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REVIEW

Assessment of Machine Learning Techniques and Traffic Flow: A Qualitative and Quantitative Analysis

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Abstract: Traffic flow analysis is an interesting study topic in transportation studies. A better understanding of traffic flow is essential for more effective traffic reduction methods. Because managing traffic flow in cities is getting more complicated, we need more methodical ways to deal with these problems. Machine learning (ML) techniques have been suggested as a possible solution because they can process great amounts of data and give insights that can be used to help make decisions about how to manage traffic. The main objective of this research is to conduct a comprehensive examination of the quantitative and qualitative aspects of utilizing ML techniques in the management of traffic flow. Using the Web of Science platform, documents from January 2007 to April 2023 were assessed. The study found that traffic flow management has been using ML techniques more and more over the past few years. This study shows the different approaches and methods that were used, as well as the results and limits of these methods. The results recommend that ML can be a useful tool for managing traffic flow in cities, but further investigation is warranted to gain a complete comprehension of both the advantages and disadvantages of the subject under scrutiny.

Keywords: machine learning, traffic flow, data analysis, Web of Science (WOS)

1. Introduction

In recent years, there has been a lot more research on how machine learning (ML) can be used in cities, especially in the area of traffic flow analysis [1]. Using techniques for analyzing data, like ML, could change the way traffic is managed in cities in a big way. Cities are having trouble managing traffic flow because of the growing population and number of cars on the roads [2–5]. The application of ML methodologies has the potential to yield valuable understandings regarding traffic patterns and subsequently facilitate the optimization of traffic movement in both urban and rural environs [6, 7]. In this work, we will explore the literature on the application of ML to traffic flow analysis in urban and rural areas, as well as the possible benefits and challenges of this approach. Also, in this paper, we review some of the most reliable scientific articles published between January 2007 and April 2023 in the field of smart transportation networks.

The field of traffic flow research has seen significant progress in recent years, as evidenced by a number of influential publications. Medina-Salgado et al. [8] published a comprehensive review of urban traffic flow prediction techniques, examining intelligent transport systems and categorizing smart techniques for traffic flow prediction. The same year, a research endeavor was carried out by Korecki to examine the feasibility and endurance of utilizing ML techniques for managing traffic signal control, proposing a highly reliable method that reduced CO_2 emissions during training [9]. Harrou et al. [10] presented a novel deep hybrid learning model called Guided-attention (GAHD) Variational Autoencoder (VAE) for forecasting pedestrian and bicycle traffic flow, which combined a long short-term memory (LSTM) model with a VAE and utilized a self-attention mechanism. Additionally, Nie et al. [11] proposed an enhanced routing and scheduling mechanism for time-triggered traffic with large period differences based on integer linear programming for real-time communication in time-sensitive networking (TSN). Azimjonov et al. [12] developed an innovative, vision-based system for monitoring traffic flow in real time at road intersections. This system employs a novel algorithm for object tracking and data association, enabling the extraction of statistics pertaining to the vehicles passing through the intersections. Sayed et al. [13] published an extensive review of ML and deep learning techniques for traffic forecast in intelligent transportation systems (ITS) in smart cities, identifying inherent obstacles and emphasizing the importance of accurate traffic prediction in the transportation industry. He et al. [14] presented an in-depth study on autonomous anomaly detection in traffic flow data using reinforcement learning and an LSTM model, learning anomaly patterns without supervision and automating the detection process. Furthermore, Li and Zhang [15] published a paper on generating a digital twin (DT) model of traffic flow for highway scenarios using radar and camera

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fusion, proposing an end-to-end method involving sensor calibration, data transformation, and target tracking using a fusion Kalman filter. The DT model could provide real-time dynamic traffic flow data to optimize traffic efficiency and enhance the functionality of ITS [15].

Traffic flow study is critical, in urban and rural areas where congestion and delays may have serious economic, social, and environmental effects. ML techniques are becoming more useful for analyzing and modeling traffic flow as more data become available from sources like connected and automated vehicles, sensors, and cameras. The goal of this study is to review the recent improvements in ML applications for analyzing traffic flow in cities. By reviewing the existing research and figuring out what works and what does not about the current methods, this study hopes to give an idea of the pros and cons of using ML techniques in research and management of traffic flow. Understanding how well ML techniques work for analyzing traffic flow can help make urban and rural transportation systems more efficient and last longer.

The subsequent sections of this work are organized as follows: Section 2 provides a brief background on traffic flow theory, ML, and data analysis techniques. Section 3 describes the methodology used to conduct the literature review, including the search approach and inclusion criteria. Section 4 presents a comprehensive review of the latest research on the application of ML and data analysis methods to traffic flow management in urban and rural areas. In Section 5, we talk about the most important findings and what they mean for the studies we looked at. Section 6, the last part of the paper, is a summary of the research gaps and some ideas for future study directions.

2. Methodology

To assess the state of knowledge, identify research gaps, and highlight their limitations, a literature review is a crucial step [16, 17]. This study will look at all of the relevant research articles and documents about using ML to analyze traffic flow in cities. The review will focus on articles that were published in reputable scientific databases like Web of Science (WOS). The usual way to do a literature review is to first find the right search words (keywords), then pick the right keywords, and then look at the results. In this research, the six-step process shown in Figure 1 is used to evaluate the research on ML techniques for traffic flow [16]. Similar study methodologies may be found across the current literature.

