Research article

Intelligent transportation systems (ITS): A systematic review using a Natural Language Processing (NLP) approach

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ABSTRACT

Intelligent Transportation Systems (ITS) is not a new concept. Notably, ITS has been cited in various journal articles and proceedings papers around the world, and it has become increasingly popular. Additionally, ITS involves multidisciplinary science. The growing number of journal articles makes ITS reviews complicated, and research gaps can be difficult to identify. The existing software for systematic reviews still relies on highly laborious tasks, manual reading, and a homogeneous dataset of research articles. This study proposes a framework that can address these issues, return a comprehensive systematic review of ITS, and promote efficient systematic reviews. The proposed framework consists of Natural Language Processing (NLP) methods i.e., Named Entity Recognition (NER), Latent Dirichlet Allocation (LDA), and word embedding (continuous skip-gram). It enables this study to explore the context of research articles and their overall interpretation to determine and define the directions of knowledge growth and ITS development. The framework can systematically separate unrelated documents and simplify the review process for large dataset. To our knowledge, compared to prior research regarding systematic review of ITS, this study offers more thorough review.

1. Introduction

ITS first appeared in 1996 [1]. In this book, the writer outlines ITS and then discusses the early history of their emergence. However, systematic reviews regarding ITS as a field are considerably rare. A few recent systematic reviews of ITS have used only a few journal articles, resulting in a fragmented perspective [2, 3, 4, 5, 6]. Moreover, the number of research articles regarding ITS is increasing every year. Figure 1 shows the increase based on search results from Scopus with the keyword 'intelligent transportation system'. The ITS research field has experienced growth and development in an interdisciplinary manner. Various research articles have introduced numerous concepts spanning technology (both application and core science), policy, management and strategy, method development, and other topics. These broad ranges of concepts and scientific fields can lead to confusion in understanding the direction of ITS knowledge development.

In 2020, Scopus alone provided more than 22,000 research articles with the keyword 'intelligent transportation system'. Note that the keyword consists of 3 words, which might lead to other journal articles and proceedings papers that are not ITS related being returned. Additionally, there is an absolute needed for homogeneous journal articles

and proceeding papers datasets to perform a systematic review. Thus, the systematic review screening phase is always laborious, and this study intends to address this issue first.

The dataset was taken from the Scopus database with an API key. The keywords resulted in as many as 23,823 titles and abstracts from English journal articles and proceeding papers from 1974 to 2020. A tag was used for each document with words (terms) in the ITS context. Terms such as traffic management systems, area traffic controls, traveler information systems, bus information systems, and other terms might be represented or written differently. It is impossible to read and tag all papers in the dataset manually. Therefore, the study uses a custom NER method and constructs all the possible terms as a data train, classifies each document, and tags words in documents. Thus, each document can be labelled and documents them based on their labels.

The study involves a reproducible data train and test, and this approach could be updated. This approach allows the addition of tags that are already available in NER for the English model database. Therefore, the method is commonly known as custom NER. Custom NER can effectively extract information from large or regular datasets with reasonable accuracy. Some studies have verified NER for various purposes [7, 8, 9, 10].

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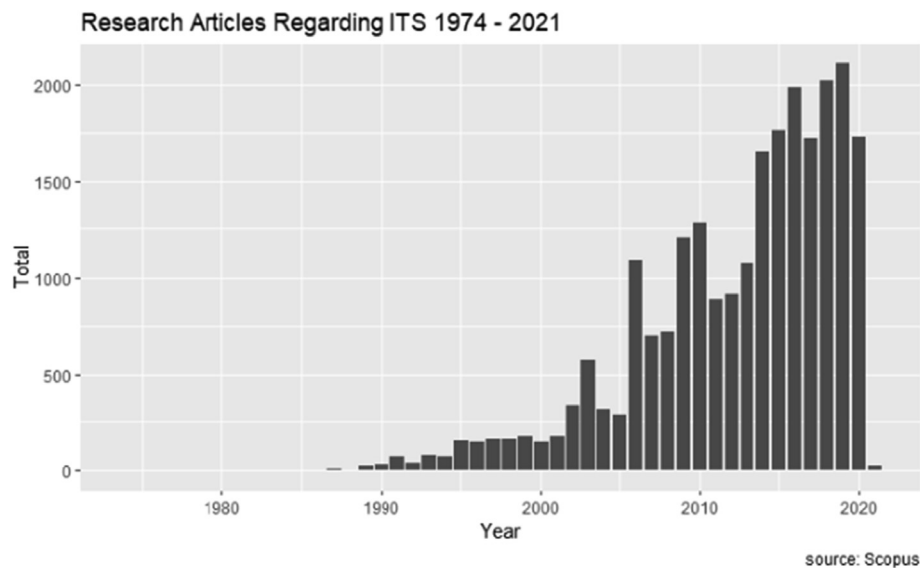**Research Articles Regarding ITS 1974 - 2021**

Figure 1. The number of ITS publications from 1971–2020.

The next stage after document screening is systematic review. Although the first phase succeeds in removing unrelated documents with ITS terms, the number of documents in the corpora is still approximately 20,000, which will complicate the systematic review process. Therefore, this study combines other methods to obtain at least an overview of the essence of journal articles and paper proceedings. A conventional method such as bibliometric mapping is an effective way to explore research gaps and topics. Notably, the more significant the scale of mapping is, the more complex the visualization will be [11]. This relation correspond to the increase in ITS emergence in journal articles and proceedings papers. Consequently, we need an efficient way to perform systematic reviews.

The existing tools for bibliometric mapping (such as VxOrd) cannot provide complete specifications that maximize graph mapping results [12]. Another tool, VosViewer, uses the frequency concept and then looks for similarities among concepts using the Jaccard Index [13]. However, to obtain complete results, many parameters are required. Inevitably, the systematic review process is highly complicated and laborious. Dachyar *et al.* [14] conducted a systematic review of the Internet of Things (IoT) with a significant number of documents. In the process, first, they needed to ensure that a large homogeneous dataset was used. Subsequently, VosViewer was used to visualize the scientometric analysis. However, they still had to interpret and manually read every document that had a high impact value, and this number was not small. This study proposes the combination of other NLP methods to solve the systematic review problem. The methods are LDA and word embedding, which are based on the idea that journal articles and proceedings papers often have similarities or interrelationships based on topics or themes.

Asmussen and Moller [15] describe the variety of LDA applications and specifically describe LDA as a tool for exploratory literature review. Grouping articles based on the likelihood of each article helps to dissect the topics in the dataset systematically. In other words, each article group has similarities regarding the research theme/topic based on its bag-of-word. On the other hand, the distribution hypothesis states that context can be interpreted as a series of texts surrounding the reference text in a continuous vector space. The word embedding (continuous skip-gram) function works based on this hypothesis. Therefore, based on these two things, this study decided to use word embedding to help shorten the manual reading process to find the main context of each group of articles.

The core NLP methods used in this study are text classification, topic modeling, and word extraction. Generally, the study constructs the proposed methods as a framework, and we expect it to be more advanced and thorough than the conventional systematic review in the following ways:

1. It is able to screen journal articles and proceedings papers given the importance of document homogeneity in a systematic review dataset.
2. It is able to establish effective topic representations for systematic reviews.
3. It is able to eliminate one or several processes to make laborious systematic reviews more efficient.

Therefore, there are two utilization tasks that this study tries to produce. First, document classification eliminates unrelatable documents with ITS terms. Second, systematic reviews are used to effectively and efficiently examine ITS knowledge growth based on a collection of journal articles and proceedings papers and to identify research gaps in the long term.

As guidance for the review process, the following predetermined research questions were asked:

1. How does the core knowledge of ITS evolve over time?
2. What are the substantial approaches used in research regarding ITS?

The paper structure is as follows. First, the background that led to the research questions is discussed. Second, the research methodology, data collection procedure, and results are presented in the context of the proposed framework. Third, the results are analyzed and interpreted, the direction of knowledge growth is discussed, and ITS development is assessed. The final section presents conclusions and suggestions for future research.

2. Methodology and proposed framework

The data were collected from Scopus using an API key with the R programming language as the interface, the keyword "intelligent transportation system", and the publication time interval from 1974 to 2020. The dataset is structured (tabular) with attributes consisting of the publication year, author, title, abstract, citations, and affiliations collected for as many as 23,823 journal articles and proceedings papers. The study adopts and improves a previously designed framework [16].

