Traffic & Transportation

Bibliometric Analysis of Traffic Accident Prediction Studies from 2003 to 2023: Trends, Patterns and Future Directions

Mesut ULU[1], Yusuf Sait TÜRKAN[2]

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[1] Corresponding author, mulu@bandirma.edu.tr, Bandirma Onyedi Eylul University, Occupational Health and Safety Department
[2] ysturkan@iuc.edu.tr, Istanbul University-Cerrahpasa, Industrial Engineering Department

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ABSTRACT
Traffic accidents are one of the main causes of fatalities and serious injuries among both adults and children worldwide. Due to the ongoing significant socio-economic losses brought on by traffic accidents, precise estimation of the risk of accidents is crucial to reducing subsequent incidents. For this reason, a significant proportion of the studies in the literature include studies on estimating the risk, severity, frequency, location and duration of accidents. The objective of this article is to identify patterns, gaps and future research trends in traffic accident prediction studies conducted between 2003 and 2023. A bibliometric study is carried out to investigate the links and trends in traffic accident and forecasting studies, with a focus on identifying dominant narratives and networks within the academic community. In the keyword search, 1,566 articles were analysed using the Web of Science main collection and bibliometric indicators such as annual publications and citations, top 10, authors, journals, institutions, most cited articles, and a citation analysis of the articles was presented. The results obtained suggest that the discernible patterns identified in this bibliometric analysis of traffic accidents and their predictions will find a much broader application in new paradigms that are ready to catalyse transformative advances in this field, such as artificial intelligence, machine learning and Industry 4.0 applications.

KEYWORDS
traffic accident; prediction; bibliometrics analysis; research status; trend analysis; literature review.

1. INTRODUCTION

Road accidents are one of the leading causes of injuries and deaths in many countries in the world. According to the World Health Organisation (2022) [1] approximately 1.3 million people die in traffic accidents every year in the world, and road traffic accidents cost 3% of the gross domestic product of most countries. Traffic accidents are predicted to be the seventh leading cause of death by 2030. Currently, a significant proportion of fatalities in accidents occur in urban and metropolitan areas, which are characterised by the synthesis of risk factors exacerbated by heavy traffic congestion and a high density of vehicles and pedestrians [2]. According to the road safety annual report (2022) [3], average road deaths in 34 countries increased by 0.1% in 2021 in comparison with the number of accidents between 2017 and 2019. It is indicated in this report that despite the prevalent decline in accident and fatality rates globally in 2021, a significant increase by 16.3% in road accident mortality rate was witnessed in the USA. The decline in traffic fatalities from 2010 to 2021 points out the influence of the pandemic on the issue. Examining the data before 2020 reveals an accident-related mortality increase after 2010 in some nations whereas in many other countries a steady decline. Therefore, a thorough investigation of the factors determining the trajectory of traffic accidents and fatalities seems necessary in light of the above analysis.

Road traffic is a complicated system made up of a variety of elements, including people, cars, roads and the surrounding environment. Multiple variables that are frequently grouped in relation to infrastructure (road condition), vehicles (vehicle condition) and drivers (human condition) interact with each other in road accidents

[4]. Some researchers [5, 6] emphasised the importance of indirect factors in addition to the primary causes due to their complicated mechanisms. A thorough understanding of the relationship between accident frequency/severity and the analysed variables is made possible by the commendable theoretical interpretability of statistical frameworks like logit, probit, Poisson and negative binomial regression models. Their assumption of a linear relationship between risk factors and accident frequency, however, is a key weakness and may not be suitable in most situations. The nature of the "black box" approach, which restricts the direct and unambiguous interpretation of data in comparison to statistical models, is one of the most significant drawbacks of machine learning models, which have been utilised more in prediction studies for traffic accidents [7]. To accurately forecast potential traffic accidents, big data analysis on a wide range of factors has to be taken into consideration. Real-time large data collection is now possible because of the growth of the smart city idea in recent years, which has led to significant technology investments in many major cities. In particular, it has been observed since 2009 that administrations in large cities have made investments in a variety of fields such as IoT, big data and cloud technologies. Today, smart mobility can provide data that will facilitate the analysis of traffic accidents [8]. Hence, prediction studies related to the patterns of traffic accidents using artificial intelligence techniques have been of interest rather than classical forecasting research in recent years [9].

The review studies on the analysis of the patterns for the accidents on various topics such as traffic accident risk, traffic flow, traffic congestion, number of accidents, traffic accident severity, injury level and traffic incident length are subject-specific. In the literature on traffic accidents, analysis and prediction studies have been conducted in specific areas such as psychological determinants [5], factors affecting accidents [6], frequency and severity of road accidents [9], mortality [8] and traffic injuries [7, 10, 11]. Instead of focusing on a very specific area such as deaths, injuries and psychological factors in road crash prediction studies, this study was the first in the literature to discuss traffic accident prediction studies from a broader perspective. In this context, all prediction studies in different areas related to accidents such as accident duration, accident location, traffic congestion, factors affecting traffic accidents, injuries and deaths were included in the analysis. Our study examines what type of traffic accident prediction studies are conducted in what areas and what techniques are used in these studies. It also aims to identify the latest study trends in this area and to provide researchers with a general assessment of their areas of research. Traffic accidents, prediction, forecasting and estimation terms were chosen as the keywords, and the analysis covered the years 2003–2023 with the aim of identifying descriptive statistics about influential authors, countries, institutes and journals on the topic which will make possible to obtain potential collaboration opportunities, most popular forecasting tools and trend fields.

Bibliometric analysis uses a highly structured and sequential methodology, in contrast to traditional literature review approaches. The ability of bibliometric analysis to produce a wealth of information from the bulk of research published on a particular topic has been enhanced by the use of advanced multivariate analysis methods [12]. To visualise the intellectual structure of a certain research field, bibliometric analysis is frequently integrated with scientific mapping approaches [13]. Depending on the different types of information utilised in the research, bibliometrics uses a variety of analysis methods [14]. Citation-based analysis, common word analysis, keyword co-occurrence analysis and co-authorship analysis may be cited among the most commonly used methods. In citation-based analysis, another classification includes citation analysis, co-citation analysis and bibliographic matching [15]. It may be seen from examining the literature data that no attempt has been made so far to do a bibliometric analysis based on a conceptual framework incorporating the existing scientific evidence on traffic accident prediction. This study was conducted to close a research gap in the prediction of traffic accidents and will assist researchers in evaluating the prediction studies from a more integrative and multidisciplinary standpoint.

2. RELATED WORKS

Accurately predicting traffic accidents at a high spatiotemporal level is crucial in the field of accident prevention and proactive damage prevention. This requires predicting the location, time, risk and accident-related concerns related to road accidents. However, this task has proven to be difficult due to the complicated nature of the traffic environment, unpredictable individual behaviour and a lack of real-time traffic information [16]. In recent years, new models have been proposed as a result of the emergence of machine learning, which has replaced the previous statistical models used for predicting traffic accidents. Academic studies have utilised various machine learning algorithms [17–21] to predict traffic accidents. Additionally, other methodologies, such as fuzzy logic [22] and deep learning [23–27], have also been investigated.

Upon examination of the literature, it is evident that prediction studies related to traffic accidents primarily centre on various topics, including traffic congestion [19, 21], traffic accident risk [24, 28, 29], traffic flow [22, 30], traffic accident severity [20, 31, 32], injury level [27], traffic incident length of time [33–35], number of accidents, severity and safety indicators [18, 36]. However, instead of analysing forecasting in a specific area of traffic accidents, our analysis aims to examine forecasting studies on different topics related to accidents from a more comprehensive perspective. Thus, in addition to examining the areas in which forecasting studies on traffic accidents are conducted

and the methods used in these studies, it also aims to determine the trending areas and methods for forecasting accidents.

Artificial intelligence (AI) and machine learning (ML) approaches are being progressively used in road safety research for a variety of purposes. The focus of notable studies, such as Panda et al. (2023) [37], has been on employing cutting-edge computational algorithms to anticipate the severity of traffic accidents. In the study, feature analysis was used, and the performance of the machine learning model with SHAP was analysed. Models for predicting traffic accidents and methods for reducing risk have recently been the subject of thorough evaluations, such as those by Marcillo et al. (2022) [38] and Ma et al. (2022) [39]. Marcillo et al. (2022) [38] classified and detailed the data used for prediction models in the traffic accident prediction literature study as vehicle data, driver data, weather conditions, light conditions, traffic accidents, traffic flow, traffic incidents, road infrastructure, taxi journeys, points of interest, population and others. The most commonly used prediction models are classified as neural networks, support vector machines, Bayesian networks, regression trees, logistic regression, multilayer perceptron and others, respectively. Classical performance measures were mostly used in the evaluation of the models. Accuracy, recall, precision, F1-Score and AUC performance metrics were generally used for classification. Performance metrics such as mean absolute error, mean relative error, root mean square error and mean square error have been widely used for regression problems [38]. Ma et al. (2022) [39] for example, studies on drunk driving, tired driving, distracted driving, and the characteristics of old and young drivers are the subject of human factor risk research. Studies on driver support systems, prediction and evaluation of vehicle collision risk, vehicle lane-changing safety, and risk prevention and control of hazardous material transportation vehicles are the subject of the vehicle factor risks research area. Studies on road alignment safety, climbing lane safety and features, and other topics fall within the research area of road factor risks. Rainy, snowy and foggy weather conditions are included in the research area of environmental factor risks [39].

