



# Artificial Intelligence and Transportations on Road Safety: A Bibliometric Review

Seung Ho Woo, Min Soo Choi<sup>(✉)</sup>, and Vincent G. Duffy

School of Industrial Engineering, Purdue University, West Lafayette, IN 47906, USA  
{woo44, choi502, duffy}@purdue.edu

**Abstract.** The topic of road safety modeling by applying artificial intelligence has been aroused in the research field. The purpose of this study was to explore artificial intelligence enhancing road safety using bibliometric analyses. The data sources were collected from three databases: Scopus, ProQuest, and Web of Science. Numerous analysis tools were applied to visualize the trends and get meaningful outcomes, such as MaxQDA, Vicinitas, Scopus, etc. The measures of analysis were shown in five individual analysis results which include content, co-citation, keyword, trend, and statistical analysis. Statistical analysis was performed by ANOVA to distinguish the significant predictors in publication yields with interpretation. The recent trend in artificial intelligence and road safety has increased in the field of research. All analysis and findings are shown in the analysis section. We briefly mention the future work area ideas in various aspects of the study.

**Keywords:** Artificial Intelligence · machine learning · road safety · transportation · human-computer interaction

## 1 Introduction and Background

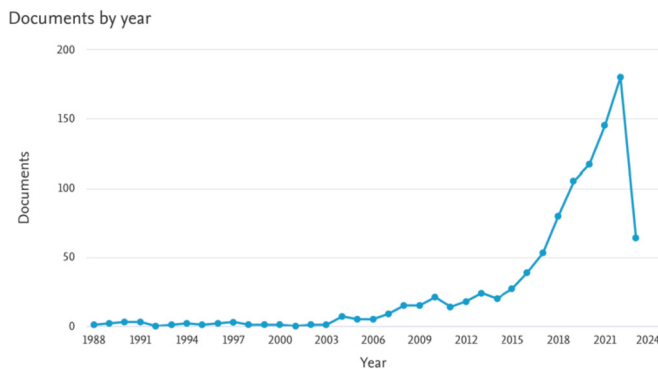
Road safety and human factors are of utmost importance because of the wide-ranging impact that road accidents have on society. Road accidents are responsible for not only the loss of human lives but also for leaving many individuals with permanent disabilities. The economic costs of these accidents are also staggering. The World Health Organization (WHO) has reported that road traffic accidents cause about 1.35 million deaths globally each year, ranking them as the eighth leading cause of death [21]. Furthermore, the economic burden of road accidents is significant. The estimated cost of road traffic crashes is approximately 3% of the Gross Domestic Product (GDP) of high-income countries, and up to 5% in low- and middle-income countries [22]. This significant economic impact makes it essential to develop effective measures to reduce the number and severity of road accidents, considering the role of human factors, such as driver behavior and perception, in road safety. Therefore, it is essential to carry out research in road safety and human factors to ensure that effective measures are developed and implemented to enhance road safety, reducing the number of accidents and saving lives.

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S. H. Woo and M. S. Choi—Equally contributed the work.

One of the key applications of AI in road safety is through advanced driver assistance systems (ADAS). ADAS uses sensors, cameras, and machine learning algorithms to analyze data from the environment around a vehicle and provide drivers with real-time information about potential hazards on the road. For example, a forward-facing camera and radar sensor can detect the distance between the vehicle and the one ahead, and if the vehicle gets too close, the system can automatically apply the brakes to prevent a collision. [24] Other ADAS features include adaptive cruise control, which automatically adjusts the speed of the vehicle to maintain a safe distance from the vehicle ahead, and lane departure warning, which alerts drivers if they start to drift out of their lane. [25].

Furthermore, AI is also being used to analyze data from infrastructure such as traffic lights and road signs. One of the applications of the AI, Computer vision algorithms can detect pedestrians, cyclists, and other hazards on the road, and provide real-time warnings to drivers. If a pedestrian is detected crossing the road ahead, the system can alert the driver with a visual or audio warning. [23] The other area where AI is being used in road safety is in predictive maintenance systems. These systems use data from sensors and vehicle diagnostics to detect potential issues with a vehicle before they become serious safety concerns [26]. In addition to these applications, AI is also being used to analyze data from cameras and sensors in vehicles to provide insights into driver behavior. This data can be used to identify patterns of behavior that are associated with increased risk, such as distracted driving [28, 29]. By identifying these patterns, safety officials can develop targeted interventions to reduce the risk of accidents caused by these behaviors. Overall, the use of AI in road safety is a rapidly evolving field with many potential applications, as we can see from the publication increases in Fig. 1.