Putri [16] initially proposed a systematic review framework based on analysis of content-based recommendation system using word embedding (continuous skip-gram). It uses various keywords to collect research
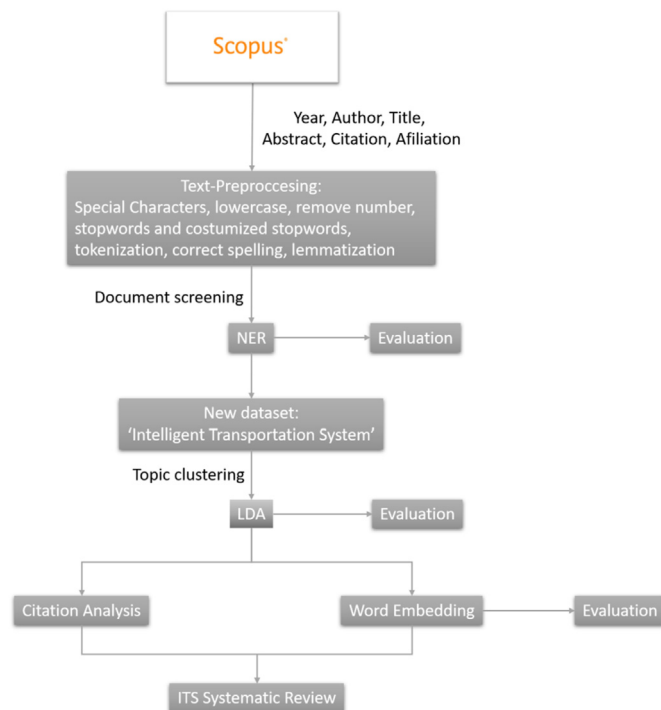
Figure 2. The proposed framework.

articles dataset with publication time range between 1931 to 2020, and it also used various hyperparameters. The method captured context from each research article and calculated similarity to display its magnitude toward other research articles. The similarity value was then used as the basis of a content-based recommendation system for research articles. The hyperparameter variety generated various results, which were then compared and analyzed. The main goal was to determine whether the assigned method can extend its utility. Putri [16] determines which word embedding hyperparameters were suitable for systematic review and proposed a framework. The initial framework consists of text pre-processing, word embedding to separate research articles that do not have similarities with the target word "intelligent transportation system", clustering, topic modeling, and bibliometric analysis.

This study found major obstacles in conducting a systematic review during the data processing phase. Firstly, the target word was semantically too general for large datasets (as explained in the introduction section, several terms are also considered as part of ITS, such as traffic management system). Thus, word embedding was not adequate to separate research articles that were not really related to the term ITS. Secondly, the quality of dataset homogeneity and considerable time for the reading process. Therefore, this study added NER, LDA, and word embedding is used in smaller topic clusters to make it easier to capture the various contexts inside the cluster. Figure 2 depicts the adopted improved proposed framework. The extent of the usefulness of the framework will be explored.

The framework consists of the following components:

1. NER to classify and screen documents that contain ITS terms;

2. LDA to cluster document topics related to ITS terms;
3. Word embedding to capture all words that provide context by using a target word. In this way, the framework can extract the context to reduce the reading process;
4. Citation analysis to determine the direction of ITS knowledge core development and the overall research trend.

2.1. Text preprocessing

This study uses the title and abstract of journal articles and proceedings papers as input variables for the NER embedding layers. This stage eliminates words and characters that are irrelevant to the context in the input variables, such as "@Elsevier Ltd. Rights Reserved", "Published @IEEE", etc. Irrelevant characters such as numbers, punctuation, and extra spaces are also eliminated. The process continues with tokenization, spelling correction, and lemmatization to give the words in the dataset a consistent structure and context. An example result is as follow (see Table 1).

2.2. Custom NER

This process begins by creating a data train for all terms that fall within the ITS scope. Custom NER parse the terms by utilizing the IOB (inside-outside-beginning) form and reserved 2% of the original data as a data train development set. The study uses the en_core_web_md English model from the SpaCy library in the Python programming language and stochastic gradient descent (SGD) optimizer for the NER pipeline with 10% dropout.

The custom NER model is evaluated by using a data test, our in-house evaluation set, by randomly picking 23 sentences. The study used the loss number, F-1 score, precision, and recall as evaluation metrics; subsequently, the results are 61, 85%, 90%, and 83%, respectively.

The custom NER result is POS (part of speech) tagging for ITS terms, and later, the tags are used as labels to separate documents. Documents that do not have an ITS-POS tag are unrelated documents with ITS terms. Thus, this process eliminates them and create a new dataset containing only documents related to ITS terms. The example result is as follows (see Table 2).

2.3. LDA

The new dataset consists of 21,995 documents. The study clusters the new dataset by topic, and then the movement of a topic cluster over time can be assessed. It uses coherence (c_v measurement) for model evaluation. Topic coherence reflects how semantically the high score word tokens fit within each topic cluster. In the first step, it proposes an initial model using k (number of topics) = 10 to establish a coherence baseline, and the result is 0.41. Then, hyperparameter tuning to determine the hyperparameters k, alpha, and beta with default alpha and beta values of 1 and k values ranging from 2–11. We choose the k, alpha, and beta values that yield the highest coherence. The results are k = 10, alpha = 0.3 and beta = 0.9, which yield a coherence score of 0.45.

In the second step, the study creates another initial model with k = 10, alpha = 0.3, and beta = 0.9. Subsequently, the model creates a graphic to see which k has the highest coherence (Figure 3). Based on the

Table 1. Text preprocessing results (Example).

Before		After
Title	Abstract	Text Cleaned
Building Highway Systems With Computer Graphic Simulations.	A number of computer applications generate perspective drawings of proposed highway designs as a means of design evaluation. The use of this capability is rare in the United States …. technology are available. Â© 1974, IEEE All rights reserved.	[build highway systems computer graphic simulations number computer applications generate perspective draw propose highway design mean design evaluation use capability rare unite state …. available]

Table 2. Custom NER results (Example).

Context	Named Entity	Label
implementation area traffic control surveillance system silicon emergence also technology new opportunities become available real time process traffic parameters objective paper consider several design issue implementation traffic monitor surveillance system silicon	[('area traffic control', 15, 35, 'B_ITS'), ('traffic monitor surveillance system', 217, 252, 'B_ITS')]	True
mk buy leave profitable alone centennial engineer specialize design construction management firm base armada colo found originally staff persons specialize transportation sixteen years later firm employees morrison knudsen corp purchase retain previous employees	[('sixteen years', 171, 184, 'DATE'), ('morrison knudsen corp', 206, 227, 'ORG')]	False

chart, several k numbers give the best coherence scores. If we use a small number for k, the dataset may be overgeneralized. However, if k is too high, there terms in each cluster will be limited, which might affect the review process using word embedding. Additionally, there is a possibility that topic groups may become redundant. Therefore, to choose the final k number, we directly use the "eyeball" approach for the topic content in addition to considering the coherence number. The model decision is based on coherence and whether the topics have redundant information or contain research articles with certain similarities. Hereafter, the final hyperparameters are k = 6, iteration number = 2000, alpha = 0.3, and beta = 0.9.

LDA will produce phi and theta values. Phi is the distribution of word tokens within a topic, while theta is the distribution of topics in a document. This study uses theta to help determine the dominant topics in research articles in each topic cluster. This approach simplifies the systematic review process to determine the direction of ITS knowledge development based on these dominant topics. Additionally, as an a priori approach, we choose documents with theta ≥0.5 in each topic cluster. In this way, it distinguishes the prevailing context in every topic cluster. Table 3 lists the topic modeling results.

This study found that several topic groups (topic groups one and three) have very distinct research objects. Although they share the same research theme, due to differences in research objects, they have the result of review in different directions. For example, in topic one, this group clearly discusses control and safety. However, we found that these articles discuss 'safety' from various objects, namely 'vehicle', 'drive behaviour', 'traffic signal', and 'alarms'. Therefore, we decided to repeat the LDA process on these topic groups to make it easier to comprehend the research.

2.4. Word embedding and citation analysis

The study uses word embedding and citation analysis to help minimize the manual reading process. Word embedding is used to find specific words from each topic cluster as a context using certain words as a keyword that we want to check. As an example, we use "method" as a

keyword. We manage word embedding to show words from each cluster that implied the same context as the keyword. Keywords such as "Markov chain", "neural network", "reinforcement learning", and "deep learning" were used. In this way, word embedding can find the dominant context within the cluster topics without reading them individually. The study uses citation analysis to identify documents with a more significant impact than other documents in each cluster. The same treatment applies to each cluster to dive deeper into each topic and answer the research questions.