Traffic video anomaly detection is made possible by deep learning, as studied by Khan, S.W. et al. (2022) [40]. In parallel, Cheng, G.Z. et al. (2021) [41] and Rajabli, N. et al. (2021) [42] conducted a study on the topics of autonomous vehicle software validation and highway safety, respectively. These studies, which range from behavioural facets to technology developments, aim to fully improve road safety. Bibliometric methods employ bibliographic data sourced from online databases. The utilisation of bibliometric analysis using the provided data enables a comprehensive examination of a scientific investigation and the domain of scientific research. The proliferation of bibliographic data has led to a rise in bibliometric studies across various research domains [43]. This approach has been utilised in numerous research inquiries. *Table 1* presents a literature review and bibliometric analysis studies using a methodology similar to that used in our research on topics such as traffic, road conditions, traffic behaviour and traffic accidents.

Table 1 – Bibliometric analysis and systematic literature review studies on traffic

Authors	Publication year	Publication type	Article title
Ji, W; et al. [44]	2023	Bibliometric analysis	Knowledge Mapping with CiteSpace, VOSviewer, and SciMAT on Intelligent Connected Vehicles: Road Safety Issue
Li, C; et al. [45]	2023	Bibliometric analysis	A bibliometric analysis and review on reinforcement learning for transportation applications
Amlan, H.A; et al. [46]	2023	Bibliometric analysis	Discovering the global landscape of vulnerability assessment method of transportation network studies: A bibliometric review
Moreno, F.C; et al. [47]	2022	Systematic literature review	Relationship between human factors and a safe performance of vessel traffic service operators: A systematic qualitative-based review in maritime safety
Ferreira-Vanegas, C.M; et al. [9]	2022	Systematic literature review	Analytical Methods and Determinants of Frequency and Severity of Road Accidents: A 20-Year Systematic Literature Review
Hassan, S.A; et al. [48]	2022	Bibliometric analysis	Vulnerability of road transportation networks under natural hazards: A bibliometric analysis and review
Jing, L.L; et al. [15]	2021	Bibliometric analysis	A bibliometric analysis of road traffic injury research themes, 1928-2018
Gil, M; et al. [49]	2020	Bibliometric analysis	A bibliometric analysis and systematic review of shipboard Decision Support Systems for accident prevention
Dominguez, J.M.L; Sanguino, T.J.M [50]	2019	Systematic literature review	Review on V2X, I2X, and P2X Communications and Their Applications: A Comprehensive Analysis over Time
Sharma, N; et al. [14]	2018	Bibliometric analysis	A bibliometric analysis of the published road traffic injuries research in India, post-1990

3. METHODS

Bibliometrics, a technique for measuring the effectiveness of work-based outputs from scientific investigations, holds a unique place among other statistical analyses. In order to determine the impact of scientific investigations, bibliometric methods were originally put forth in the 1950s. Most of the advancements in bibliometric approaches may be attributed to Price and Garfield [51]. The bibliometric approach involves assessing the numerical attributes of literature and studying the quantitative connections and evolving patterns within the structural arrangement that regulates knowledge. This technique can be useful in identifying research patterns in a specific area and assessing and anticipating the advancement of the field. Bibliometric indicators such as citations and citations per publication are used in this process, as well as in evaluating the research outputs of researchers, organisations and countries [52]. Bibliometric analysis offers researchers specific methodologies by combining many different tools to systematically search the literature. This analysis brought order to the literature reviews and played an important role in reducing the deficiencies of commonly used methods. Findings obtained as a result of bibliometric studies are useful in determining how the related discipline has developed and revealing problems or deficiencies and discussing the corrections to be made or suggestions to be made in this context [53].

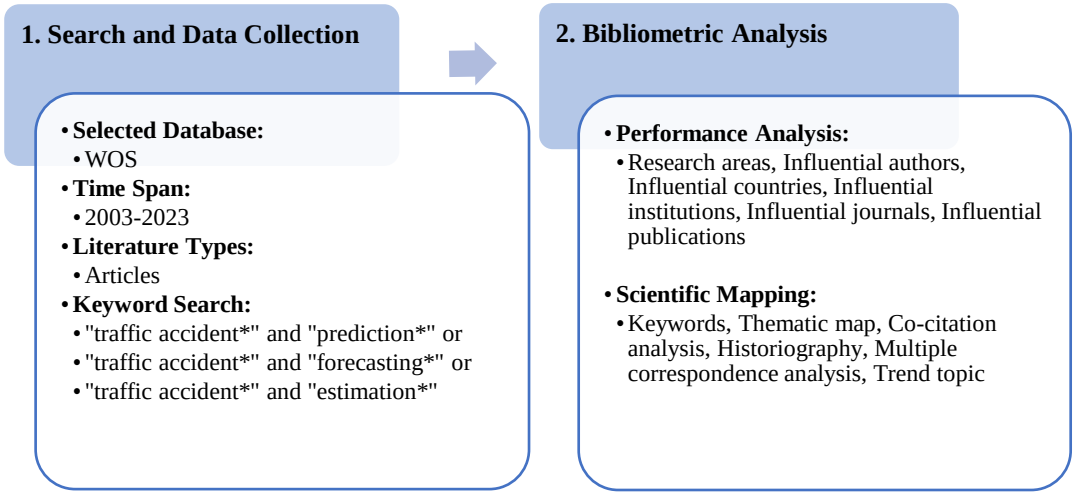

Figure 1 – Steps in the research

Bibliometric analysis involves two distinct phases: “search and data collection” and “bibliometric analysis of the data set” [54]. During the first phase, researchers establish search terms and collect preliminary data from a designated database. Next, they select a database for research purposes and gather raw data using their search terms. The first phase concludes with obtaining a data set suitable for analysis by applying pre-processing and filtering techniques. In the second stage, known as bibliometric analysis, two types of analysis are conducted: performance analysis and scientific mapping [11, 54]. The study followed these two phases, as illustrated in *Figure 1*.

3.1 Search and data information

The goal of a literature review is to locate and assess a body of literature, as well as to identify possible areas for future research and the boundaries of current understanding. In a literature review, sequential processing typically takes place in accordance with search terms and criteria. In this study, the Web of Science (WoS) database, which is one of the databases with the highest data quality (Mingers and Leydesdorff, 2015) was used for bibliometric analyses. The reason for this is that WoS is a comprehensive database that addresses a wide range of disciplines, evaluates the quality of publications to high standards, and provides a platform where globally recognised reputable journals are indexed. Apart from these, the articles in WoS generally have a significant impact in the academic field, and this database, which has a standardised data structure, offers various advanced

tools and filtering options for bibliometric analyses, allowing researchers to examine the data in depth and analyse them according to the criteria they want. The research theme is the prediction of traffic accidents, with the keywords "traffic accident", "prediction", "forecasting" and "estimation" used as search criteria (*Table 1*). The aim is to analyse prediction studies on traffic accidents from a broad, interdisciplinary perspective, rather than a specific area. On 15 February 2023, 2,404 papers were discovered after the WoS database's search for the relevant keywords. 1,566 articles from 710 journals were determined after filtering the publication years of the studies, the language of the study and the document type shown in *Table 2*.

Table 2 – Search and data information

Description	Results
Main Information About Data	
Timespan	2003:2023
Sources	710
Documents	1566
Annual Growth Rate %	3,84
Document Average Age	6,28
Average Citations Per Doc	23,17
References	45939
Document Contents	
Keywords	4610
Authors	
Authors	5426
Authors Of Single-Authored Docs	61
Authors Collaboration	
Co-Authors Per Doc	4,36
International Co-Authorships %	23,18

The first article relating to the search terms was published in 1991. In order to compensate for the limited number of publications between 1991 and 2003, and the scarcity of publications overall, the study range was selected to cover the years 2003–2023. From the number of studies conducted according to the years shown in *Table 2*, it is seen that the average annual growth rate of the studies on the subject is 3.84%, and the average age of the article is 6.28 years. Of the 1,566 articles, 61 were published by a single author, and the average number of co-authors per article was 4.36. In 1,566 articles, 4,610 keywords and 45,939 references were given, and the average number of citations per article was 23.17.