**Fig. 1.** The number of published papers per year from the SCOPUS search result.

Consequently, there have been many review papers on AI and Road Safety as well. Bhattacharya et al. [12] reviews the techniques adopted for implementing an intelligent road safety system, with emphasis on the behavior of drivers, vehicle condition, road and bridge health, and theft-related issues using RFID, highlighting the role of IoT and AI. Sagberg et al. [14] This study outlines a conceptual framework for understanding driving styles and conducts a systematic literature search to review the state-of-the-art research on driving styles in relation to road safety. Wang et al. [14] examines China's traffic

problems, focusing on pedestrian and bicyclist safety and aggressive driving, through a review of 43 Chinese journal articles on road safety. Torbaghan et al. [15] provides a systematic review of the potential of digital technologies, such as AI, Machine-Learning, and IoT, in improving road safety, and highlights a key gap in their effectiveness in real-world environments. Olugbade et al. [16] discusses the potential use of artificial intelligence and machine learning in establishing an automatic incident detection system to decrease road accidents, with a systematic review, focusing on the application of these technologies in road management and safety, as well as the challenges and potential solutions associated with their use. Zheng et al. [17] reviews the use of traffic conflicts as an alternative measure of road safety and identifies conceptual and methodological issues associated with the modeling of traffic conflicts, indicating that more research is needed to address these challenges. Vecino-Ortiz and Hyder [18] reviews the available literature on the links between Bus Rapid Transit (BRT) systems and road safety and calls for more research to strengthen the evidence on the effect of BRT systems on road safety in low- and middle-income countries. Tselentis and Papadimitriou [19] reviews the AI and ML approaches developed for driver profile and driving pattern recognition, identifying efficient methodologies, and proposing a new framework for combining microscopic and macroscopic driving behavior analysis to improve traffic risk models and the development of applications that monitor drivers in real-time to enhance road safety. However, most of the review papers on AI and Road Safety depend on authors' selections of articles, and focus on one or a few aspects of factors that affect road safety.

In our study, utilizing computer-aided software, we conducted a *bibliometric* literature review in AI and Road Safety, and provided insights on the history and the trends of the previous research. At the best of the authors' knowledge, this is the first *bibliometric* literature review in this research area. The use of bibliometric analysis for various purposes, such as identifying emerging trends in article and journal performance, exploring collaboration patterns and research constituents, and understanding the intellectual structure of a particular field in the existing literature. This type of analysis deals with large and objective data sets, such as the number of citations and publications or the occurrences of keywords and topics. Interpretations of the data often involve both objective and subjective evaluations established through informed techniques and procedures. Bibliometric analysis is useful for deciphering and mapping the accumulated scientific knowledge and nuances of established fields, making sense of unstructured data in rigorous ways. Well-conducted bibliometric studies can provide a solid foundation for advancing a field by helping scholars gain an overview, identify knowledge gaps, derive novel ideas for investigation, and position their intended contributions to the field. The tools of the bibliometric analysis we have used were Scopus, Web of Science (WoS), ProQuest, Harzing software [27], VOSViewer co-citation software [30], MAXQDA [31], and further.

The rest of this paper is organized in the following manner: Sect. 2 of this paper elaborates on the details of our literature review methodology, which involves the use of several software tools to extract, analyze, and organize relevant research papers from a vast database. We will discuss the advantages of using these tools and how they helped us streamline the literature review process. In Sect. 3, we present the results of our analysis, highlighting the most commonly used methodologies and techniques in the field of road

safety research, as well as identifying research gaps and areas for further investigation. Lastly, in Sect. 4, we summarize our findings, provide insights into the current state of research on AI and road safety, and offer concluding remarks on the importance of continued research in this area.

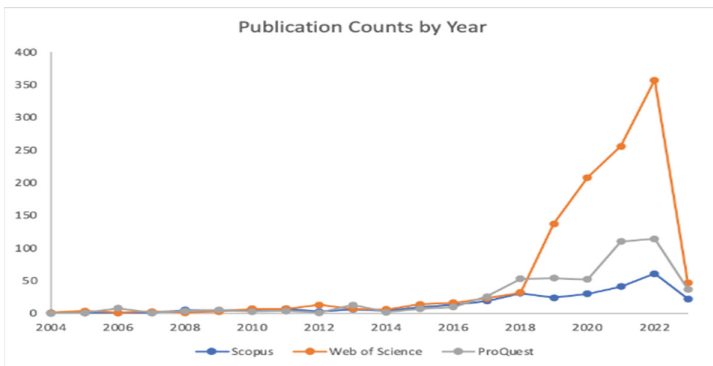
## 2 Procedures

### 2.1 Data Collection

Initial data sources were acquired from multiple resource databases, including Web of Science, Scopus, and ProQuest. The search process was conducted by Harzing’s Publish or Perish software and direct search from the databases. The aimed timeline of the search was 20 years of publications; we set up the timeline as 2004 to 2023, which sums to 20 years. The investigation was done by whole publication counts and publication counts of each year. 20 years of the timeline was set up to visualize and track the trend of publications in the Artificial Intelligence and Road Safety area. The initial search of three databases were shown in the Table 1 below, and the annual publication trends were visualized in the Fig. 2. Furthermore, after collecting the publication counts from each database, significant reference research articles were extracted from the database. In each database, four relevant articles were extracted from the original source to conduct the analysis overall.