The word embedding method is the Skip-Gram method because the purpose of this study is to use one or more keywords to obtain words

Table 3. Topic groups.

| Topic number	Bag of words	Interpretation
1	Traffic, vehicle, control, vehicles, drive, road, safety, driver, speed, signal	Traffic control and safety
2	Information, transport, service, management, data, public, development, provide, technology, research	ITS in general and public/urban transport issue
3	Detection, vehicle, propose, image, method, road, position, track, algorithm, feature	The detection system in ITS
4	Energy, control, design, model, power, railway, train, cost, electric, monitor	Emissions reduction and electric vehicles, energy resource substitutions, and intelligent systems for the train system
5	Network, communication, vehicular, vehicles, vehicle, propose, wireless, data, applications, service	Vehicle communication system
6	Traffic, model, time, data, network, propose, flow, algorithm, prediction, travel	Traffic optimization, traffic flow prediction, traffic networks and model, and traffic data
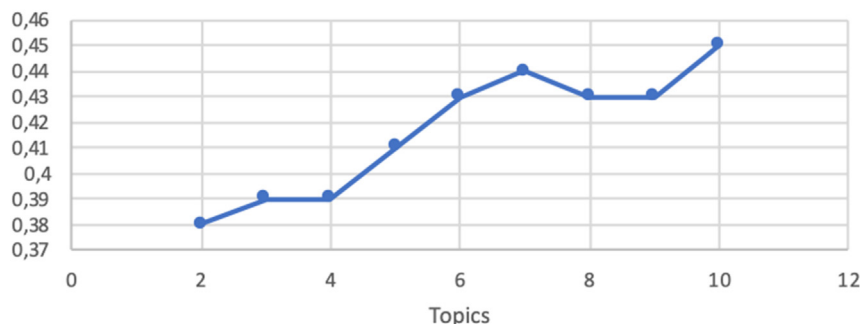
Figure 3. Best topic number (k).
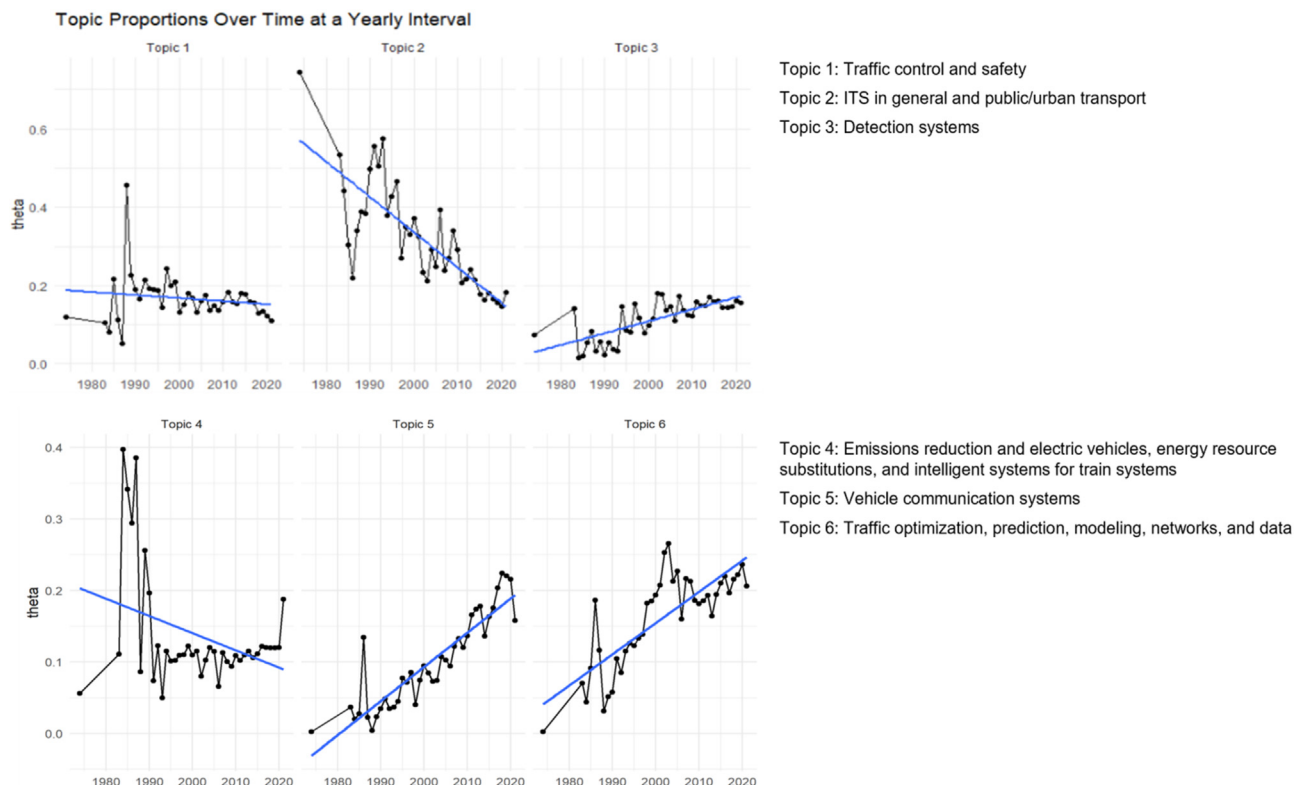
Table 4. Intrinsic evaluation results.

Topic number	Pair of words	Results	Skip-Gram Hyperparameter
1	safe – centralize + dangerous	decentralize	min_count = 10, window = 2, embedding size = 50, sample = 6.10^{-5}, and negative = 40, epoch = 30
2	vehicle – road + passengers	bus	min_count = 5, window = 2, embedding size = 50, sample = 6.10^{-5}, alpha = 0.01, and negative = 40, epoch = 30
3	recognition – detection + detect	recognize	min_count = 20, window = 2, embedding size = 100, sample = 6.10^{-5}, alpha = 0,01, min_alpha = 0,0007, and negative = 40, epoch = 30
4	*/The study found that the articles in this topic cluster were less homogeneous. Therefore, we decided not to apply word embedding for this topic cluster. More explained in the section 'Topic Four: Emissions reduction and electric vehicles, energy resource substitutions, and intelligent system for the train system'		
5	intelligent_transportation – system + communication	systems	min_count = 30, window = 2, embedding size = 50, sample = 6.10^{-5}, alpha = 0,01, min_alpha = 0,0007, and negative = 40, epoch = 30
6	advance_traveler - systems_ais + intelligent_transportation	systems	min_count = 30, window = 2, embedding size = 100, sample = 6.10^{-5}, alpha = 0,01, min_alpha = 0,0007, and negative = 50, epoch = 40

(context) similar to these keywords. The first problem is that the words that construct the context are phrases or combinations of two words, such as deep learning, molecular cameras, intelligent transportation, highway systems, and others, that cannot be separated. Therefore, before entering the modeling and pretraining process, we create a bigram dictionary from each topic cluster. For word embedding, the study uses intrinsic evaluation, and the following results were obtained (see Table 4).

The study uses the citation numbers to determine which articles are mostly referred to by other researchers. Broadly speaking, after completed the modelling and pretraining Skip-Gram, we look for the context with keywords as references (research questions as the guidelines and scope). Hereafter, we look for articles that contain the context. Articles that can be considered influential or have the greatest impact are articles with considerable citation numbers. Additionally, to keep up to date with the most sophisticated technology and the latest methods, we limit the reading process. We heavily focus on research articles published after 2010 and 2015. Old publications were only retain in certain cases requiring us to know the origin or initial source of knowledge within the ITS scope.

3. Results and discussions

ITS integrates systems (users, road infrastructures, and vehicles) to significantly improve safety, efficiency, and convenience and preserve the environment by creating good traffic patterns. To achieve this concept, ITS utilizes and combines state-of-the-art information systems and telecommunication technologies. In other words, ITS involves a collection of various disciplines to achieve the desired concepts and goals. Therefore, it is mandatory to examine research articles in each topic cluster to obtain complete details about the disciplines that have been researched and developed concerning ITS. We determine the topic distribution according to the publication year to obtain an aggregate picture of ITS research topic evolution over time (Figure 4). Mainly, the dataset is divided into six main topic clusters, including:

Topic 1: Traffic control and safety
Topic 2: ITS in general and public/urban transport
Topic 3: Detection systems
Topic 4: Emissions reduction and electric vehicles, energy resource substitutions, and intelligent systems for train systems
Topic 5: Vehicle communication systems
Topic 6: Traffic optimization, prediction, modeling, networks, and data

Figure 4. Topic distributions in documents according to the publication year.

- Topic one: Traffic control and safety
- Topic two: ITS in general and public/urban transport
- Topic three: Detection systems
- Topic four: Emissions reduction and electric vehicles, energy resource substitutions, and intelligent systems for train systems
- Topic five: Vehicle communication systems
- Topic six: Traffic optimization, prediction, modeling, networks, and data

Visually, topics 1, 2, and 4 displayed a decreasing trend over time, and topics 3, 5, and 6 displayed an increasing trend.

3.1. Topic 1: traffic control and safety

Figure 4 shows that the overall theta distribution for topic one (traffic control and safety) has decreased slowly over time. The study performs another LDA with k = 4, iteration number = 1500, alpha = 0.3, and beta = 0.9 to further assess the research themes associated with this cluster. This cluster consists of four subtopics (Figure 5):

- Subtopic one: Vehicle control systems and models
- Subtopic two: Driving and driver behavior models
- Subtopic three: Traffic signals
- Subtopic four: Crash alarm systems

3.1.1. Vehicle control system and model

Research related to vehicle control systems and models began to appear in the 1990s. This particular research theme has increased annually in popularity (as Figure 5 shows). From its first appearance, the research theme has considered autonomous vehicles. Later, the research shifted from stand-alone vehicles to vehicle groups (platoons). Control systems and models of safety issues have focused on sensors, body parts, and even global positioning autonomous vehicles (either individuals or platoons). The goal (regarding safety issues) is to control vehicle velocities under all circumstances and on all roads through mathematical or simulation approaches. Previous studies proposed various approaches, and no study dominated one another's, whether they focused on big data, linear programming, high-fidelity simulations, model-in-loop simulations, or other research themes.