3.2 Limitations

This research has several limitations. First, the analysis in this paper relied solely on the Web of Science database. With data from various sources, including Scopus, Google Scholar and others, it is possible to obtain varying results. Among the advantages of WoS, there is typically a meticulous selection of publications, ensuring the provision of high-quality, reliable data. WoS serves as a platform for indexing reputable journals across a wide range of disciplines, providing standardised data. Additionally, WoS offers advanced analytical tools, enhancing researchers' ability to delve deep into data for thorough examination and analysis. However, WoS's limitations include potential coverage gaps, particularly in new or interdisciplinary fields, and a tendency towards certain types of publications or research methodologies. Additionally, constraints such as access limitations and delays in indexing new publications exist. On the other hand, other databases like Google Scholar and Scopus may have broader coverage and tend to update faster. However, the quality and accuracy of data in these databases may not be scrutinised as meticulously as in WoS.

Second, the period is limited to 2003–2023, which could result in the absence of a number of prior studies. Third, the study was restricted to scientific keywords, and research articles were chosen based on combinations of "traffic accidents" and "prediction". Due to the constant change of data in the WoS database, the results of

the bibliometric analysis frequently lag behind actual research advancements. In addition, bibliometric analysis can be combined with other techniques to produce more meaningful results.

4. RESULTS OF PERFORMANCE ANALYSIS

4.1 Bibliometric analysis

In conducting a comprehensive bibliometric analysis, the appropriate selection of statistical tools is equally crucial as the careful curation of articles. For the purpose of conducting bibliometric analysis, the R program's "bibliometrix" package was chosen in this study. The study conducted by Persson et al. (2009) determined that the "bibliometrix" module in R offers a higher level of comprehensiveness compared to the commonly utilised "BIBExcel" package. The "bibilometrix" module in the R package was considered the most suitable statistical package due to its ability to conduct network analysis [55].

Bibliometric analysis studies aim to identify the most influential authors, institutions and journals based on various criteria. These metrics include citation count, which measures how often an author's work is referenced by others, and the H-index, which considers both the number of publications and their citations. Journal impact factor (JIF) assesses the average citation rate of articles in a journal, while authorship position and citation density also contribute to the evaluation. Expert opinion may also be considered. It is important to note that influence can vary depending on the field. Co-authorship networks and altmetrics are commonly used to measure influence within a research community. The use of these criteria in combination provides a comprehensive understanding of influence. However, it is preferable to examine some basic metrics rather than presenting all the metrics in the studies and making the analysis complex. To this end, this section analyses the basic metrics for the most influential authors, influential countries, influential institutes, influential journals and influential publications, respectively, concerning traffic accident prediction studies.

4.2 Influential authors

Figure 2 displays the authors who are considered to be most productive within the given context. This productivity was determined by the number of articles published by authors in this field. The authors deemed the most significant, as determined by a rigorous evaluation process, have collectively contributed to 9% of the overall body of academic research published within the past two decades. Wang has published 25 articles in this field, and the articles' fractionalised ratio is 5.

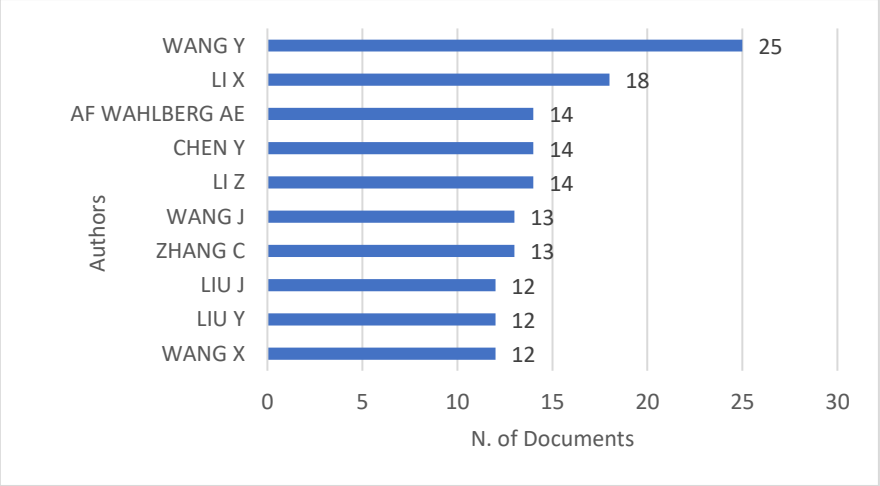

Figure 2 – Most relevant 10 authors

Wang holds a dominant position in the research field. Li is thought to be the second most prolific author in terms of publications, while the top five authors collectively have made a significant contribution to the field by publishing a total of 85 papers over a span of 20 years. *Figure 3* illustrates the productivity of the authors who received the highest number of citations and are considered to be the most influential. Wang commenced his research endeavours in 2013 and disseminated a total of five scholarly articles in the year 2019. Furthermore, his annual citation count amounted to 80.6.

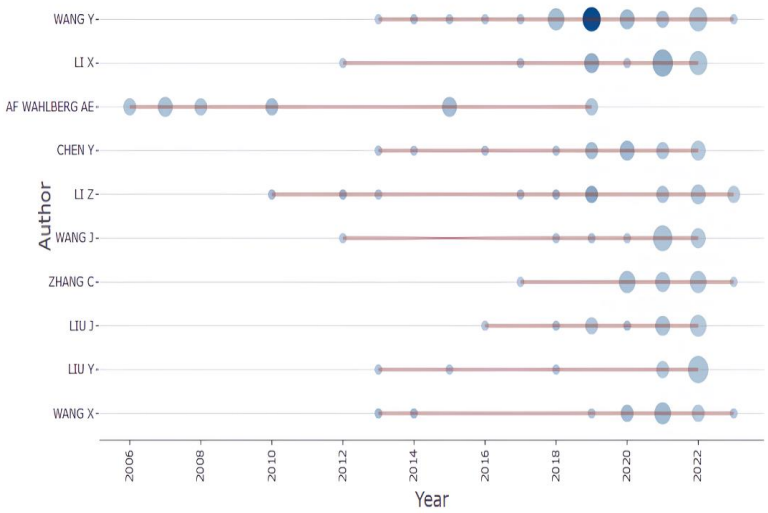

Figure 3 – Top-authors' productivity over time

4.3 Influential countries

The global map portrayed in *Figure 4* illustrates the countries that have demonstrated productivity in scientific production. Research on the subject has been carried out in a total of 81 countries, with 34 of these countries having conducted three or fewer studies. There are 18 countries with 20 or more studies. China is the front-runner in terms of total frequencies, boasting a count of 1,336, while the United States follows behind with a total of 641 frequencies. The United States of America has witnessed a notable surge in research efforts on the subject since 2006. Similarly, China has also experienced a significant increase in its research endeavours in this field, commencing in 2009. The Chinese government has determined the issue of traffic safety to be a priority, and important steps have been taken in this field. In this context, research on road traffic accidents and their prevention is encouraged and supported. China shares its experiences and findings on traffic safety by cooperating internationally. This is a factor that supports the country's position as a pioneer in research on road accidents.

The countries making up the top 10 are China, the United States, Iran, the United Kingdom, India, South Korea, Australia, Japan, France and Spain. Economically developed countries are nations that make significant contributions and advancements in scientific and academic fields. The five countries with the highest number of citations are the United States, China, the United Kingdom, Australia and Turkey. Although Iran ranks among the top three countries in terms of the number of studies produced, it does not feature within the top ten countries in terms of citation count, instead occupying the fourteenth position.

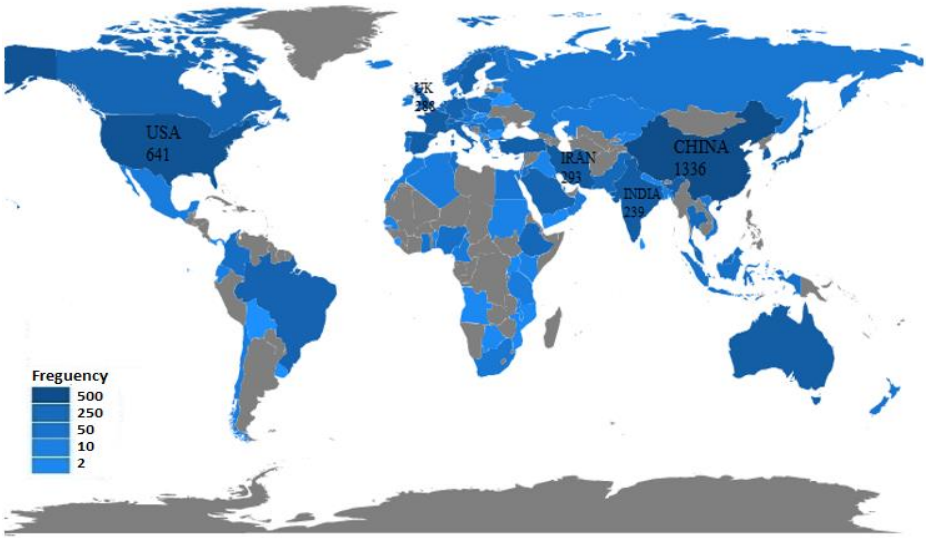

Figure 4 – Scientific productivity map by country

The countries of the corresponding authors are presented in *Figure 5*, demonstrating the top 10 nations. The publication count can be categorised into two types: single-country publication count (SCP) and multi-country

publication count (MCP). In the context of China, a comprehensive analysis of 365 articles reveals that 92 of them were authored through multinational collaborations, while the remaining 273 articles were produced by single-national entities. In this context, while a quarter of the most effective countries carry out MCP, China, the USA, the UK and Spain are the countries that are prone to doing MCP.