This study uses both qualitative analysis and quantitative analysis to look at the documents that were found. Figure 2 shows a view of the two techniques used in this study [18]. The main goal is to review how well ML techniques work for analyzing traffic flow in urban and rural area. The selected time frame for this study is from 2007 to 2023. The purpose is to investigate the latest research trends and how ML has contributed to addressing traffic issues in urban and rural areas in recent years. It should be noted that the keywords were selected in a brainstorming session between the authors and experts.

3. Machine Learning

ML is a field within computer knowledge and artificial intelligence (AI) that focuses on utilizing algorithms and data to simulate human learning mechanisms and progressively improve their precision [19, 20]. As part of the expanding domain of data science, ML is a significant constituent. Due to the expansion of the use of IT in more and more industries, there is a growing desire to automate decision-making processes. ML-based solutions rely heavily on AI to address these issues. ML can be used as a tool to improve operational intelligence in various fields. ML approaches consider computational and statistical techniques to gain knowledge straight from data, rather than relying on a predetermined formula [21, 22].

ML models are constructed through the process of training ML approaches on a designated dataset. Subsequently, the trained algorithm is capable of integrating new input data into the model, with the objective of generating predictions. To expand the performance of ML approaches, they can be optimized by increasing the sample size and amount of data during repeated learning [23]. The ML methods have the potential to vastly improve traffic data analysis [24]. ML systems can make accurate predictions about traffic conditions by analyzing massive volumes

Figure 1
A six-step procedure for reviewing the literature

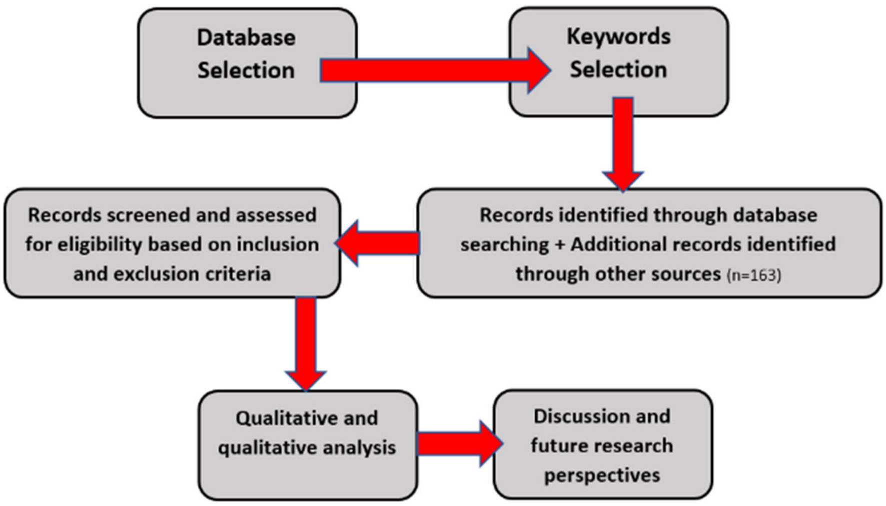
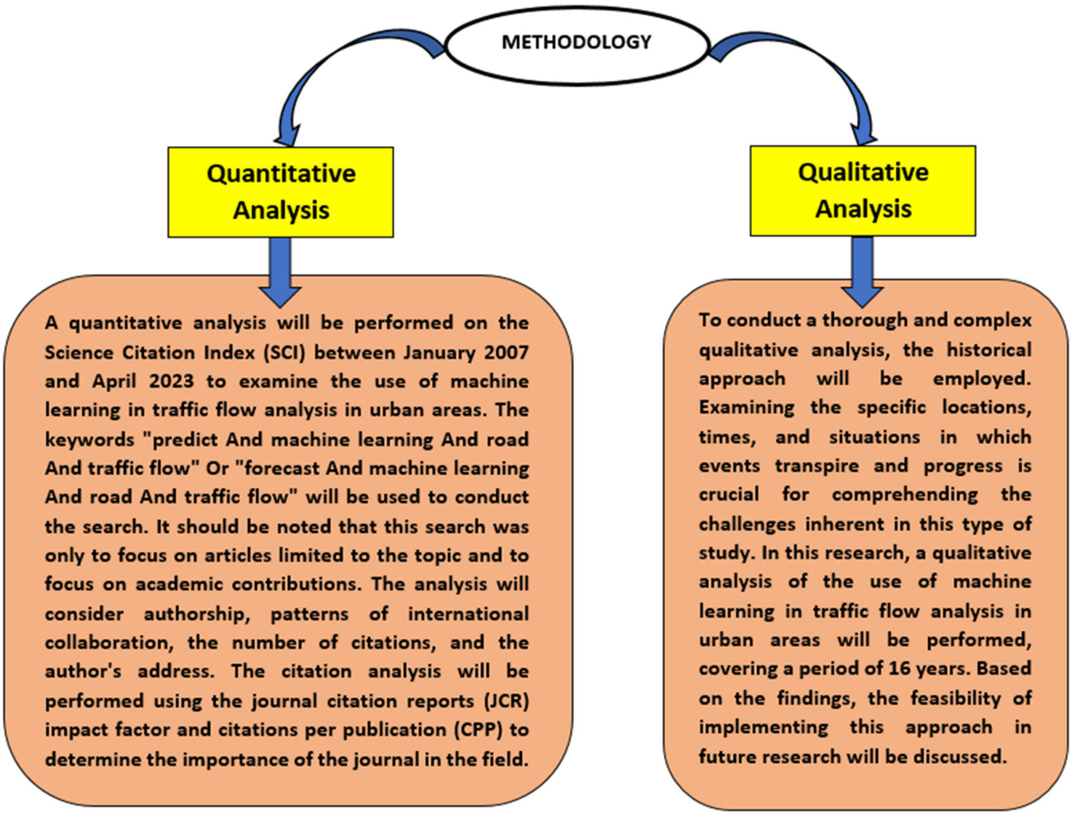