Milanes et al. [17] developed a mathematical model (fuzzy controller) to enhance vehicle-to-vehicle communication through an intersection-detection system that automatically allows vehicles to take turns at an intersection while avoiding collisions. Guo et al. [18]

proposed a framework for connected automated vehicle (CAV) platoons by using model predictive control (MPC) to stabilize CAV platoons under dynamic uncertainties. Both research articles used a mathematical approach, and another research article used a closed-loop simulation approach (enhancing X-in-the-loop simulation with cooperative adaptive cruise control) to test vehicle control functions in platoon mode [19]. Another study combined both approaches, proposed a mathematical model to stabilize the follower vehicle speed in platoon mode and simulated various cases with a series of robots that acted as vehicles [20].

Hou et al. [21] used a different approach to propose a collision-avoidance system considering two types of collision avoidance system algorithms: those for collision avoidance systems with and without interrobot communication. Both were developed and tested in two main road crash scenarios: rear-end collision and junction-crossing intersection collision scenarios. Both algorithms were tested and run in both simulations and experiments; they use vehicle velocity and positioning inputs obtained through vehicle-to-vehicle communication in the current autonomous car collision avoidance system.

3.1.2. Driving and driver behavior model

This subtopic has been around since the 1980s. The research articles focus more on driving patterns, the physical conditions of drivers, and responses in various driving situations, especially in relation to navigation devices. In 2014, the scope of driving behavior model research expanded into enhancing sensor-based functions and vehicle-to-vehicle communication, and microscopic traffic simulation has dominated the research methods. Moreover, driver behavior models have also been developed with a focus on the use of technology to model time responses associated with disturbances (devices or hearing speech), physical responses (such as awareness, drowsiness, fatigue, stress detection, and recognition of traffic signs), decision making (lane, route, and intersection decisions), and software interference effects for drivers.

Drastic changes have occurred since 2015, when most of the research themes were related to autonomous vehicles. Mathematical methods, including big data, machine learning, and technology-based methods, have become increasingly popular for use with sound and image recording devices and sensors. However, the distribution of this particular subtopic has been relatively stagnant over time. Regarding safety issues, modeling driving patterns is about the early detection of risky manual driving behaviors with or without autopilot mode and for various transition times (time to switch on and off autopilot) [22, 23, 24]. Optimal safety measures while changing lanes, with or without autopilot model, remain a hot research theme. Lane change maneuvers are among the largest contributors to road traffic accidents. Hou et al. [25] studied
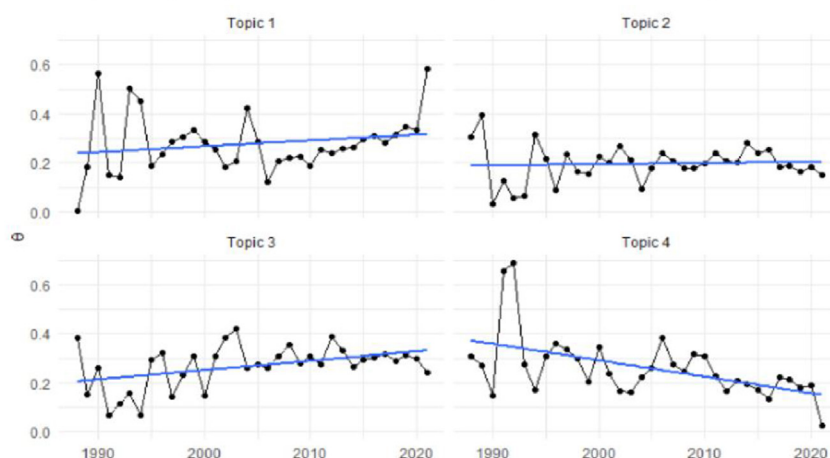
Topic 1 (subtopic 1): Vehicle control systems and models
Topic 2 (subtopic 2): Driving and driver behavior models
Topic 3 (subtopic 3): Traffic signals
Topic 4 (subtopic 4): Crash alarm systems

Figure 5. Subtopic distributions for topic one according to publication year.

this problem by creating an advanced driver assistance system with machine learning. Another study used an in-vehicle platform to detect risky behavior within a short window of time, such as in cases with tight spaces between vehicles while driving and during lane changes. A mathematical model was embedded in a neural network to improve classification [26]. This particular research theme was then expanded to include intelligent driving assistance for autonomous vehicles, with decisions not just for changing lanes but also to avoid risk with or without autopilot mode activated [27, 28, 29]. Overall, there are more studies regarding driving behavior modeling than driver behavior modeling.

Driver behavior models are mainly related to reading cognitive and physical responses using technology to avoid accidents. Physiological signals, such as electrocardiogram, galvanic skin response, and respiration signals, were measured using in-vehicle devices and classified using sparse Bayesian learning; principal component analysis was then used to detect stress and help drivers better manage negative status situations [30]. The study was then expanded to consider various distractions simultaneously. Another study focused on developing algorithms for detecting simultaneous distractions using only data related to vehicle dynamics. An experiment was designed that included two distracted driving scenarios and control with multiple runs for each. A medium-fidelity driving simulator was used to acquire vehicle dynamics data for each scenario and each run. Several data mining techniques (linear discriminant analysis, logistic regression, support vector machines, and random forests) were explored to investigate the performance of each method in detecting distractions [31].

Bylykbashi *et al.* [32] proposed an intelligent fuzzy-based driver monitoring system (FDMS) for safe driving. They presented and compared two fuzzy-based systems: FDMS1 and FDMS2. To make a decision, FDMS1 considers the vehicle's environmental temperature (VET), the environmental noise level (NL), and the driver's heart rate (HR). FDMS2 considers the driver's respiratory rate (RR) as a new parameter to determine the driver's situational awareness (DSA). The driver's ability to operate the vehicle was evaluated by monitoring their condition. The research themes mentioned above focus on the detection of disturbances and also compare methods and consider various disturbance types. Another focus is the use of machine learning and neural network methods in clustering and classifying driver behavior, responses, and potential accidents.

3.1.3. Traffic signals

Traffic signals keep traffic moving at a stable speed and as efficiently as possible under any conditions (routine or emergency). Currently, the research focus is integrating traffic signals with vehicles using a wireless connection. Therefore, real-time data are needed to conduct this type of research. Nonetheless, these challenges have not discouraged researchers because the distribution of this subtopic has increased over time.

In this subtopic, the studies achieved integration in two specific ways. First, traffic signals were enhanced by implementing the proposed algorithms and sophisticated systems to regulate traffic. Second, vehicle-to-vehicle communication and vehicle-to-infrastructure systems have been improved (i.e., vehicles can predict each other's trajectories without overlapping or determine the traffic density). For this subtopic, word embedding helped identify the most frequent research objects: intersections, urban road networks, freeway networks, and route guidance. Conversely, ramp meters, variable message signs (VMSs), and weaving were found to be the least-common subjects. The mathematical approach is also a favorable choice for this particular subtopic, also simulation and machine learning approaches are common.

One particular study [33], was commonly cited. In the study, cooperative vehicle intersection control (CVIC) was investigated in a connected vehicle environment to enable cooperation between vehicles and infrastructure for effective intersection operations and management when all vehicles are fully automated (i.e., no traffic signals). The goal was to avoid collisions and overlapping trajectories. Many other studies have attempted to develop proposed algorithms to achieve better results.

Further research, such as [34], focused on connected vehicle safety issues and noted that traffic signal control strategies mainly rely on infrastructure-based vehicle detectors. However, this approach has drawbacks, and the vehicle location and speed cannot be directly measured. Data collected from connected vehicles provide a complete picture of the traffic states near an intersection and can be utilized for signal control. A real-time adaptive signal phase allocation algorithm was developed using connected vehicle data, and corresponding problems were solved as two-level optimization problems. A real-world intersection was modeled in VISSIM to validate the algorithms. Wang *et al.* [35] developed a joint control model that simultaneously optimizes the connected vehicle speeds and coordinate signals along an arterial road (in platoon mode to pass through intersections together with no stops, at least with a minimum stop time). Simultaneously, signal timing plans along an arterial road can be optimized to achieve reduced signal delays and increased throughput. In scenarios with or without traffic signals, connected vehicles remain a hot research theme.

The general findings for this subtopic are in line with those in [36]. Notably, emerging technologies toward a connected vehicle-infrastructure-pedestrian environment with big data have made it easier and cheaper to collect, store, analyze, use, and disseminate multisource data. The realization of collaborative control relies on the vehicle network. A real-time communication function is utilized in a vehicle-infrastructure collaborative environment to collect and analyze vehicle information from areas near intersections. The signal timing is optimized to guide the vehicle speed to a certain extent.

