sobczak, 2018).

The EU has planned to reduce pollution by 60 percent in 2050. One of the major culprits contributing to pollution is the overloading of commercial vehicles, which also leads to damage to road infrastructure. Therefore, the authority has installed sensors to estimate the load on the wheel, travel speed, and type of vehicle, thus providing real-time data needed to reduce pollution (Dontu et al., 2019).

Another development in ITS gaining momentum in the recent decade is the concept of smart mobility within the framework of smart cities. Although there has yet to be a consensus on the meaning of a smart city, some suggested that it could monitor its infrastructures, such as roads and buildings, using ICT. Then it can use its resources effectively by planning preventive maintenance, monitoring security, and providing complete services to its citizens. (Sumalee & Ho, 2018).

Future issues in ITS

Another area of the developing model for the ITS is Vehicular-to-Everything (V2X) communications. It can improve traffic efficiency and reliability through its ability to deliver data to the traffic monitoring, control, and management structure. Raza et al. propose a Social V2X system employing ultra-high speed integrated cellular 5G technologies. The proposed model must support various communications such as vehicle-to-vehicle (V2V), vehicle-to-pedestrian (V2P), a vehicle to infrastructure (V2I), and vehicle to network (V2N) in the social internet of vehicles environment (Raza et al., 2018).

Another research focus in ITS is big data, which has attracted many research projects globally. ITS will produce a large amount of data which will significantly affect the design and application of the systems. The feedback in the form of big data can increase ITS safety, efficiency, and profitability. Researching big data analytics in ITS is a flourishing field. However, there are some challenges to using big data analytics in ITS. (Zhu et al., 2019). In ITS, data can be gathered from multiple sources, such as sensors, GPS, smart cards, video detectors, social media, and others. The volume of data generated in ITS is expected to increase from Trillionbyte to Petabyte. Traditional data processing systems are inefficient enough to process such a large amount of data. Big data analytics may offer ITS A solution for processing these large data (Zhu et al., 2019).

The implementation of ITS can lead to new vulnerabilities in cyber-attacks. In addition, new technologies are exposed to threats that have yet to be fully known. Thus, resilience is the system's capacity to recover and adjust to existing and new threats.

Ganin et al. studied ITS resilience in response to random and targeted disruptions. The attacks disrupted 20 percent of intersections and led to an average of 14.60 percent delays. They conclude that cities that installed ITS must consider the system's resilience from potential cyber-attacks (Ganin et al., 2019). Siergiejczyk et al. suggest that one factor that may affect the reliability of ITS is the reliability of the electric supply to the system (Siergiejczyk et al., 2017).

Guan et al. propose the coordination of ITS from four aspects: intelligent, functional, structural, and scale. The study shows that the functional coordination of the ITS in the sample city lags behind the scale and structural coordination, and the intelligent coordination lags behind the functional coordination (Guan et al., 2020).

Conclusions

In conclusion, even though traffic laws and regulations and traffic management mechanisms such as traffic lights and signs can be found in almost every country, these instruments need to be updated and capable of dealing with the increase in traffic. In order to resolve these problems, scientists and governments have developed an intelligent transportation system (ITS) that can integrate various elements such as communication, sensing, traffic control, and information distribution. This article systematically reviews the literature concerning the technological development of intelligent transportation systems over the last ten years with the PRISMA methodology. We found that most articles regarding ITS focus on land transportation only. ITS employs ICT in the transportation system to collect data from equipment and sensors in vehicles and infrastructures and utilizes it to improve the transportation system. Most papers found that ITS contributes to safer, more efficient, sustainable, and environment-friendly cities. However, future issues in ITS are the vulnerability to cyber-attacks and the resilience and reliability of the system.

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Figure 1: Literature review table

	Author (Date)	Contribution
1	Alam, Ferreira & Fonseca (2016)	Overview of ITS
2	Sumalee & Ho (2018)	Component of ITS ITS categories Defining smart city, future of ITS & smart city
3	Guan et. al. (2020)	Coordination of ITS
4	Guan&Zhang (2020)	How ITS contributes to economic development
5	Dontu et. al (2019)	How ITS can help to reduce pollution
6	Wang et. al.(2017)	Police, strategy and experience of ITS development in China & international cooperation
7	Huang et. al,(2017)	ITS development in China
8	Siergiejczyk (2017)	Realiability of ITS
9	Ganin et. al.(2019)	Study resilience of ITS in response to random & targeted disruptions.
10	Zhu et. al (2019)	Big data analytic in ITS
11	Raza et. al (2018)	Propose vehicular-to-everything (V2X) communications with 5G
12	Stawiarska & Sobczak (2018)	ITS and economic development
13	Miles & Walker (2006)	How AI can assist transport network
14	Van Brummelen et. al (2018)	How technological application can improve transportation. Connected & autonomous vehicle (AV)
15	Shladover (2017)	History and concepts of connected vehicle (CV)
16	Conde (2019)	AI can make transport safer, more reliable, efficient, cleaner
17	Khan et. al (2022)	AI to alleviate traffic congestion
18	Abduljabbar (2019)	How AI can improve transportation in cities
19	Lendel et. al. (2016)	Predictive method of AI in ITS
20	Machin et. al. (2018)	The use of AI in ITS
21	Stencl & Lendel (2012)	Selected AI methods in ITS

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