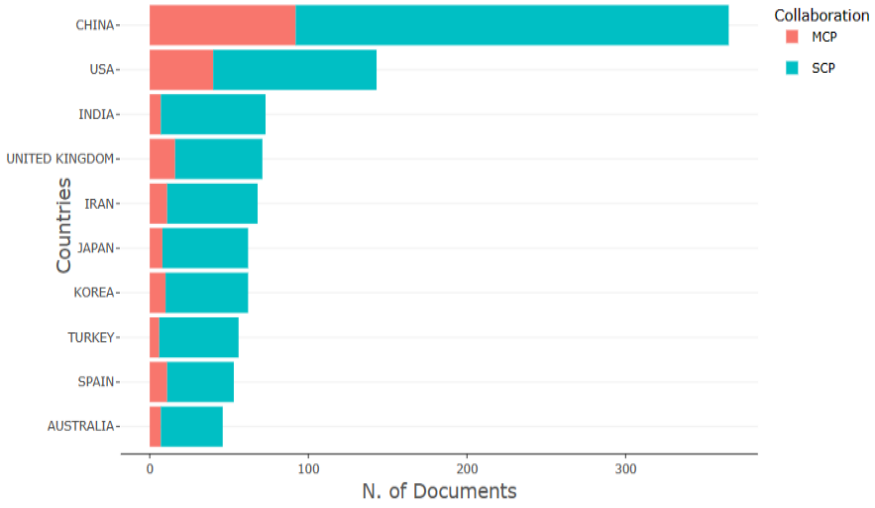

Figure 5 – Countries of the corresponding author

4.4 Influential institutions

Figure 6 lists the most influential institutions that hold the highest degree of influence. In this context, the most effective institutions were determined according to the number of articles published in this field. Changan University has emerged as a prominent institution in this field, making significant intellectual contributions through the publication of a total of 61 articles, followed by Southeast University. Southeast University has observed a rise in the number of scholarly articles published since 2010, whereas Changan University has experienced a surge in the number of scholarly articles published since 2015. Several factors are behind Changan University's pioneering work on road accidents and prediction. Firstly, the university is known as an institution specialising in the fields of traffic engineering, logistics and transportation and is home to leading research centres and experts in this field. China's rapidly growing population and economy have highlighted the country's traffic problems, which has encouraged the university to play a major role in traffic accidents and safety. The university also supports traffic accidents and prediction studies and increases its impact in the field by collaborating with various public and private sector organisations at local and national levels.

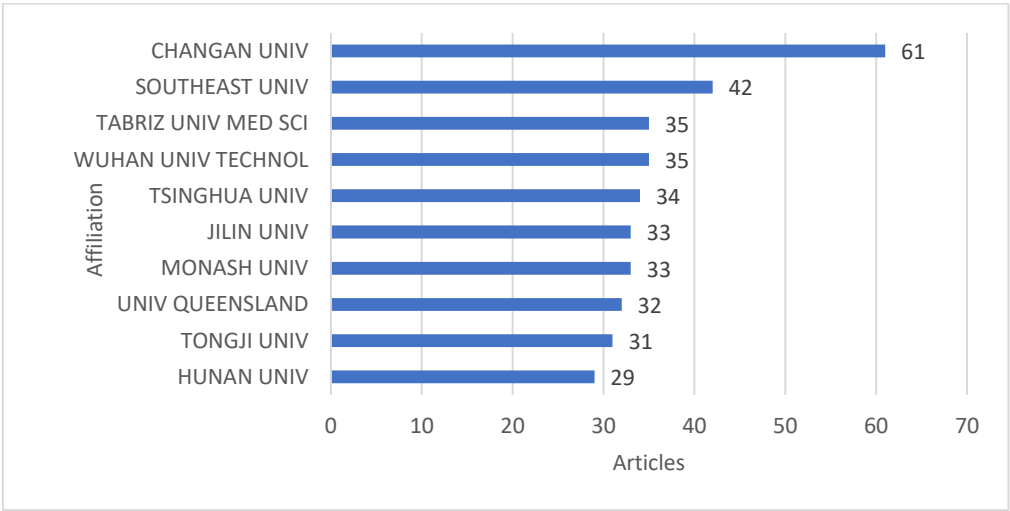

Figure 6 – The most relevant institutions

4.5 Influential journals

A compilation of the ten most influential lists of publishing organisations is given in *Figure 7*. In this context, the most effective publishing organisations were determined according to the number of citations received by the published articles. The four most influential journals in the field were Accident Analysis and Prevention, Transportation Research Part F: Traffic Psychology and Behavior, Environmental Research, and Traffic Injury Prevention. In the 20-year time frame, a notable sum of 367 articles was observed within the top ten publications renowned for their influence. Furthermore, it is noteworthy that the initial three journals on the list accounted for over fifty per cent of these articles. The top three most cited journals are Accident Analysis and Prevention, Transportation Research Record, and Transportation Research Part F: Traffic Psychology and Behavior. *Figure 8* illustrates the cumulative annual growth of these notable publishers.