Regardless, in the future, the physical infrastructure of traffic signals may be reduced. Other studies have explored how to optimize and advance traffic signals (including ramp signals) to reduce wait times and traffic delays in conventional road scenarios. Tachet *et al.* [37] proposed slot-based intersections to solve problems regarding how intersections work. In addition, others have attempted to reduce bottlenecks at conventional intersections. HomChaudhuri *et al.* [38] developed a fast model predictive control (MPC)-based fuel economy strategy for a platoon operating in urban road conditions. The signal phase and timing information from traffic lights are used to reduce stopping at red lights and improve fuel economy. Ma *et al.* [39] developed a coordinated signal control system for urban ring roads in a vehicle-infrastructure environment. Speed guidance is provided based on four subsystems, including detection, communication, signal control, and expected speed calculation. The proposed signal control system was tested using a VISSIM simulation model. Other studies have used artificial intelligence, machine learning, neural networks (such as reinforcement learning or deep learning), and optimization methods to improve adaptive traffic signal control. Reinforcement learning is also a common method in this subtopic.

3.1.4. Crash alarm systems

Figure 5 shows that this subtopic distribution has decreased over time, and the number of related studies has also decreased. Mathematical approaches dominate this subtopic, followed by machine learning and big data analysis methods. Research themes related to alarm systems for rear-end collisions also dominate this particular subtopic. The core objective is determining the optimum distance at which signals are given to the driver and the optimum distance at which an autonomous system operates at a certain speed. Such methods were developed for not only rear-end collisions but also other collision types (sideswipes, single-vehicle crashes, etc.).

The study found that the core development of alarm systems aligned with vehicle-to-X communication systems and technological advancement. There are two directions in which this subtopic develops. First, studies have developed and enhanced the current (already on the market) vehicle sensory parts and systems to avoid safety issues. Studies on vehicle sensors have calculated the crash risk and the optimum distance between vehicles for bad weather conditions and reduced visibility. Peng *et al.* and Wu *et al.* [40, 41] add that different vehicles and lanes affect the

percentage of traffic crash risk. Peng *et al.* [40] proposed a different mathematical approach (log-inverse Gaussian regression modeling) to explore the relationship between the collision time and visibility considering other traffic parameters. Other parameters, such as road geometry [42], animal detection [43], and vulnerable road users (VRUs) [44], were considered in other studies to improve alarm systems. The adaptive speed limit was also included in this subtopic group; this limit can be used to control the optimum distance between vehicles, even though it is not commonly considered as a safety metric for rear-end collisions [45].

Second, studies are focusing on concept development for vehicle-to-X communication as part of cooperative intelligent transportation systems (C-ITS) for safety improvements. Such studies treated autonomous systems as definite embedded systems in autonomous or semiautonomous vehicles. For example [46], presented the results of a quantitative safety impact assessment of five systems that were estimated to have high potential to improve the safety of VRUs, especially cyclists, and these systems included, blind spot detection (BSD), bicycle-to-vehicle communication (B2V), intersection safety (INS), pedestrian and cyclist detection + emergency braking (PCD + EBR) and VRU beacon systems (VBS). Ehlers *et al.* [47] proposed bowtie analysis as a conceptual framework for evaluating the safety of C-ITS and the prevention of road traffic accidents or consequence mitigation (using three case studies under the assumption of a single-vehicle accident). Grembek *et al.* [48] proposed a design for an intelligent intersection (an intersection that manages all surrounding information).

3.2. Topic two: ITS in general and public/urban transport

The distribution of this topic has decreased dramatically over time. This topic is divided into two research perspectives. First, some studies provide a general discussion of ITS, which focus on the benefits of ITS in other fields or analyses/evaluations of ITS element functions. Subsequently, this first perspective can be divided into two categories for discussion:

1. The most recent technology applications for ITS: This subtopic focuses on exploring the novelty of new technology that can be extended to ITS. Menouar *et al.* [49] discussed the potential and challenges of implementing unmanned aerial vehicles (UAVs) as part of ITS applications. Amini *et al.* [50] proposed big data analytics for real-time traffic control. Rathore *et al.* [51] explored big data graphs to design a smart digital city. The benefits of this approach were extended to designing intelligent transportation systems. Veres and Moussa [52] presented a survey highlighting various modeling techniques within the realm of deep learning in ITS. Zichichi *et al.* [53] discussed Ethereum for data management and services in smart transportation systems.
2. Reviews: This subtopic involves providing an overview of ITS element functions in whole or in part. Shladover *et al.* [54] introduce the history of connected and automated vehicle systems and some corresponding concepts. Guerrero-Ibáñez *et al.* [55] explored various sensor technologies integrated with transportation infrastructures to achieve a sustainable ITS and discussed how safety, traffic control, and infotainment applications can benefit from multiple sensors deployed in various ITS elements. Machardy *et al.* [56] performed research across many topics in V2X, from historical developments to standardization activities at high levels in several important fields. Zhu *et al.* [57] discussed a framework for big data analytics in ITS.

The second perspective of this research involves ITS as part of a city or smart city. Public/urban transport is part of the problem (this study found that this theme is uncommonly cited). Notably, an advanced public transportation system combines several elements that need to be presented into an integrated information service for the public. For example,

this study find that optimal bus route selection can reduce passenger waiting times. The model output is an estimated arrival time that can be given to prospective passengers. The core development of traffic route optimization itself is described in the traffic optimization subsection, and other elements that may exist in the context of an advanced public transportation system are noted.

Problems such as parking [58] can be studied to provide insight into the guidance, monitoring, and reservation components of smart car parking and directions for future research. Ref. [59] proposed a mathematical approach for dynamic location-dependent parking pricing and reservation to improve system-wide performance (in an intelligent parking system). Moreover [60], provided an extensive literature review and analysis of dynamic pricing techniques used in the ITS literature. Additionally, the discussion was expanded to bikes and car sharing to promote accessibility with available transportation systems and enhance the intramodality and utilization of nonmotorized transportation modes. Other discussions included bus arrival time prediction and route optimization (others used the IoT to propose intelligent bus transportation systems), integrated public transportation systems (using the IoT), visualization of passenger flows, transit travel times, route planning, and emergency crowd evacuation.

3.3. Topic three: detection systems

Figure 4 shows that the overall theta distribution of topic three has increased slowly over time. The study performs another LDA with k = 4, iteration number = 1500, alpha = 0.3, and beta = 0.9 to dig deeper into the research themes inside this cluster. This cluster consists of four subtopics (Figure 6):

- Subtopic one: Traffic detection
- Subtopic two: Road/lane detection
- Subtopic three: Position/navigation systems
- Subtopic four: Vehicle detection

3.3.1. Traffic detection

Figure 6 shows that this subtopic has slowly decreased in popularity since 2005. A drastic change in the subtopic trend was observed between 2017 and 2019. Conventional technologies such as induction loops and magnetic sensors have become increasingly desirable since 2017. In 2020, video-based technology became dominant in collecting data. Computer vision technology has revolutionized ITS, especially in regard to detection systems.

The best methods (regarding traffic detection) can produce online detection results (in real time) over long durations and for multiple objects, and these methods are capable of multitarget trajectory tracking. Machine learning methods (clustering in particular), neural networks (especially deep learning methods), and computer vision are very prominent in this field. Additionally, novel studies such as [61] have applied generative adversarial networks (GANs) to detect incidents. Spatial and temporal rules are used to extract variables from traffic data, and a random forest algorithm is applied to rank the importance of variables. Then, new incident samples are obtained using GANs. Finally, a support vector machine (SVM) algorithm is used as the incident detection model. Additionally [62], investigated accident detection and proposed an integrated two-stream convolutional network architecture to perform real-time detection, tracking, and near-accident detection for road users based on traffic video data. The two-stream model consists of a spatial stream network for object detection and a temporal stream network to leverage motion features for multi object tracking. Near accidents are detected by incorporating appearance features and motion features from the two networks.