**Table 1.** Keywords search result from three databases

| Database       | Search keywords                             | # publications | Time period |
|----------------|---|----------------|-------------|
| SCOPUS         | “Artificial Intelligence” AND “Road Safety” | 290            | 2004–2023   |
| Web of Science | “Artificial Intelligence” AND “Road Safety” | 1143           | 2004–2023   |
| ProQuest       | “Artificial Intelligence” AND “Road Safety” | 505            | 2004–2023   |



**Fig. 2.** Publication trends per database per year, from 2004 to 2023.

### 2.2 Content Analysis

By the initial search, four research articles of each database were collected. Total 12 research articles were applied to perform the content analysis. The content analysis was conducted by the MAXQDA software. The irrelevant words including preposition, article, and pronouns were removed before conducting the analysis. By utilizing MAXQDA software, the word cloud was generated with the most relevant terminologies regarding artificial intelligence and road safety as Fig. 3 shown below.

After generating the word cloud, MAXQDA software was applied to find the most frequent terminologies in the searched articles. Figure 3 below describes the top 10 frequent words from the contents. The most frequent words were vehicles, drivers, systems, detection, etc., in the field of the topic.

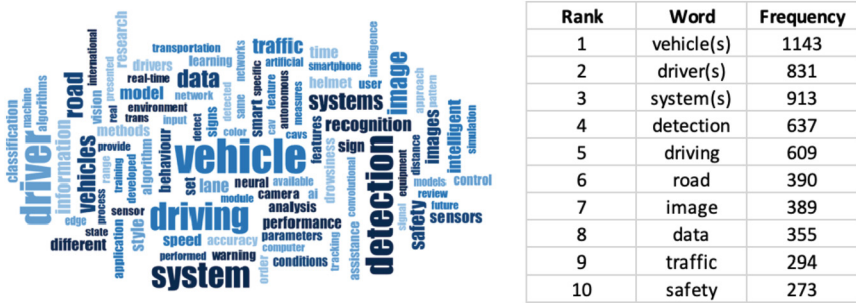


Fig. 3. Word cloud visualization (left) and the 10 most frequent words (right) after removing stop words (e.g. and, is, then).

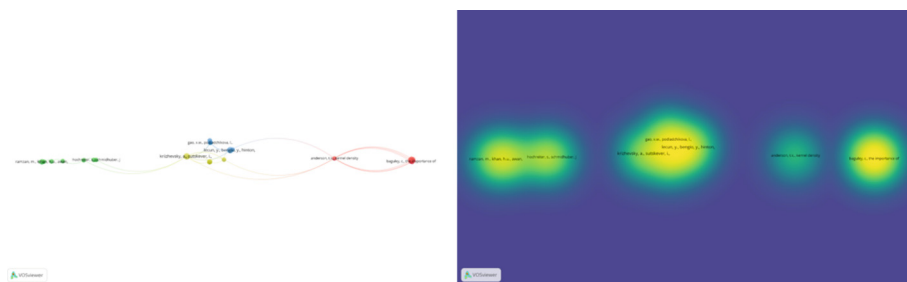
### 2.3 Co-citation Analysis

Co-citation analysis is a bibliometric technique used to identify the frequency of citation of two or more documents by other documents. It helps researchers to uncover the intellectual structure of a research area by mapping relationships between the most cited articles, authors, or journals in a given field. Co-citation analysis is used to identify the key concepts and themes that are frequently discussed in a field, as well as to identify the most influential works and authors in that field. In this study, we used two softwares, VOS Viewer and Citespace, for a co-citation analysis. Furthermore, we conducted a keyword analysis on the same list of articles using VOS Viewer. For the analysis, we used 290 articles sourced from SCOPUS search results.

VOS Viewer is a software tool for constructing and visualizing bibliometric networks. It uses various clustering and mapping techniques to create a visual representation of the co-citation network. In our co-citation analysis using VOS Viewer, we set the minimum citation count parameter as 2, and in total 87 out of 290 papers satisfied this threshold. However, most of the 87 are singleton clusters, and only 23 of them belong to non-singleton clusters (i.e. connected to one or more articles). Figure 4 shows results of the co-citation analysis in the form of the network visualization and the density visualization.

There are in total four clusters detected: namely, cluster 1 for reds, cluster 2 for greens, cluster 3 for blues, and cluster 4 for yellows. The two-to-three articles of the most link strengths from each cluster are provided in the Table 2.