Figure 2
An overview of the methodology including qualitative analysis and quantitative analysis



of data. In turn, this may help traffic management make more accurate and timely decisions about things like lane allocation, route selection, and infrastructure upgrades [25].

It is noteworthy that while ML techniques offer numerous benefits for traffic control management, there are practical restrictions when applying these approaches in real-world scenarios. Among these constraints, the challenge of acquiring accurate and sufficient data stands out as one of the most critical. Ensuring the precision and reliability of collected data is crucial to avoiding hindering the analysis and prediction processes. Furthermore, the expenses associated with procuring data collection equipment, such as sensors and video cameras, must be appropriately weighed when developing intelligent traffic control systems. In addition, privacy and information security represent some pivotal factors that must be considered when applying ML to traffic flow management. Nevertheless, the possibility of unauthorized access by hackers and the misuse of sensitive data pose a serious threat to citizen safety. Therefore, these issues represent critical considerations that require special attention.

4. Traffic Flow

One of the key elements of transportation and traffic research is traffic flow and related models [26]. The idea of "road capacity" refers to the highest number of vehicles capable of traversing a single lane or the full breadth of a roadway, in a unidirectional or bidirectional fashion, within a specified time frame while maintaining a satisfactory performance standard. Road capacity depends on various factors such as geometric design, pavement composition, weather conditions, driver characteristics, and traffic situations. The quality of road traffic conditions is largely influenced by the level of service provided [27, 28].

With the fast growth of the urban population and the expansion of industries, the activity of vehicles in the cities has increased and has caused various problems for the residents [29]. Environmental destruction and noise pollution stand out as two important issues in this field. As a result of the importance of this topic, many valuable researches have been conducted in this field. In order to control the flow of traffic on the roads and determine the appropriate distance between cars, road control rules have been proposed based on various regulations. But due to the existence of many variables and uncertainty in some variables, the need for more modeling, investigation, and analysis is felt in this case.

5. Results and Discussion

5.1. Assessment of publications and citations

Using data extracted from the WOS website, we analyzed the number of publications in the field of traffic flow and ML from January 2007 to April 2023. A total of 163 publications were found during this period. Figure 3 demonstrates a graphical representation of the yearly publication frequency, elucidating the dispersion of articles published across different years. It is evident from Figure 3 that the number of publications has been steadily increasing since 2007, with a significant jump in 2016 and a peak of 45 publications in 2022. As of January 1, 2023, there have been four publications in this field. The overall trend indicates a growing interest in the intersection of traffic flow and ML. There

Figure 3
The number of documents published every year from 2007 to 2023

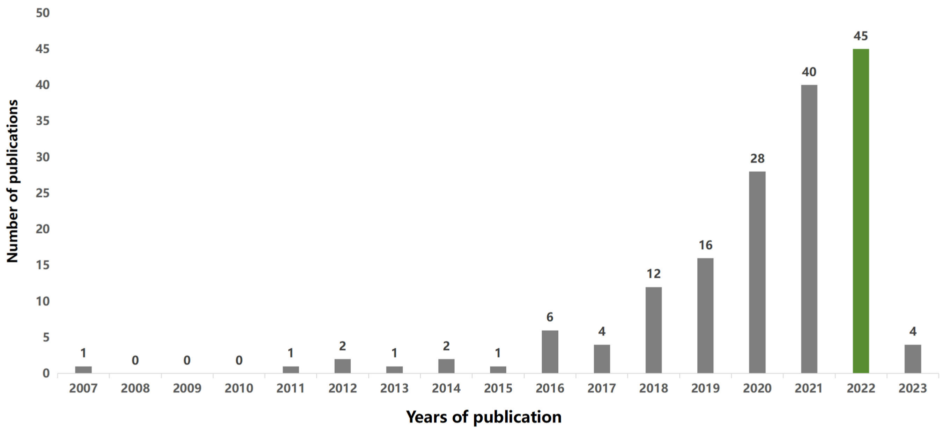
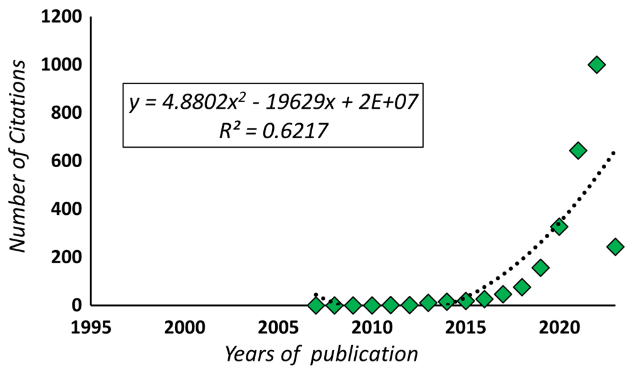