Ahmed *et al.* [63] proposed a method to generate meaningful and smooth synopses of long-duration videos of traffic monitoring because

Topics Regarding Detection System in ITSs Over Time at a Yearly Interval

Topic 1 (subtopic 1): Traffic detection
Topic 2 (subtopic 2): Road/lane detection
Topic 3 (subtopic 3): Position/navigation systems
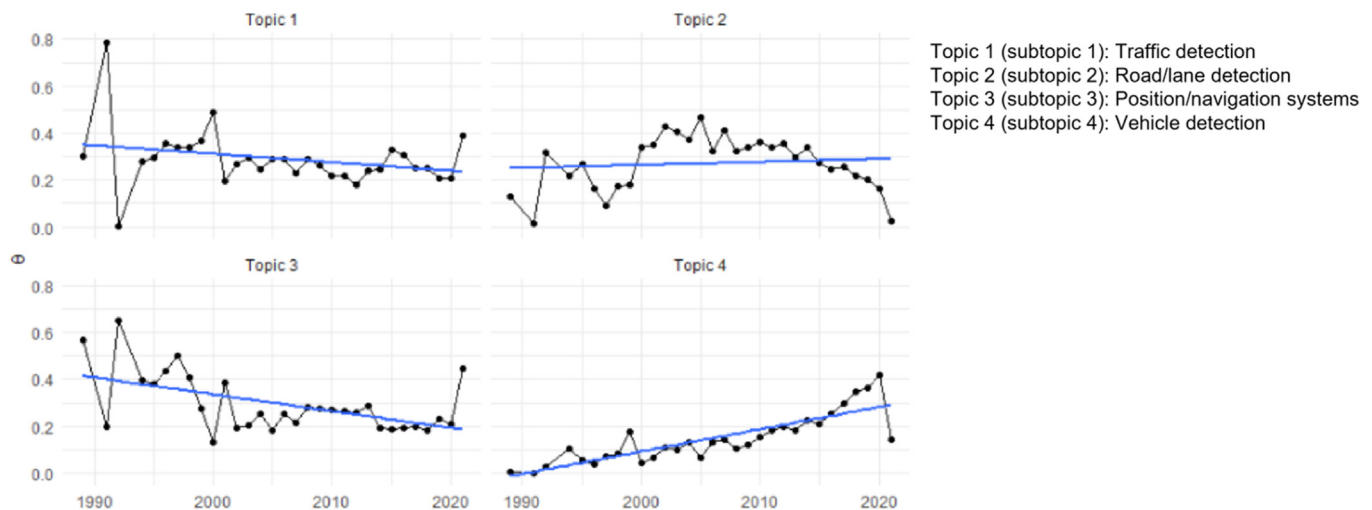Topic 4 (subtopic 4): Vehicle detection

Figure 6. Subtopic distributions for topic three according to publication year.

outputs are often summarized and include redundant content or activities that may not help the observer. Ospina and Torres [64] proposed different approaches, such as reidentification (ReID) and multitarget single-camera tracking (MTSC), to extract vehicle attributes. Analysis of these attributes can promote multi-target multi camera tracking. Notably, the vehicles that travel a predefined path can be counted. Therefore, in detecting traffic flows, this approach is not limited by pedestrian flow [65], traffic incident, or traffic volume conditions. Developments for this subtopic are more likely to coincide with the methods used than the technology applied. The development of new methods can increase the effectiveness of traffic detection.

3.3.2. Road/lane detection

Figure 6 shows that this subtopic has slowly decreased in popularity over time. This study found that the research results for this subtopic often overlapped with those for vehicle detection. The road/lane detection process also involves detecting other entities (such as VRUs and surrounding vehicles). While this research subtopic has decreased in popularity, vehicle detection research has increased.

Mathematical, machine learning, and neural network methods are commonly discussed. The data collection process includes geospatial, camera-based, video-based, light detection and ranging (LIDAR), and mobile laser scanning (MLS) methods, among others. The goal is to recognize, analyze (all the markings, boundaries, and surrounding, especially in unstructured environments), and optimize trajectories. Additionally, 3-D is the desired output dimension to have a complete road/lane geometry structure in foreign areas.

Zai *et al.* [66] presented a method to automatically extract 3-D road boundaries from mobile laser scanning (MLS) data. The proposed method includes two main stages. First, a supervoxel is generated by selecting smooth points as seeds and assigning points to facets centered on these seeds using several attributes (e.g., geometry, intensity, and spatial distance). Second, 3-D road boundary extraction is performed. Wang *et al.* [67] presented an offline mapping algorithm for autonomous vehicles (AVs) that consisted of five key steps. First, data preprocessing was performed to calibrate the original odometry data. Second, a 2D laser scanner and the calibrated odometry data were used to build a virtual 3D LIDAR system. Third, loop closure was performed to search the revisited region and calculate the distance displacement. Fourth, an optimizer was applied to generate the final trajectories. Finally, by fusing the point cloud data from virtual 3D LIDAR and the final trajectories, a point cloud map was generated.

Nevertheless, other researchers are still exploring and developing different methods. No study in this subtopic has dominated one another's. However, the development direction is clear, namely, toward improved representations and lane/road detection results. For example [68], proposed a new cumulative density function (CDF)-based symmetry verification method for lane change detection, forward collision warning, and overtaking vehicle identification. The motion cues obtained from an optical flow are used for overtaking detection. This approach was further combined with a convolutional neural network. Dairi *et al.* [69] addressed urban scene monitoring and tracking obstacles based on unsupervised deep-learning approaches. They designed an innovative hybrid encoder that integrates deep Boltzmann machines (DBMs) and autoencoders (AEs). This hybrid autoencoder (HAE) model combines the greedy learning features of DBMs with the dimensionality reduction capacity of AEs to detect the presence of obstacles accurately and reliably. Then, the researchers combined the proposed hybrid model with one-class support vector machines (OCSVMs) to visually monitor an urban scene. Additionally [70], used a deep neural network architecture to detect lane markings in a complex environment by analyzing the corresponding structural information. First, they used a semantically guided channel attention (SGCA) module to select the low-level features from a deep convolutional neural network (CNN) by using high-level features for guidance. Second, a deformable pyramid convolution (PDC) module was developed to enlarge the receptive fields and capture the complex structure of lane marking by applying deformable convolution through multiple feature maps with different scales.

3.3.3. Position/navigation systems

Figure 6 shows that this subtopic has slowly decreased in popularity over time. In ITS applications, high horizontal positioning accuracy is needed. Many conventional map-matching algorithms have been developed and involved topological analyses of spatial road network data, probabilistic theory, Kalman filters, fuzzy logic, belief theory, hierarchical classifiers with class unfolding paired and context-based localization, two direction-of-arrival (DOA) estimation, and many other methods. Mathematical methods dominate this subtopic. Conversely, artificial intelligence and machine learning are rarely considered.

Over time, an increasing number of problems, such as frequency pairing, vehicle localization judgment, and curved road issues, have been considered in the context of meeting autonomous driving requirements, such as real time, centimeter-level accuracy, storage efficiency, and usability requirements. Gwon *et al.* [71] attempted to simultaneously meet

these three requirements and proposed a precise and efficient lane-level road map generation system that conforms to the relevant requirements. The proposed map-building process consists of three steps: data acquisition, data processing, and road modeling. The data acquisition and processing system captures accurate 3-D road geometry data by acquiring mobile 3-D laser scanner data.

Later, problems were divided into two types: navigation systems for conventional vehicles and navigation systems for autonomous vehicles; both are affected by navigation technology development and information, communication technology development, and mathematical method development. Moreover [72], stated that to make better positioning and navigation, next generation ITS will be required to provide reports on traffic status, road condition, and driver behavior information. Their study aimed to reduce noises and biases on navigation systems (especially on road with high anomalies and vehicles that use low-cost sensors). Regarding autonomous driving, a study such as [73] used a novel adaptive federated Kalman filter (FKF) with time-varying information sharing factors to enhance unmanned ground vehicle (UGV) integrated navigation systems for better high-precision positioning and navigation. As stated before, mathematical methods very dominated this issue.

3.3.4. Vehicle detection

This subtopic has displayed an increased distribution over time. Neural network methods (especially deep learning, convolutional neural networks, and long short-term memory) are dominant, also reinforcement learning, machine learning, and video surveillance technologies are used. Some other studies, such as [74] have used different technologies and approaches; notably, an architecture was presented to detect a vehicle and compute continuous global six-degree-of-freedom (6-DoF) poses through joint 2D landmark estimation and 3D pose reconstruction. Additionally [75], focused on developing a roadside magnetic sensor system for vehicle detection. However, since 2016, technological and other methods have rarely been applied.

The goal of vehicle detection is to analyze and recognize vehicles or other entities in real time at a large scale (multiple targets and moving objects), rapidly, and with good image quality. Thus, this subtopic is highly dependent on video surveillance technology and methods. In ITS applications, research on proposing or developing existing recognition methods is more common than research involving the development of video surveillance technology. In this particular research field, neural network methods are common. Ref. [76] proposed an embedded system for fast and accurate license plate segmentation and recognition using a modified single-shot detector (SSD) with a feature extractor based on depth wise separable convolutions and linear bottlenecks. Additionally [77], proposed methods to recognize vehicle colors in complex traffic scenes, and a new network type, namely, a multiscale comprehensive feature fusion convolutional neural network (MCFF-CNN), based on residual learning was developed for color feature extraction. First, the MCFF-CNN network is used to extract the in-depth color features of vehicles. Then, a support vector machine (SVM) classifier is employed to obtain the final color recognition results.