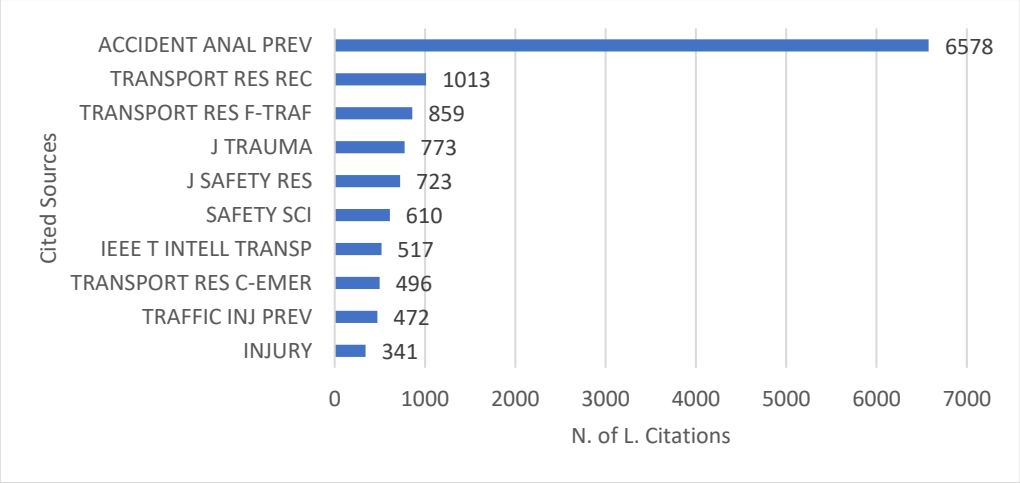

Figure 7 – The most influential journal

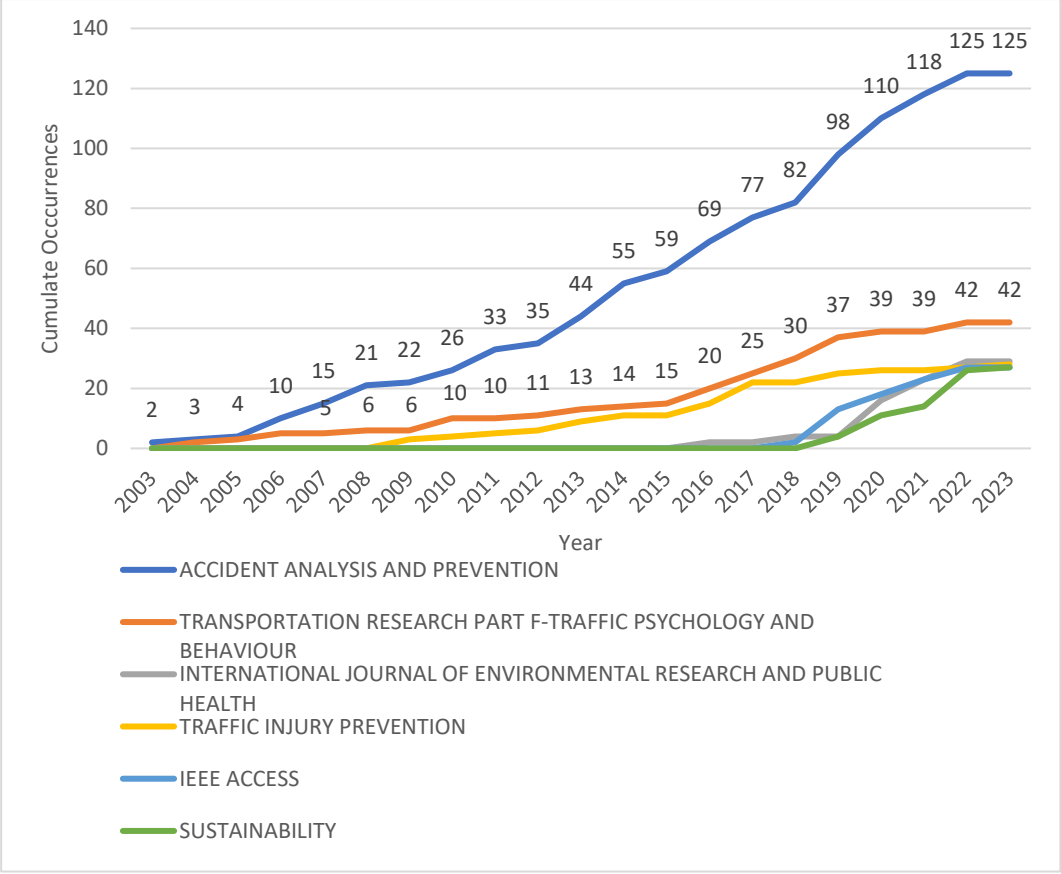

Figure 8 – Production of resources over time

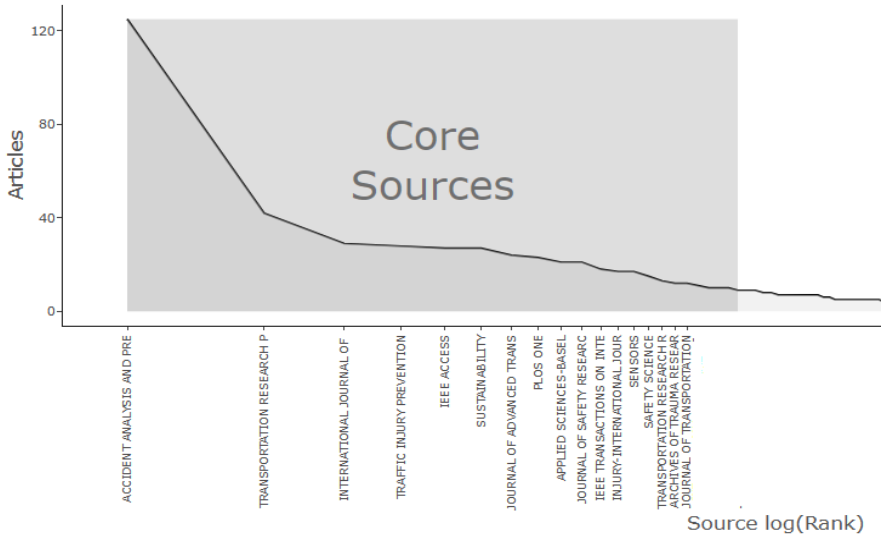

Figure 9 – Basic sources according to Bradford's law

The concept of "Bradford's law", as established by Bradford in 1934, encompasses the act of disseminating or distributing a scholarly publication about a specific topic across various journals (Bradford, 1934; Garfield, 1980). Based on the research conducted by Garfield (1980), the utilisation of Bradford's law in the process of constructing a bibliography related to a specific subject reveals a consistent pattern. This pattern indicates that a limited set of journals, constituting a small core group, consistently encompasses a substantial portion (approximately one-third) of the articles published within that particular subject area or academic discipline. Then, a secondary and more substantial cluster of journals constitutes an additional one-third, whereas a significantly larger cluster of journals encompasses the remaining one-third. *Figure 9* illustrates the primary sources as per Bradford's law. A total of 710 publications were examined, and the first 22 journals were classified as Region 1, journals 23–199 were classified as Region 2, and journals 200–710 were classified as Region 3. Quantitative analysis revealed that a range of 2 to 9 articles were published within Region 2. In the third region, it was observed that there was only one article relating to the topic within the publication venues.

4.6 Influential publications

Figure 10 shows the most globally cited papers within the time frame of 2003 to 2023. Lozano and their colleagues (2012) received the highest number of citations, totalling 7,524. Additionally, there was a significant increase in the average number of citations in 2012. A comprehensive analysis was conducted to estimate the global and regional causes of death among individuals aged 20 years and older. The authors in *Figure 10* have conducted studies on various topics, including injury severity prediction and determinants, prediction of crash numbers by severity, analysis of highway crash frequency, investigation into the relationship between driver behaviours and meta-analysis, and the utilisation of big data.

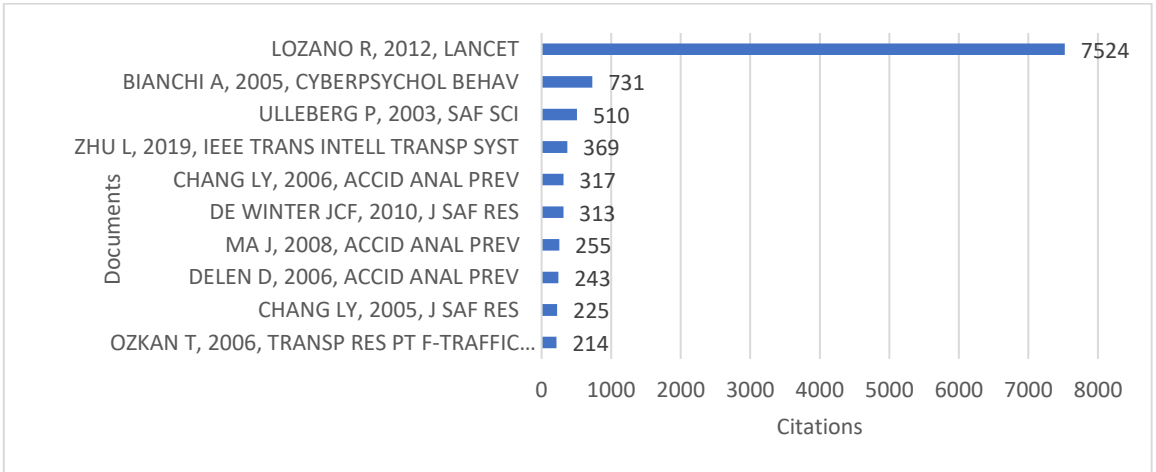

Figure 10 – The most cited documents worldwide

5. RESULTS OF SCIENCE MAPPING

The technique of network analysis is extensively employed to determine the structural relationships among factors based on their relative significance. Bibliometric analysis frequently employs various network studies, which can be categorised into three main types: keyword networks, co-citation networks and networks of cited authors.

5.1 Keyword

This analysis presents an examination of the correlation between traffic accidents and prediction keywords. Academic researchers typically incorporate multiple keywords into their articles. The purpose of this analysis is to identify prevalent research trends, determine gaps in the discussion regarding traffic accidents and prediction, and identify potential research domains that may be of interest. *Figure 11* displays a word cloud of the most popular keywords after keyword analysis. The three primary keywords employed within this domain encompass traffic accidents, risk and prediction. The utilisation of the three most frequently occurring keywords constitutes 10% of the overall keyword count, while the ten most commonly used keywords account for approximately 25% of the total.

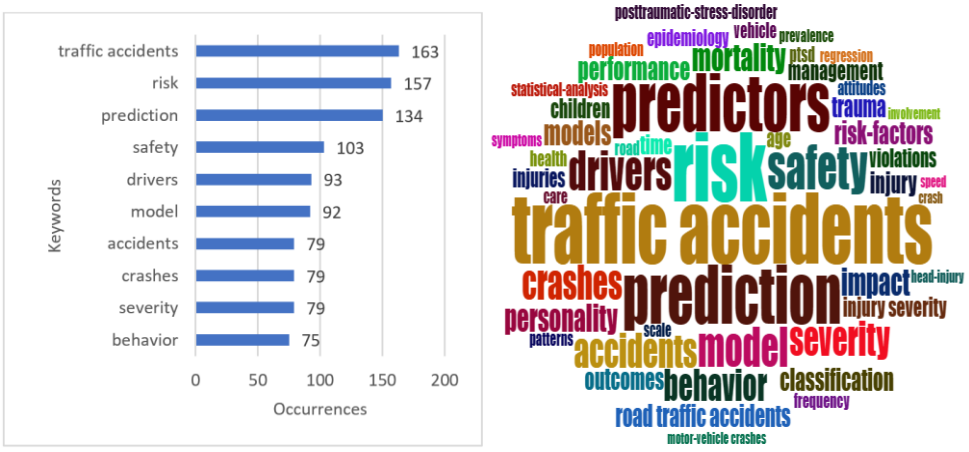

Figure 11 – Keyword frequency and cloud

Figure 12 shows a comparative analysis of the dominance of keywords within a keyword tree map. Additionally, it underscores the combination of potential keywords about traffic accidents and prediction.