Figure 4
The number of citations for every year from 2007 to 2023



are a few possible reasons for the fluctuations in the number of publications over the years. One contributing factor could be the rapid advancements in ML technology, which has led to its increased application in various domains, including traffic flow. Additionally, the growing awareness of the importance of efficient traffic management and the potential benefits of applying ML techniques to this field may have contributed to the rise in publications. Despite the variations in the number of publications each year, it is clear that the topics of traffic flow and ML have gained significant attention in the world of academic research. This can be attributed to the novelty of the subject matter and the continuous improvements in technology. As the field continues to evolve, we can expect to see further growth in the number of publications exploring the intersection of these two important areas.

The total number of citations collected from the WOS for the study was 2566, and this is depicted in Figure 4. Notably, the year 2022 recorded the highest number of citations, with a total of 1001, which is not surprising given the current time frame. The citation trend exhibits a consistent upward trajectory, indicating an increasing number of researchers referencing this topic in their scholarly works. This surge in interest is likely attributed to the novelty and importance of the subject, which have captured the attention of numerous scholars. To model the correlation between the number of citations and the number of years, a polynomial equation (Equation (1)) was employed, which yielded a correlation coefficient of 0.62. The aforementioned polynomial equation (Equation (1)) forecasts an upward trend in the number of citations for the forthcoming years. In this equation, Y denotes the total number of citations, while X signifies the year.

$$Y = 4.8802x2 - 19629x + 2E + 07 \tag{1}$$

5.2. Assessing by research area, source topics, and document types

Figure 5 illustrates how printed material is distributed among different subject areas, indicating that there were 62 documents related to the subfield of Engineering Electrical Electronic, while Transportation Science and Technology had 43 published papers, ranking as the second most creative field out of 10 categories based on the WOS. It can be evidenced that more than 64% of all publications related to the use of ML tools in predicting or forecasting traffic flow are found in these two categories. This demonstrates the high interest in the development of these topics, as well as the existing opportunities to explore these fields from the perspective of other areas of research and engineering. However, it is important to highlight the high participation of the categories Computer Science Information Systems, Computer Science Artificial Intelligence, and Telecommunications with a total of 38, 29, and 28 publications, respectively. It was expected that there would be more papers published on these topics, considering the extensive coverage of these five categories.

The distribution of document types over the period between 2007 and 2023 is depicted in Figure 6. The gathered data indicate that articles made the largest contribution, constituting 115 of all other published publications. Furthermore, nearly 27% of the studies were as proceeding documents. This means that approximately 44 publications correspond to the presentation of results in international conferences and congresses, which infers that the interest in this type of subject matter is noteworthy worldwide.

Table 1 displays data on the primary titles featured in the WOS database that have published works with ML, traffic flow, prediction or forecast in their titles, abstracts, or keywords. The WOS core collection includes a selection of the top 10 journals, which provide detailed information regarding the total number of published documents and the proportion of those documents that received citations. Notably, the leading journal in this collection is

Figure 5
Research areas of machine learning and traffic flow prediction/forecast from 2007 to 2023