3.4. Topic four: emissions reduction and electric vehicles, energy resource substitutions, and intelligent systems for train systems

The distribution of this topic has decreased very sharply over time and is now close to 0. Two causes for this trend were identified. First, many paper titles and abstracts in this cluster contain only one or two words in the term 'intelligent transportation system'. It happened because we allowed the dataset to have excess article loads rather than lack of the actual number of ITS articles. LDA can reduce the excess load by using the theta variable. However, the drawback is that articles in this group can be inhomogeneous. Therefore, this section might not represent actual knowledge development in the discussion hereafter. Second, extensions of main ITS topics are given as follows:

1. Antenna and other technology specifications for communication. Those with suitable specifications for ITS applications are considered [78, 79, 80].
2. Intelligent systems for train systems. These articles do not directly discuss ITS core knowledge; instead, they discuss enhancing train systems with various developments, technologies, and elements that support ITS concepts, such as timetable management, intelligent fault detection, intelligent operation, and maintenance systems.
3. ITS applications for emission reductions [81, 82].
4. Electric vehicle and energy source substitution applications. This subject is quite distinguishable in this cluster. The relationship between ITS and these terms is related to reducing emissions and enhancing green transportation. The scope of the discussion includes the technology used in electronic vehicles in the ITS context [83], nanogenerators as a substitute energy source for vehicles or infrastructures [84, 85, 86], and energy management for electric vehicles in the ITS context [87].

3.5. Topic five: vehicle communication systems

Figure 4 shows that this topic has increased in popularity over time. Most studies in this cluster are about vehicular ad hoc networks (VANETs) and the corresponding problems (routing, security, confidentiality in data transmission, quality-of-services, etc.). The following subjects were noted in this topic cluster.

1. Routing problems

Studies on this subject have mainly proposed or developed routing schemes/protocols (no schemes/protocols dominate others in this topic cluster); in addition, routing optimization is often considered. The goal is to find the best scheme/protocol for the vehicular environment or any other scenarios and tackle scalability issues. Additionally, safety-critical information can be shared and routed to other intended vehicles in real time with high mobility and varying densities (in other words, the data can be used to solve highly dynamic topological problems). Moreover, the vehicular concept has evolved toward autonomous vehicles. In this context, the study was conducted solely using a word embedding approach, and there are some points worth noting.

- The most discussed scenarios are urban and highway scenarios.
- Mathematical and optimization approaches highly dominate this subject (the terms fuzzy logic algorithm and heuristic algorithm are common); very few studies use machine learning approaches.
- Terms that occur a lot and are closely related to the context of 'route problem' are position-based routing (PBR), hybrid, media access control (mac) protocols, greedy forwarding method, and multihop broadcasting.
- The emergence of 5G network applications for message dissemination is notable.
- Hamdi *et al.* [88] described and reviewed the routing problem for vehicle communication systems.

2. Communication channels

Studies on this subject often discuss channel characteristics, implications toward other subjects, models, and channel performance; propose/develop communication channels; and explore radio frequencies. Thus, this subject is associated with advances in routing and network communication technology. Method development has continued in accordance with the technological development. The goal is to deliver an ultrahigh data transmission rate with low end-to-end delay.

Radio waves are still popular topics, but millimeter waves (mmWaves) in particular have begun to dominate the discussion in various studies since 2018, especially for vehicle-to-vehicle (V2V) communication applications. Since then, discussion of the application of

5G for V2X communication has been ubiquitous. He *et al.* [89] reviewed state of the art methods for mm-wave V2V channel measurements and modeling, described recent directional V2V channel measurements performed in the 60-GHz band, and discussed future challenges to be addressed in mm-wave V2V channel measurements and modeling.

3. Security for vehicle communication systems

El-Rewini *et al.* [90] and Manivannan *et al.* [91] reviewed and summarized the safety issues related to vehicular communication from various angles. This study noted several crucial factors, namely, data security, user privacy/authentication, and message authentication, that can affect the security of VANETs. A security countermeasure protocol can simultaneously be created when technology is developed. Studies on this subject have focused on proposing security frameworks/protocols or new methods/technologies to improve security framework/protocols. For example [92], presented a framework for effective user identification and authenticity to control access. Tan and Chung [93] proposed a secure authentication and key management scheme with blockchains.

4. Quality of services (QoS)

This subject is mainly related to developing network services under ITS requirements. VANETs are the relationships between roadside units (RSUs) and vehicles and among vehicles, and now the topic has expanded to include vehicle relations with other entities on the road (pedestrians and others). The direction of development is in line with advances in network and cloud computing technology, such as fog computing. This subject is focused on how networks can provide better and more efficient services in the context of the Internet of Vehicles (IoV) and vehicular cloud computing (VCC).

A study worth noting [94], proposed a novel architecture for real-time ITS big data analytics in the IoV environment. The proposed architecture merges three dimensions, including intelligent computing (i.e., cloud and fog computing), real-time big data analytics, and IoV dimensions. The IoV environment, ITS big data characteristics, lambda architecture for real-time big data analytics, and several intelligent computing technologies are described. Additionally, the opportunities and challenges associated with implementing fog computing and real-time big data analytical methods in the IoV environment are discussed. Other studies have connected network service enhancement directly to ITS elements, as in [95], where the optimal deployment and dimensioning of a fog computing-based IoV infrastructure for autonomous driving was investigated.

3.6. Topic six: traffic optimization, prediction, modeling, networks, and data

3.6.1. Traffic optimization

This cluster involves finding the optimal route and optimizing traffic signals in conventional road scenarios (traffic signals are discussed in the traffic signal subsection). The goal is to achieve the fastest travel time. Two discussion categories were identified: route optimization in environmental scenarios and conventional vehicles and route optimization in advanced environmental and vehicle scenarios (such as those with autonomous systems).

In the first category, the tendency has been to study and determine the optimal route for a specific case rather than to develop a route optimization method. Research on particular issues has included determining optimal ridesharing routes (carpooling), fleet sizes (trucks), bus routes, etc. Route selection methods are dominated by optimization, statistical, and mathematical approaches. Very few studies have suggested methods other than those discussed earlier in the paper (such as machine learning or dynamic traffic assignment).

In the second category, studies have focused on complex and broad-scale problems. The route selection methods are dominated by optimization and mathematical approaches. Hu *et al.* [96] presented a real-time dynamic path planning method for autonomous driving that avoids both static and moving obstacles and provides appropriate acceleration and speed constraints for a vehicle based on a mathematical approach. First, a centerline from a set of predefined waypoints is construed. A series of path candidates is generated based on the arc length and offset to the centerline in the s-ρ coordinate system. Subsequently, the point coordinates are converted into Cartesian coordinates. Rossi *et al.* [97] did almost the same thing but with more complex objectives, namely, modeling the search for optimal ridesharing routes decoupled with rebalancing self-driving vehicles. Other studies, such as [98], proposed traffic path planning algorithms based on data prediction to find the shortest travel time or path. Predictive models based on historical traffic data and current traffic information with load balancing have been developed based on both mathematical methods and clustering.

3.6.2. Traffic flow prediction

The study found two types of traffic flow prediction, namely, short-term and long-term prediction. The short-term prediction predicts traffic flow within minutes to approximately 1 h. Meanwhile, the long-term prediction is a prediction of traffic flow over a more extended period. Overall, the approaches are dominated by big data, machine learning, and neural networks: clustering (k-nearest neighbor and SVM), random forest, deep learning, long short-term memory (LSTM), artificial neural network (ANN), recurrent neural network (RNN), CNN, stack autoencoder, generative adversarial networks (GANs), gradient boosting; and a spatial-temporal approach. Statistical and time-series approaches tend to be less desirable, and very few combine all of these methods with optimization. It is important to note that all of these methods were selected and developed to predict different traffic flow characteristics. Very few studies have reviewed the relationship between traffic flow characteristics and the various methods selected and developed.

The study also found that researchers tend to use more statistical approaches, time series (ARIMA and SARIMA), machine learning, and neural networks for short-term prediction. However, some studies use machine learning and neural networks for spatial-temporal approaches or hybrid models (combining two or more different approaches). In contrast to long-term prediction, researchers are very much dominated by big data approaches, machine learning, and neural networks. Currently, the spatial-temporal approach is cited a lot. Lv *et al.* [99] proposed a stacked autoencoder (trained in a greedy layerwise fashion) method for traffic flow prediction, which inherently considers the spatial and temporal correlations. Zhao *et al.* [100] proposed a model by combining the graph convolutional network (GCN) and the gated recurrent unit (GRU). The model is called Temporal Graph Convolutional Network (T-GCN). The model is able to study complex topological structures and comprehend dynamic changes in traffic data to apprehend spatial and temporal dependence. Afterwards, they use the model to employ traffic forecasting based on the densely populated road networks. It can be said that the knowledge development direction of traffic flow prediction is highly dependent on the development of machine learning methods, neural networks, and statistics.

3.6.3. Traffic flow networks and models

This subtopic is closely related to the traffic lights/signals research theme described in the subtopic of traffic signals. However, this subtopic is not as ubiquitous as traffic control and traffic signals. A few recent articles have many citations compared to those published in previous years. Traffic flow can be observed microscopically, macroscopically, and at the network level. This study found that none of the three types of observations has dominated one another's.