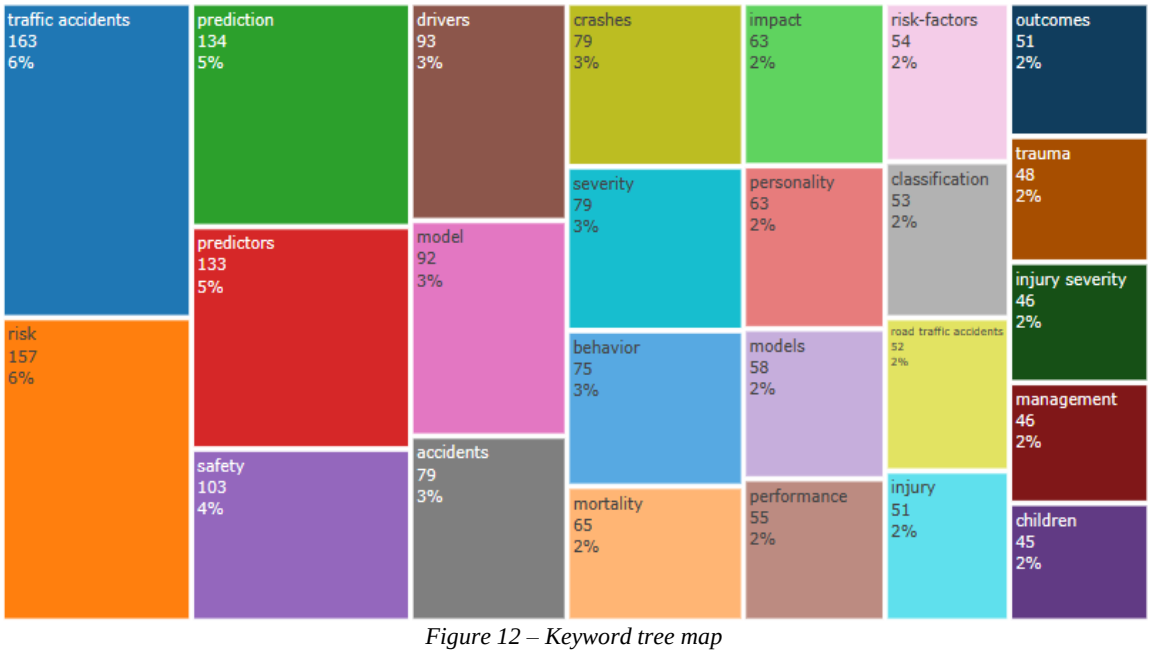

Figure 12 – Keyword tree map

Keyword networks refer to conceptual frameworks that facilitate the identification of relationships and associations among concepts by using the frequency of keyword co-occurrences. The goal of keyword (co-word) analysis is to uncover the conceptual frameworks within publications. The identification of a word that signifies prevalent concepts or ideologies is achieved through the utilisation of both the co-occurrence map and the keyword set.

Figure 13 depicts a thematic map illustrating the keywords employed in the analysed articles. A thematic map exhibits a visually organised representation, resembling a graph, wherein various topics are assessed and categorised within distinct quadrants. The thematic map is structured based on the dimensions of centrality (x-axis) and density (y-axis). Density is a metric that measures the degree of development of the selected theme, whereas centrality assesses the significance or importance of the central theme. The thematic map comprises four sections and serves as a simplified diagram that categorises readers' themes into four quadrants. The themes depicted in the lower left quadrant of the map can be classified as either descending or ascending themes. The researchers have the option to either eliminate such themes from their research or expand further upon them. The basic themes are represented by the lower right quadrant of the thematic map. These particular issues have been the subject of extensive scientific research. The quadrant located in the upper left of the diagram represents the "niche themes" that have been developed but are still isolated. The themes in the upper-right corner have been further developed. Below, a comprehensive analysis of the themes is provided, categorised according to their respective quadrants.

In the basic theme section, keywords such as "traffic accidents", "risk", "prediction" and "mortality" highlight underdeveloped areas in the field, suggesting potential avenues for future research. In this quarter, the keywords "predictive" and "risk factors" demonstrate a higher degree of development compared to "forecast" and "risk", respectively.

The terms "driver", "behaviour" and "personality", which fall within the domains of motor and niche themes, are frequently used, and their co-occurrence is more closely associated with other publications. Keywords such as "model", "injury severity" and "frequency", which pertain to the niche theme area, exhibit an obvious upward trend in the relevant academic literature. The projected trend in flow between the emerging or declining theme and the niche theme indicates an upward trend.

The human factor in traffic events is highlighted in the motor and niche themes. Keywords like "drivers", "behaviour", "personality", "violations" and "road" indicate the dynamic interaction between the psychological constructs of the individual and the surrounding environment. These themes reflect a focus on understanding the underlying causes of accidents, highlighting the possibility for treatments aimed at driver education and behaviour modification, given the emphasis on the actions and personalities of drivers.

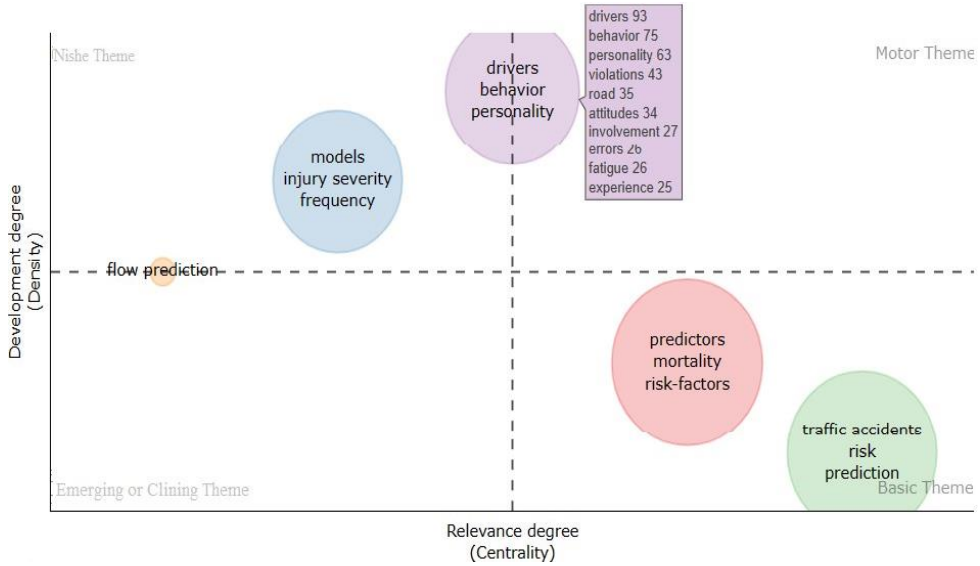

Figure 13 – Keyword thematic map

5.2 Co-citation analysis

Co-citation analysis is a commonly used method in the field of literature review for the purpose of explaining the conceptual structure underlying the advancement of knowledge. It is one of the most widely

used classical techniques in bibliometric analysis. Co-citation networks demonstrate the potential intellectual framework of a particular discipline (authors, article, journal or source) by examining the connections between nodes, wherein each node represents a specific field. In the study, 45,939 citations were made in 1,566 articles. The mean value of these citations over a period of 20 years was 29.3. *Figure 14* illustrates the network of cited authors and shows five clusters of authors. The analysis of each cluster of authors outlines the significant domains of studies. Wang, as the author with the most significant influence, has actively participated in co-citation analysis, thereby forming an influential cluster.

The collaboration network cluster in the centre of the graph, with Wang in the foreground and most of the research in this cluster, and the researchers in the cluster to the left of this cluster have significant collaborations. Examining the studies of the researchers in these clusters, it can be seen that traffic control at traffic control centres, real-time highway networks, traffic flow prediction, traffic monitoring, intelligent transportation systems, traffic congestion prediction, spatiotemporal data prediction, travel time prediction, wireless traffic prediction, traffic speed prediction are used in traffic accident prediction studies. In particular, the abundance of traffic network and traffic flow prediction studies attracts attention. Although machine learning studies are included in the prediction studies in the middle group, we see that traditional statistical methods and geographic information systems are mostly used, while more recent machine learning and artificial intelligence techniques are used in the cluster on the left. The far-right cluster, shown in red, and the cluster just below it, shown in blue, focus on behavioural and sociological aspects, studying individual differences and external factors such as traffic conditions and enforcement policies, respectively. The collaborative cluster at the bottom, shown in green, is characterised by its epidemiological focus, studying population-level patterns and risk factors associated with road crashes. These findings underscore the multidisciplinary nature of traffic accident prediction research, ranging from technological innovations to behavioural and epidemiological investigations, and highlight different approaches to understanding and mitigating traffic accidents.