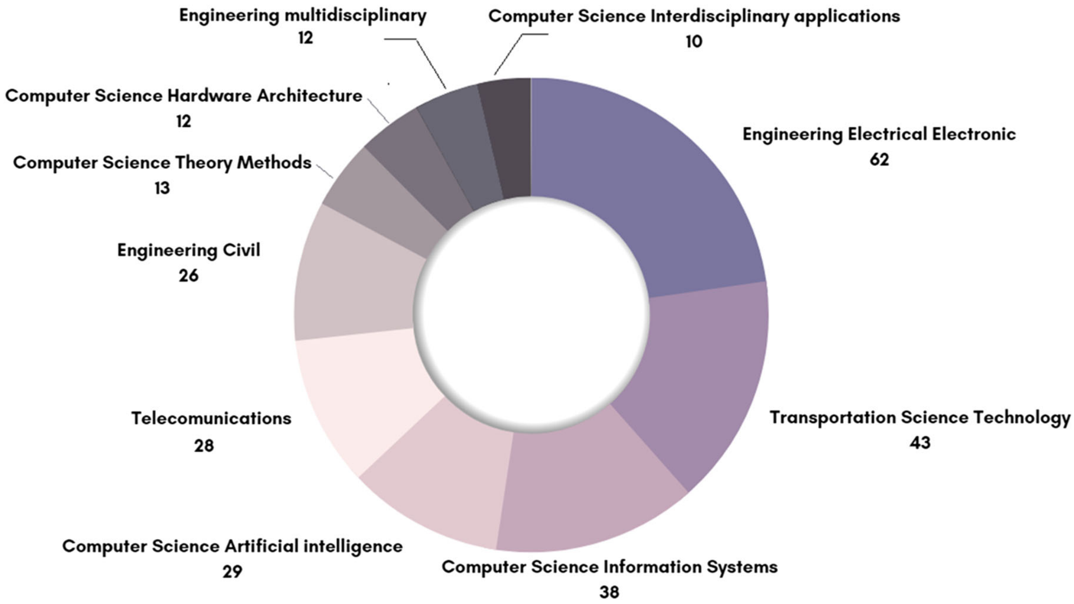


Figure 6
Category of published documents between 2007 and 2023

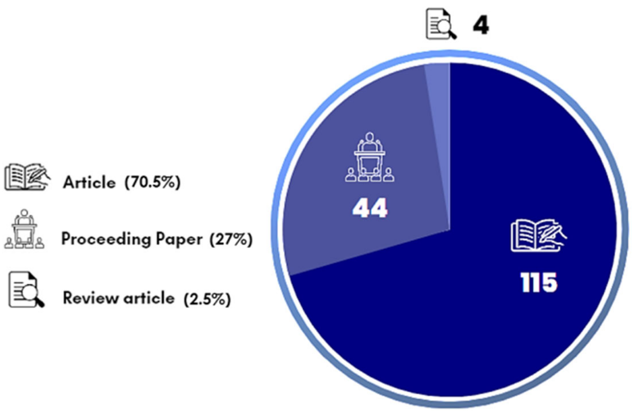


Table 1
Publication titles between 2007 and 2023

Publication titles	Record count	% of 163
IEEE Transactions on Intelligent Transportation Systems	14	8.6%
IEEE Access	7	4.3%
Applied Sciences-Basel	5	3.1%
Journal of Advanced Transportation	5	3.1%
Sensors	5	3.1%
Sustainability	5	3.1%
Computer Networks	3	1.8%
Mathematics	3	1.8%
Transportation Research Part C-Emerging Technologies	3	1.8%
Transportation Research Record	3	1.8%

IEEE Transactions on Intelligent Transportation Systems, which constitutes roughly 8.6% of all published works. Following closely behind is IEEE Access, the second-ranked journal, featuring 4.3% of the published articles. The following four journals, Applied Sciences-Basel, Journal of Advanced Transportation, Sensors, and Sustainability, each have 3.1% representativeness with a total of five published articles. In general, a total of 53 articles are part of the top 10 journals in the WOS database, which represent about a third of the total articles found. The statistics indicate that almost 76.1% of the articles in the analyzed journals were published by four esteemed publishers: IEEE, Elsevier, MDPI, and Springer Nature.

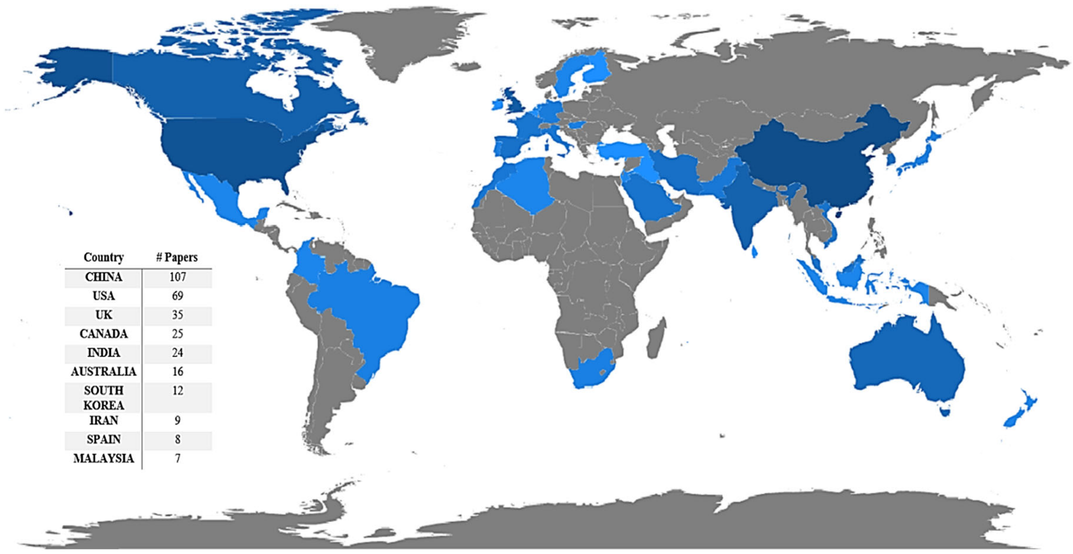
5.3. Top 10 authors, countries, and keywords

Table 2 displays the number of publications and the most frequently cited authors in the top 10 countries for research on ML and predicting/forecasting traffic flow. Boukerche leads the list with eight publications, accounting for around 5% of the total publications in this field. Sun and Wang rank second and third, both having four publications each. Lana and Tao follow in the fourth and fifth positions with three publications each. The remaining authors in the top 10 have 2 publications each.