The objectives include analyzing traffic congestion (including the different types of congestion), identifying traffic bottlenecks, controlling traffic signals (adaptive traffic signal control), placing traffic lights/signals, and selecting optimal routes in route guidance. These objectives are

often linked directly as a final result rather than evaluating traffic flow networks and modeling in separate steps. The following modeling and approaches were the most common:

1. Mathematical modeling based on communication systems. Such cases include the topological structure of the VANET communication scheme, the number of vehicle arrivals at a particular node, or a weighted network model. Other studies, such as [101], have proposed cyber-physical system (CPS) sensors for autonomous vehicles to model traffic flows. Such models can also assist neighboring autonomous vehicles by communicating the required information through ad hoc network communications or a centralized cloud.
2. Mathematical modeling based on traffic density at a particular travel time and speed-density functions. Other related models include car-following, cell transmission, intelligent driver (ID), macroscopic fundamental diagram (MFD), and Markov chain models.
3. Optimization approaches are the most ubiquitous of all methods and include bilevel multi-objective optimization, genetic algorithms, and ant colony optimization.
4. Big data, machine learning, and neural network (autoencoder stacking, reinforcement learning, deep learning, ANNs, CNNs, and LSTM networks) methods have been used to analyze vehicle densities. Other studies have extended these approaches for spatial-temporal applications.
5. Simulation approaches, such as VISSIM simulations.
6. Dynamic system modeling approaches that treat traffic as a hybrid dynamic system.

This study found that this subtopic mainly involves the continuous evolution of traffic congestion in various road scenarios and the development of methods to improve vehicle mobility. Variables such as speed, density, and other parametric controls continue to be explored to obtain the best modeling results.

3.6.4. Traffic data

Some problems related to data can be identified. First, data collection within the ITS scope can performed with sensors, smart cards, communication systems, Google functionalities, surveillance cameras, etc. Smart cards are used to determine individual mobility capacities, such as through origin-destination (OD) flows. Such data can be used to design an advanced traveler information system (ATIS) or public transportation information system. OD matrixes have been increasingly used to predict individual travel flows and estimate the time of arrival.

Second, data storage is also a problem related to ITS requirements. Existing studies have attempted to make data storage more efficient. For example, a study aware that trajectory data storage may consist of traceability and vector storage. State vectors are extracted from the analysis of the original sample data (from sensing devices). The study effectively reduces the frequency of sampling data storage, reduce query and analysis operations, also the study uses a vector function that is able to transform road network into indexes. Therefore, an insignificant amount of vector data and road networks can be stored [102].

Third, another problem is missing data. The existing studies have attempted to assess data by exploring the related spatial-temporal patterns. For missing data, singular value decomposition (SVD), singular value regression (SVR), neural network (feedforward neural network) approaches, ARIMA, Bayesian models (Bayesian augmented tensor factorization), low-rank matrix decomposition, kriging, GAN methods, unsupervised methods, and other methods have been combined with tensor decomposition to estimate missing values. Additionally, check-in data from social media, synthetic data, road network representations with embedded graphs, and GANs can be used to generate road traffic state information in real time. The most common mathematical and

statistical approaches include lp-norm regularized sparse self-representations, which incorporate nonconvex lp-norm information with $0 < p < 1$, and kernel sparse representations with based on a combination of the L1-norm and L2-norm. Fourth, dimension reduction and data evaluation problem. Dimension reduction can use a variational autoencoder (VAE) or similar tool to generate and infer data by exploring latent spaces for data selection. Data evaluation can use the expert system.

4. Conclusions

The systematic review is teamwork, which is also one of the obstacles of this research. Several platforms have been developed to conduct systematic reviews. Still, the screening process remains a separate part and one of the reasons why it is teamwork. On the other hand, ITS is a combination of various disciplines within transportation system (communication technology, management systems, and others). When we generate a dataset with the keyword 'intelligent transportation system', two things happened. First, it will generate research articles containing these keywords. Second, Scopus categorizes articles that do not contain these keywords, but the research themes in it are considered related to each keyword. The fact that several articles discuss aviation being returned inside dataset as part of the keyword 'transportation'. However, these articles are not part of the 'intelligent transportation system' context. Thus, filtering in Scopus alone is not good enough as a benchmark for the quality of dataset homogeneity, and the quality of the screening process results is essential. Problems will arise if these unrelated articles have high citation numbers. If we directly use the unscreened dataset on the platform, the platform will make the unrelated articles as part of high-impact documents for review, which will cost more time. Therefore, the method used in this study is highly concerned with the dataset condition, objectives, and research questions.

Custom NER is well known for tagging documents. This study utilizes the tag function to separate the unrelated research articles. Tags are proven to work well on documents containing standard terms such as medical terms 'cardiovascular' [7, 8, 9, 10]. ITS sectors also have the exact phrase in every English-language literature, for example, 'Public Transportation System', 'Traveler Information System', and others. Therefore, custom NER method can filter documents that do not coincide with ITS terms. The obtained evaluation results include a loss value of 61, F-1 score of 85%, precision of 90%, and recall of 83%. The obtained dataset contained 23,823 documents; this method can screen as many as 21,995 documents related to ITS. Documents that have the term ITS are labeled and then separated into new datasets and clustered using topic modeling.

The topic modeling approach used in this research is LDA. LDA clustered 21,995 documents into six topic clusters. Subsequently, we divided documents into subsets with theta values ≥0.5 for each topic cluster. The benefit of this method is that the study can overcome the shortcomings of the custom NER method. There is a slight possibility that custom NER will not yield an accurate label for a document that is not in the ITS scope; however, because it contains words such as 'traffic control method', the document will be labeled as an ITS document. This example highlights the dimensional curse of the custom NER approach, in which the number and sequence of words as features in the document affect the POS tagging results. LDA will mask this issue by generating theta values that cannot represent a document included in any topic cluster. An example is given in Table 5.

Although the combination of custom NER and LDA has yielded promising results, there might be other drawbacks of these methods that cannot be denied. The presented process is a systematic review method. One of the objectives of this study is to reduce the number of manual reading steps. For this, we used a word embedding method. Word

Table 5. Inaccurate results based on custom NER.

Context	POS	Label	Theta
automatic guidance mobile robots two way **traffic method control** devise guide mobile robot automatically passage without collision environment obstacles guidance strategy base premise obstacle ……. computer simulations also make model two way traffic mobile robots passage two straight wall study mobile robot turn sharp corner	[('two', 33, 36, 'CARDINAL'), ('traffic method control', 41, 63, 'B_ITS'), ('two', 769, 772, 'CARDINAL')]	True	Topic 1 = 0,4 Topic 2 and 3 = 0,0 Topic 4 = 0,4 Topic 5 and 6 = 0,1

embedding was performed for each topic cluster to generate the document information of interest. The study uses keywords such as 'optimization' and 'method' for topic cluster 6. Then, word embedding provides words as a context that have similarity with the keyword, i.e., "genetic_algorithm", "ant_colony", and "particle_swarm". Adhering to the distribution hypothesis, we can determine that in the topic cluster 6, which is related to route optimization, the most relevant context is provided by adjacent words. Then, we can determine which document index contains the context. Thus, by referring to the document index, we compare index citation magnitudes. The document index with the large number of significant citations can be used as a reference by other researchers studying vehicle detection.

Related to the first research question: The core knowledge of ITS has evolved over time. This study finds that detection system, communication, and traffic are topics that appear more frequently throughout the year than other topics. Broadly speaking, all research leads to integrating all possible entities in real-time and extending the communication not limited to V2V. It can be easily said that in the future, ITS will move toward a C-ITS concept. That is, information exchange will not be limited to V2V and V2I communication but also include other entities, such as road users and pedestrians. Significant changes are expected to occur in communications, sensors, and surveillance technology. Not all elements that already exist in traditional road scenarios will continued to be considered because autonomous systems are being developed. Traffic control will be viewed as a real-time control approach for large-scale network traffic scenarios. Smooth mobility and safety are the main goals of C-ITS.

Related to the second research question: The substantial approaches used in the research on ITS include mathematical, machine learning, neural network, and optimization methods applied in various ITS fields. This study also found that even though high-quality data are crucial, little research has been performed on the implications of using poor/limited amount of data. Various things related to standards and quality in the context of C-ITS in the future will need to be considered. Other terms worthy of being noted are as follows:

1. Spatiotemporal. This term emerges quite commonly, such as in the use of temporal GPS trajectory data to analyze driving behavior [103].
2. Taxi and urban ride hailing. This topic has recently attracted research interest due to its vast potential application in ITS. One of the benefits is reducing the number of private vehicles in use. Several studies have also discussed this topic in relation to autonomous vehicles. Some related research topics include route recommendation systems, cruising areas, minimizing passenger wait times, demand prediction, and rebalancing issues.

The major challenge of this framework is to not overgeneralize research themes with too few topic clusters. Moreover, the purpose of a systematic review is to obtain a thorough picture of developments in a field. However, if too many topic clusters are considered, the amount of vocabulary in each cluster will be limited, which will affect the review process based on word embedding. We have to be careful and creative in conducting reviews with keywords and terms that form the existing context in topic clusters when diversity is limited. Another drawback is that this study does not cover articles with small theta and citation

values. For example, traffic emergencies (accident detection, ambulance route, etc.), traffic congestion prediction, advanced traveler information systems, vehicle/traffic speed prediction, and cybersecurity for autonomous and unmanned vehicles are not covered.

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