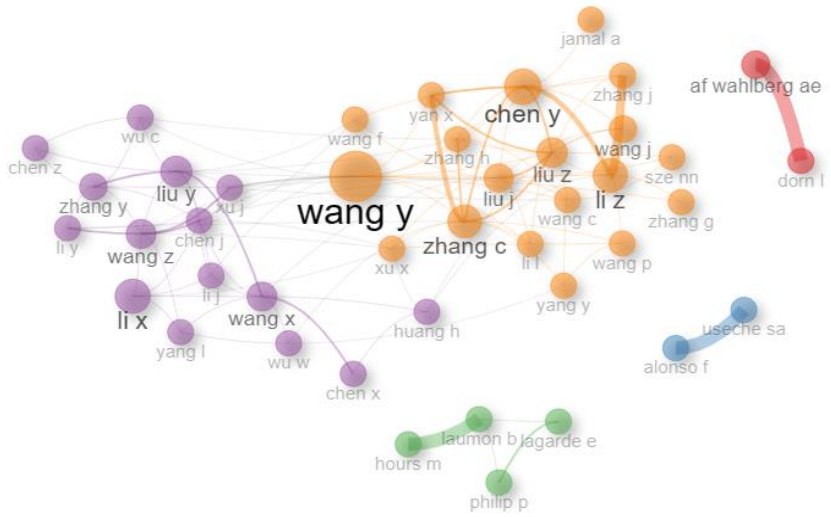

Figure 14 – Author collaboration network

5.3 Historiography

Historiography displays the intellectual connections between cited articles in chronological order. In addition, co-citation networks describe the interrelationship between research articles through citations and thus illustrate the evolution of research and its flow over time. The co-citation network between articles is depicted in *Figure 15* by colouring boxes representing citations and nodes representing the interrelationship between citations. The papers written by these authors signify the initial stages of the concepts, and these innovative methodologies have been referenced and acknowledged in a multitude of scholarly investigations in the past two decades. *Figure 15* portrays historiography in chronological order. Between 2003 and 2009 (red), the authors mostly studied the psychological consequences of traffic accidents, post-accident stress and cognitive evaluation. Between 2004 and 2018 (blue), accident severity predictions were made with statistical and machine-learning methods. Between 2007 and 2014 (green), authors studied accident risks. Between 2013 and 2019 (purple), the authors studied accident severity using machine and deep learning methods on regression models. A model proposal was made for fatal accidents and accident frequencies between 2014 and 2016 (orange).

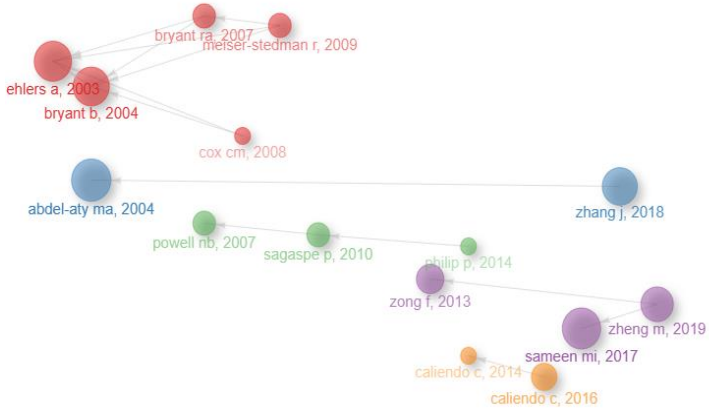

Figure 15 – Historical direct citation network

5.4 Multiple correspondence analysis

Multiple correspondence analysis (MCA) is a widely recognised technique for reducing dimensions in order to examine the relationships among a collection of categorical variables. The keywords generated from the Web of Science (WoS) database were visually organised, and two clusters were generated from a total of 4,610 keywords.

Figure 16 illustrates a conceptual structure map. The prediction of traffic accidents can be divided into two clusters. Cluster 1 (blue) is more concerned with the driver (driver behaviour, violations, personality and engagement), whereas Cluster 2 (red) is more concerned with the methods and other factors than the driver. The black dots represent separate factors associated with the clusters. While the first cluster primarily focuses on behavioural factors, the next cluster focuses on environmental, road, vehicle and traffic accident conditions. Furthermore, when considering the second block (blue), which exhibits the highest degree of division, the right side can be categorised within the perspective of traffic safety, whereas the left side is predominantly classified in terms of methodology and model, as well as driver and vehicle.

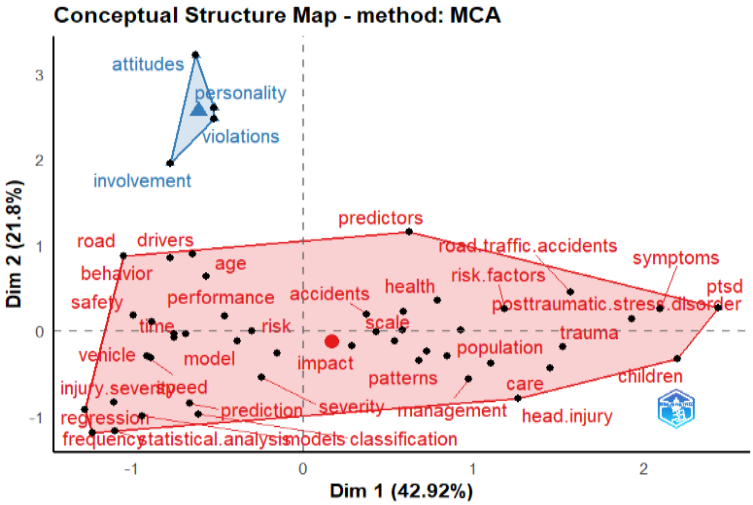

Figure 16 – Cluster map

The high variance explanation rate of 42.9% of Dim 2 on the X-axis explains a large part of the variability in the data set. In this context, while it may represent an important structural feature or relationship, the 21.8% variance explanation rate of Dim 1 on the y-axis is lower and still provides a focus in a certain direction. Clusters between 0 and 3 on the y-axis and between -1 and 0 on the x-axis reflect the driver states even though they are separated.

This helps to understand certain groupings or patterns by making the relationships and patterns between the variables in the data set apparent. While these patterns were in a single grouping for Cluster 1, they emerged as a pattern in which four different groups were formed in Cluster 2. This is the main reason for the high variance of Dim 2.

5.5 Trend topic

Figure 17 represents the research trends based on the keywords analysed. In 2004, accident risk was the focus of research, followed by driver behaviour in 2008, motor accidents and young drivers in 2012, risk, accidents and predictions in 2016, safety, violence, models, clustering and artificial intelligence after prediction, machine learning, design and mixed logic models in the 2020s.

The increasing frequency of keywords related to psychological effects, such as traumatic stress disorder and acute stress disorder, may indicate that researchers are beginning to further investigate the psychological effects of road traffic accidents. The increasing frequency of keywords such as machine learning, deep learning and predictive models may indicate that the use of artificial intelligence and data analytics in predicting traffic accidents is an important trend. Increasing frequencies of keywords such as speeding and accident severity may indicate that measures and safety measures to prevent traffic accidents are being investigated and that these topics are an important focus.