Table 2
Top 10 authors between 2007 and 2023

Authors	Record count	% of 163
Boukerche, Azzedine	8	4.9%
Sun, Peng	4	2.5%
Wang, Jiahao	4	2.5%
Lana, Ibai	3	1.8%
Tao, Yanjie	3	1.8%
Losa, Massimo	2	1.2%
Sengupta, Rahul	2	1.2%
Wu, Yonghong	2	1.2%
Murphey, Yi Lu	2	1.2%

Figure 7
Top 10 countries between 2007 and 2023



To analyze the participation of different countries worldwide in generating publications related to the topic of interest, the map in Figure 7 is presented. The map shows the participation of each country on a blue color scale, with darker shades indicating a higher number of publications. It can be observed that researchers from all continents are conducting studies related to the application of ML tools for traffic flow forecast, reaffirming the importance of these topics today. Among the top 10 countries with the highest number of publications, China ranks first with a total of 107 papers, followed by the United States in second place with a total of 69 papers, and the United Kingdom with 35 publications in third place. With 7 printed documents, the Malaysia had the most documents at the end of the top 10 countries list.

Using the data extracted from the WOS database, a statistical analysis was conducted using Bibliometrix tool to identify the most used keywords in the founded papers. Bibliometrix is a highly prevalent R package utilized in an increasing number of publications. This software facilitates the importation of a bibliography database from SCOPUS or the WOS, stored as either a Bibtex (.bib) or Plain Text (.txt) file. It is widely favored by R users for its efficiency and ease of use [30]. The top 10 most-used keywords were evaluated and are shown in Figure 8. One of the most interesting findings is that the most commonly used ML tool is neural networks, with this concept being a keyword in a total of 24 documents. As expected, the most commonly used

Figure 8
Top 10 keywords between 2007 and 2023

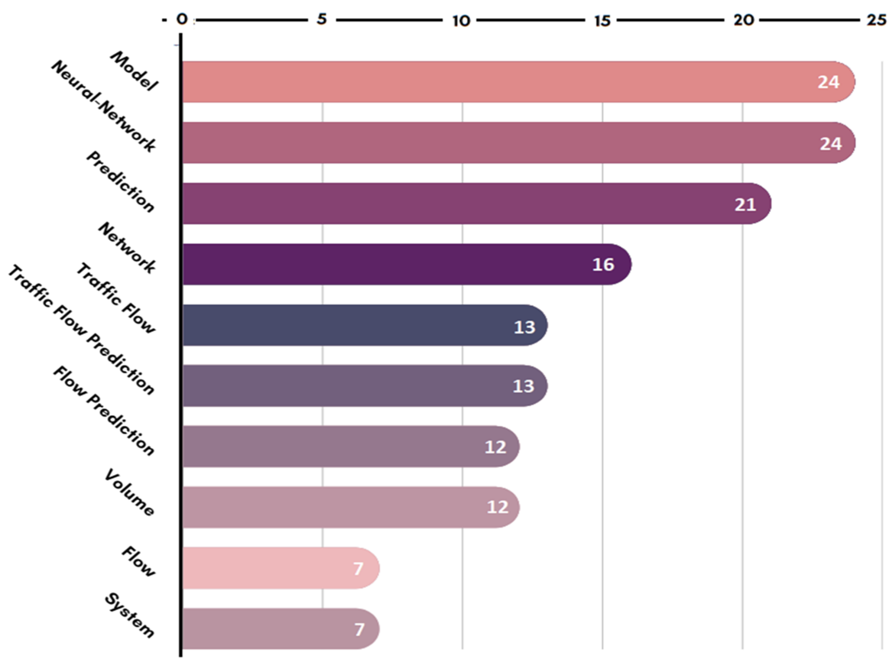
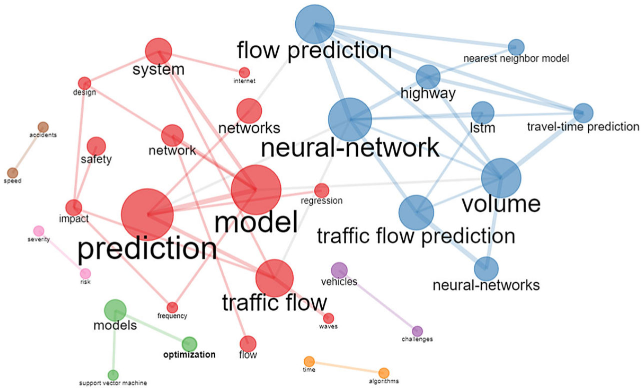


Figure 9
Category of published documents between 2007 and 2023



keywords include "Prediction" and "Traffic Flow" with a total of 21 and 13 occurrences, respectively.

A co-occurrence network was developed to analyze on a graphic visualization the potential relationships between the concepts within the founded papers. The results of this analysis are presented in Figure 9. It is worth noting that Figure 9 shows each keyword separately, even if they have the same root or are in singular or plural forms, as the software used cannot distinguish between them. For example, "driver" and "drivers" are presented as two separate keywords.