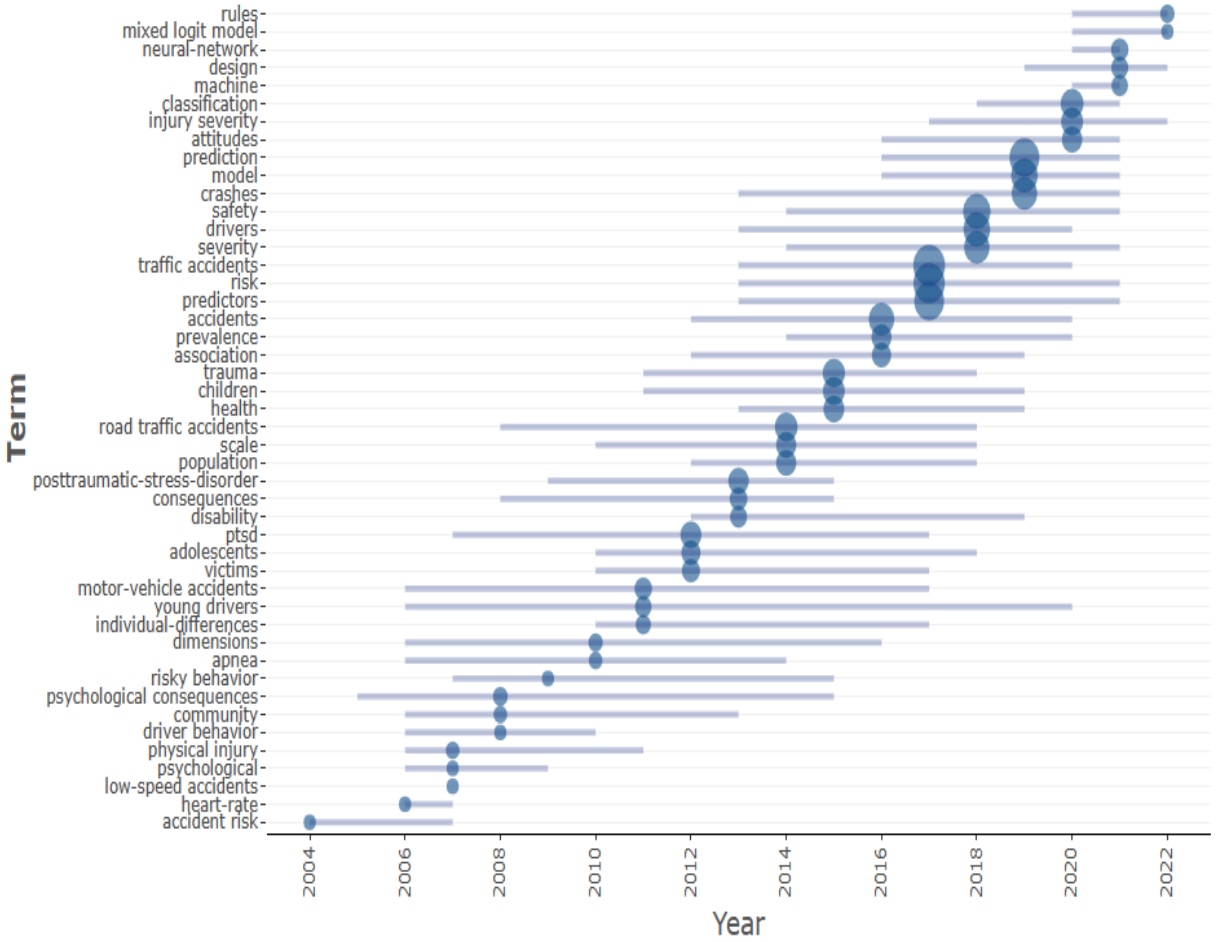

Figure 17 – Trend topic

6. CONCLUSION

Road traffic accidents are one of the leading causes of injury and death in many countries around the world. According to the World Health Organisation (WHO), globally, road traffic accidents cause approximately 1.35 million deaths and cost US$518 billion annually [57]. With 50 million injuries, the number of deaths from road accidents worldwide remains unacceptably high. Road traffic accidents are the leading cause of death in children and young adults aged 5–29 years [1].

The main purpose of this bibliometric analysis is to identify dominant research trends in traffic accidents and prediction studies by examining various factors such as authors, citations, journals, keywords and subtopics. The number of academic articles related to traffic accident prediction has experienced substantial growth since 1991. Currently, there is a substantial volume of literature available on this subject, indicating its growing importance within the academic community. While there are more bibliometric studies on traffic accidents and injuries with

studies such as traffic injuries [11, 14, 58], motorcycle accidents [59] and Accident Analysis and Prevention Journal [52], in this context, a different perspective is presented to other studies with prediction in traffic accidents.

Our research was focused on the leading countries, organisations, journals, authors and articles to determine their level of influence. The large number of journals indicates a wide diversity of research with multidisciplinary features. The journals deal with traffic, accident analysis, engineering, medicine, social sciences, human factors and road safety [59]. The analysis presented in this study provided an assessment of the quality of the research that was performed. The most major nation and the source of a substantial number of studies by numerous writers was China. Changan University in China was the organisation with the greatest influence. According to our study, the Journal of Accident Analysis and Prevention is the most influential journal in the field, which is consistent with the findings of Sharma et al. [14] and Zou et al. [52].

Wang dominates the research field, while Lazono [56] emerged as the most cited source, accumulating a total of 7,524 citations. Notably, the citation average for Lazono experienced a significant increase in 2012, reaching an average of 14.28 citations per year. This value exhibits a notable rise in comparison to the mean of previous years. Given the nature of this investigation as a literature review, it is advisable for researchers who intend to study traffic accidents and prediction to direct their attention toward the examination of traffic flow and density.

Our research on traffic accidents and forecasting has yielded some important insights into the fields of study in this area. Our study shows that familiar topics such as "traffic accidents" and "prediction" are still important pillars and point to areas that, while well-established, are ripe for in-depth research. As the field advances, it is evident that it is moving towards using more technical terms such as "predictive" and "risk factors", which are more intricate. The strong emphasis placed in traffic scenarios on the human element is noteworthy. This focus on the psychological components of drivers and how they interact with their environment highlights the potential for targeted interventions using specialised driver training and behaviour-centric approaches. The incorporation of sophisticated terms like "models", "injury severity" and "frequency" into academic discourse suggests a growing push towards utilising cutting-edge predictive models as we navigate the complex environment. Additionally, emerging areas of concentration, particularly "flow prediction", are marked as seminal domains that may redefine future trajectories, particularly in the context of smart city projects and cutting-edge traffic management paradigms.

Scholars vary in their categorisation of the traffic accident prediction problem, with some considering it a classification problem and others regarding it as a regression problem. However, most classification studies only report the accuracy metric, which is not well-suited for addressing data imbalance issues, such as those encountered in traffic accident prediction. Meanwhile, regression studies use different definitions of accident risk, making comparisons difficult. Decision trees, random forests, K-nearest neighbour, pure Bayes and neural networks are commonly used algorithms in accident prediction. In some cases, deep learning methods have been used similarly to less complex probabilistic classifiers like pure Bayes. Additionally, hybrid models are becoming more prevalent.

Safety is becoming a top research priority for the future generation of intelligent transportation systems due to the rapid advancements in artificial intelligence and intelligent interconnected models, systems and technologies. In light of the results obtained from the present study, it is advisable to develop systems that possess the capability to (1) continuously observe drivers and their immediate environment to identify potential dangers in real-time; (2) establish communication with other vehicles and the infrastructure of the road; (3) detect signs of drowsiness, fatigue or distraction in drivers; (4) optimise routes for efficient travel; and (5) offer risk evaluation and safety measures by implementing collision-avoidance and collision-impact-mitigation strategies. On the other hand, the utilisation of artificial intelligence, machine learning and neural network models has been observed in the domain of traffic accident prediction. However, it is anticipated that the future will witness a proliferation in the adoption of techniques such as deep learning and graph theory, primarily driven by the increasing density of available data. The current issue at hand relates to the prediction of traffic flow density in metropolitan areas, which is influenced by the escalating population density and the growing number of vehicles. Hence, the substantial volume of data related to traffic incidents in urban areas points out the need for forecasting traffic accidents and implementing proactive interventions accordingly.

It is clear from the patterns found in this bibliometric analysis on traffic accidents and prediction that new paradigms like artificial intelligence, machine learning and applications of Industry 4.0 are ready to further transform this field. These hot themes are not only projected to gain even greater traction in upcoming research projects but also show potential for offering innovative answers to age-old problems. However, it is important to recognise the dynamism that bibliometric studies naturally have. Although extensive, the current research only offers a snapshot of the state of science at the moment, which will alter in response to societal changes and new scientific discoveries. To retain a current and comprehensive understanding of traffic accidents and prediction, future researchers should be vigilant and open to this fluid body of knowledge.

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Mesut ULU, Yusuf Sait TÜRKAN

2003'ten 2023'e Trafik Kazası Tahmin Çalışmalarının Bibliyometrik Analizi: Eğilimler, Örüntüler ve Gelecek Yönelimleri

Özet

Trafik kazaları, dünya çapında hem yetişkinler hem de çocuklar arasında ölümlerin ve ciddi yaralanmaların ana nedenlerinden biridir. Trafik kazalarının yol açtığı önemli sosyo-ekonomik kayıpların devam etmesi nedeniyle, kaza riskinin doğru tahmin edilmesi sonraki kazaların azaltılması açısından büyük önem taşımaktadır. Bu nedenle, literatürdeki çalışmaların önemli bir kısmı kaza riskinin, şiddetinin, sıklığının, yerinin ve süresinin tahmin edilmesine yönelik çalışmaları içermektedir. Bu makalenin amacı, 2003-2023 yılları arasında yapılan trafik kazası tahmin çalışmalarındaki kalıpları, boşlukları ve gelecekteki araştırma eğilimlerini belirlemektir. Trafik kazası ve tahmin çalışmalarındaki bağlantıları ve eğilimleri araştırmak için, akademik topluluk içindeki baskın anlatıları ve ağları belirlemeye odaklanan bibliyometrik bir çalışma yürütülmüştür. Anahtar kelime taramasında, Web of Science ana koleksiyonu kullanılarak 1566 makale analiz edilmiş ve yıllık yayınlar ve atıflar, ilk 10, yazarlar, dergiler, kurumlar, en çok atıf alan makaleler gibi bibliyometrik göstergeler ve makalelerin atıf analizi sunulmuştur. Elde edilen sonuçlar, trafik kazalarının bu bibliyometrik analizinde tespit edilen fark edilebilir örüntülerin ve bunların öngörülerinin, yapay zeka, makine öğrenimi ve Endüstri 4.0 uygulamaları gibi bu alanda dönüştürücü ilerlemeleri katalize etmeye hazır olan yeni paradigmalarda çok daha geniş bir uygulama alanı bulacağını göstermektedir.

Anahtar Kelime

Trafik kazası; tahmin; bibliyometrik analiz; araştırma durumu; trand analizi; literatür incelemesi.