From the analysis, it can be seen that the majority of publications developed to date focus on two main areas: traffic flow prediction models and the application of neural networks in developing such models. Some complementary elements that represent emerging areas of interest for further research include travel time prediction, accidents, and risks.

5.4. An overview of top 10 papers and discussion

An additional analysis examined the top 10 most referenced papers by scrutinizing their authorship, titles, journals, document types, citation counts, and yearly citation rates. These results are presented in Table 3. The pattern is most evident among the highly cited articles, where the bulk of citations stem from articles. Table 3 indicates that out of 10 papers, 8 were articles and only 2 were proceeding papers. These papers are ranked by their citation count,

Table 3
Top 10 most cited papers from 2007 to 2023

Authors	Title	Journal	Document type	Number of citations	Average citation per year
Zhu et al. [31]	Big Data Analytics in Intelligent Transportation Systems: A Survey	IEEE Transactions on Intelligent Transportation Systems	Article	398	79.6
Hofleitner et al. [32]	Arterial Travel Time Forecast with Streaming Data: A Hybrid Approach of Flow Modeling and Machine Learning	Transportation Research Part B-Methodological	Article	118	9.83
Nguyen et al. [33]	Deep Learning Methods in Transportation Domain: A Review	25th World Congress on Intelligent Transport Systems (ITS)	Proceeding Papers	108	18
Zhang et al. [34]	Comparing Prediction Performance for Crash Injury Severity Among Various Machine Learning and Statistical Methods	IEEE Access	Article	86	14.33
Mackenzie et al. [35]	An Evaluation of HTM and LSTM for Short-Term Arterial Traffic Flow Prediction	IEEE Transactions on Intelligent Transportation Systems	Article	83	16.6
Nallaperuma et al. [36]	Online Incremental Machine Learning Platform for Big Data-Driven Smart Traffic Management	IEEE Transactions on Intelligent Transportation Systems	Article	77	15.4
Tedjopurnomo et al. [37]	A Survey on Modern Deep Neural Network for Traffic Prediction: Trends, Methods and Challenges	IEEE Transactions on Knowledge and Data Engineering	Article	71	35.5
Jia et al. [38]	Traffic Speed Prediction Using Deep Learning Method	2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC)	Proceeding Papers	70	8.75
Lv et al. [38]	Temporal Multi-Graph Convolutional Network for Traffic Flow Prediction	IEEE Transactions on Intelligent Transportation Systems	Article	61	20.33
Karballaeezadeh et al. [40]	Prediction of Remaining Service Life of Pavement Using an Optimized Support Vector Machine (Case Study of Semnan-Firuzkuh Road)	Engineering Applications of Computational Fluid Mechanics	Article	57	11.4

with Zhu et al. [31] being the most cited paper, having 398 citations (a yearly average of 79.6 citations). Hofleitner et al. [32] ranked second among the top 10 most cited publications, amassing 118 citations in total and averaging 9.83 citations per year. The majority of these papers were published as articles in IEEE Transactions on Intelligent Transportation Systems, which focuses on ITS. The subjects addressed in these papers encompass ML techniques in transportation, arterial travel time predictions using streaming data, and big data analytics in ITS. Examining the most cited papers reveals that, on average, the majority of these articles received over 10 citations per year. In general, these papers offer significant insights into traffic flow analysis and can be beneficial for researchers and practitioners in this area. Table 4 also provides an overview of the methodology, outcomes, and results, as well as an examination of the keywords in the top 10 cited papers.

The field of ML and traffic flow management research holds significant potential, as evidenced by the findings of literature reviews and analysis of research trends and citations. However, there are several challenges and limitations that need to be addressed to promote extensive research in this area. One of the major challenges is the need for reliable data, which is crucial for ML analysis. Gathering data for traffic flow management research can be expensive due to the high costs involved in purchasing and installing smart systems. This can limit the scope of research and restrict the ability to draw accurate conclusions. Despite these obstacles, there is optimism that advancements in technology will lead to significant cost reductions in the near future, making it more feasible to gather reliable data for ML analysis. As a result, the utilization of ML in traffic flow management research is expected to become more widespread in the coming years.

Table 4
Overview of top 10 papers in traffic flow and machine learning

No.	Method	Key finding/result	Keywords
1	They reviewed the history and features of big data and ITS	The authors addressed several unresolved challenges concerning the application of big data analytics in intelligent transportation systems and provided recommendations to overcome them	Big data, transportation, data analysis, smart cards, global positioning system
2	The researchers introduced a hybrid modeling framework that utilizes real-time GPS probe data to estimate and forecast traffic conditions on arterial roads	The findings of the study showed that the proposed approach is a substantial advancement in the prediction of traffic conditions across the arterial road network with a relatively limited amount of real-time data	Estimation, forecast, streaming data, machine learning, GPS probe data
3	The authors conducted a review of recent studies that utilized deep learning techniques to address prevalent subjects related to the processing of traffic data	Overall, the researchers concluded that the use of deep learning systems in the transportation field is still constrained, and there exist potential limitations in applying this sophisticated approach to enhance prediction models	——————
4	The researchers employed both statistical techniques, such as the ordered probit (OP) model and multinomial logit model, and four prevalent machine learning methods including K-nearest neighbor, decision tree, random forest (RF), and support vector machine	Their findings indicated that the conclusions drawn from various methods regarding the significance of variables were not always consistent, and therefore, they should be interpreted with caution	Computer crashes, injuries, machine learning, analytical models, predictive models, support vector machines, statistical analysis
5	They used the hierarchical temporal memory (HTM) and long short-term memory (LSTM)	The authors made a case that HTM has the potential to be a useful tool in short-term traffic flow prediction, with performance comparable to that of LSTM models, and with additional advantages when dealing with changing traffic flow distributions	Roads, neural networks, prediction algorithms, traffic control, predictive models, timing

(*Continued*)

Table 4
(*Continued***)**

No.	Method	Key finding/result	Keywords
6	They presented a wide smart traffic management platform (STMP) and employed three distinct machine learning techniques in their study, including unsupervised online incremental machine learning, deep learning, and deep reinforcement learning	The authors successfully demonstrated the feasibility of their proposed platform by applying it to a dataset of 190 million records of traffic data collected from a smart sensor network, which included information from 545,851 commuters, as well as social media data related to the arterial road network of Victoria, Australia	Social networking (online), roads, real-time systems, clustering algorithms, big data, machine learning algorithms, data models
7	The authors conducted a comprehensive survey of deep neural networks used in traffic prediction, providing a detailed explanation of the most commonly used architectures in the literature. They also categorized and explained the relevant studies and presented an overview of the similarities and differences among them	The authors also offered a discussion on the challenges that must be addressed and the potential future directions for utilizing state-of-the-art deep neural networks in traffic flow prediction	Neural networks, autoregressive processes, predictive models, data models, machine learning, roads, task analysis
8	They utilized a deep learning technique, specifically the deep belief network (DBN) model, to predict short-term traffic speed information	Their results indicated that the deep belief network (DBN) outperformed both the backpropagation neural network (BPNN) and auto-regressive integrated moving average (ARIMA) models across all time horizons. The superior performance of DBN suggested that deep learning held promise for the field of traffic research	Predictive models, data models, object-oriented modeling, training, machine learning, artificial neural networks, roads
9	The researchers employed a novel deep learning model that encoded non-Euclidean spatial correlations and potential semantic correlations among roads using multiple graphs. The model explicitly captured these correlations by fusing multiple graph convolutional networks.	The researchers conducted several experiments using real-world traffic datasets and demonstrated that the temporal multi-graph convolutional network (T-MGCN) outperformed the current state-of-the-art baselines in terms of performance	Correlation, roads, Semantics, predictive models, machine learning, convolution, analytical models
10	The researchers employed machine learning techniques and developed a novel prediction model for the remaining service life (RSL) of road pavement using support vector regression (SVR) optimized by particle filtering in order to overcome the existing challenges. They compared the results of their proposed model with those of support vector machine (SVM), artificial neural network (ANN), and multi-layer perceptron (MLP) models	Their results indicated that the proposed model outperformed the other models, with a correlation coefficient index of 95%	Pavement management, RSL, SVR, SVM, particle filter, MLP, ANN, prediction, forecasting, optimization, road maintenance and management, machine learning (ML), soft computing (SC)

It is noteworthy to mention that this study utilized the WOS platform as a source for documents; however, it is important to acknowledge that many articles may not be indexed in these databases. This may pose a limitation to the study as a larger number of articles analyzed in both quantitative and qualitative analyses would increase the likelihood of validating the data and enhance the ability to critique the topics explored in the future.

6. Conclusion

From 2007 to 2023, the utilization of ML approaches in traffic flow was examined in this study. The WOS platform was utilized to explore various keywords and guide the review process. The analysis indicated that the number of citations for research on ML in traffic flow was satisfactory and continued to grow over the years. Furthermore, the study found that over half of the documents related to ML in traffic flow were in the form of articles. Additionally, based on the WOS categories, over 50% of the documents were published by two major publishers, namely IEEE and Elsevier, and papers that employed ML methods in traffic flow garnered numerous citations. The authors of these papers tended to focus on the innovative aspects of these methods, such as analysis and prediction. Studies and evaluations across various fields have shown that the implementation of ML techniques can improve traffic flow and is generally well-received by researchers. It is important to note that there are still several obstacles in the field of ML research related to traffic flow. One of the significant challenges is the high costs associated with the equipment required, such as sensors, cameras, and suitable servers for databases and data processing. Also, in the process of designing intelligent systems and using ML in traffic flow management, safeguarding the privacy of individuals is a critical concern that demands particular attention. Given the rapid pace of technological advancements and the continuous production of improved data collection equipment, it is anticipated that we will witness a surge in research activities and practical implementations of ML in the domain of traffic control, leading to the development of ITS in the near future. Finally, this study suggests that researchers consider ML techniques a valuable and dependable tool for addressing various transportation issues. This recommendation is based on the fact that publications related to this field are receiving increasing citations and attention in reputable journals.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data available on request from the corresponding author upon reasonable request.

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