Cluster 1 is characterized as spatial analysis in accident hotspot identification using data-driven methodology. Both of the articles are published in the journal called Accident Analysis & Prevention. Cluster 2 is characterized as the fundamentals of neural networks. Both of the papers provide a theoretical foundation of deep learning that is the most popularly used methods in AI applications. Cluster 3 is characterized as road artifact detections (e.g. traffic signs) using computer vision-based AI. Lastly, Cluster 4 is characterized as the fundamentals of modern deep learning in computer visions. Both articles in this cluster discuss convolutional neural networks and are highly cited over many AI application domains.



**Fig. 4.** Co-citation analysis result using VOS Viewer. The left figure is a network visualization of co-cited papers and the right figure is a density visualization of the network.

**Table 2.** The highest link counts nodes from each cluster (VOS Viewer co-citation analysis).

| Cluster   | Article                          | Links count | Link strength |
|-----------|----------------------------------|-------------|---------------|
| Cluster 1 | Anderson. [33]                   | 9           | 9             |
|           | Yu et al. [34]                   | 6           | 11            |
| Cluster 2 | Hochreiter and Schmidhuber. [35] | 3           | 4             |
|           | McCulloch, and Pitts. [36]       | 3           | 3             |
| Cluster 3 | LeCun et al. [37]                | 6           | 7             |
|           | Gao et al. [38]                  | 4           | 6             |
|           | Mogelmose et al. [39]            | 4           | 6             |
| Custer 4  | Krizhevsky et al. [40]           | 9           | 11            |
|           | Szegedy et al. [41]              | 5           | 6             |

## 2.4 Keyword Analysis

Furthermore, we conducted keyword analysis in VOS Viewer with the same dataset. The results are presented in Fig. 5. Especially, Fig. 5-a shows the result of the clusters analysis,

and Fig. 5-b shows the temporal analysis on the keywords network. From Fig. 5-a, we can observe that there are four prominent clusters of risks involved in the road hazards (red), specifications of methodologies used in AI and road safety (yellow), broader categories of various methodologies (blue), and qualitative and systemic point of views (purple and cyan). Looking at the temporal analysis result, we also find interesting evolutions of research topics. In the 2010s, the major keywords are the road safety related risks, and, as it goes to the current time, keywords related to advanced AI methodologies become more prominent. Furthermore, in the very recent keywords (light yellow colors), we can also view the emerging interests in viewing road safety in a bigger context (i.e., the systems); as keywords such as communication, traffic management, vehicular networks, traffic sign detection implies.

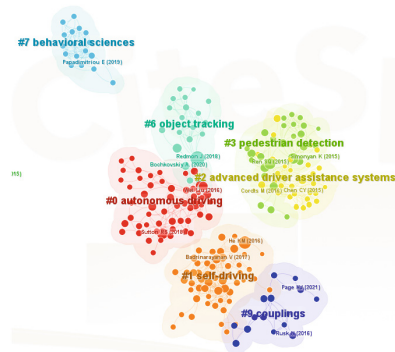


**Fig. 5.** Keyword analysis result using VOS Viewer. The left figure is the basic network visualization of papers' keywords and the right figure is the same network with the temporal feature overlaid. (Color figure online)

Moreover, in Fig. 6, the keyword analysis using CiteSpace is presented. In this case, we sourced the raw data from Web of Science which consists of about 1300 articles, and among them we analyzed the papers from 2014 to 2023. There are three major categories on machine learning methodologies (cluster 3 and 6), on systems (cluster 0, 1, 2, and 8), non-ML human factors research (cluster 7). Interestingly, unlike the keywords research from VOS Viewer, there are no prominent clusters with keywords related to the risks of road conditions itself. However, there are also overlapping areas on AI/ML methodology, and road systems. We believe this is attributed to the years included in the analysis. Due to the technical limitation, we used articles published since 2014 only in CiteSpace, and they includes more AI and system-based analysis, as we can view from Fig. 5, the temporal feature graph.

## 2.5 Trend Analysis

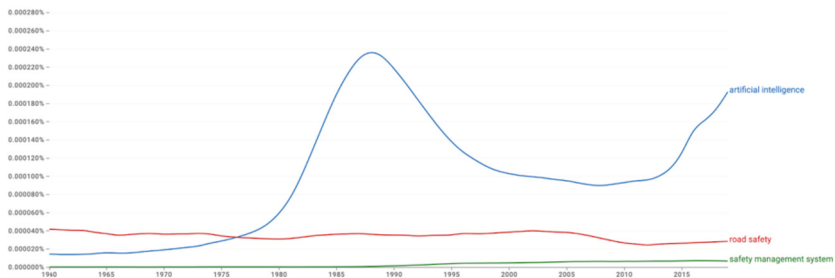
In the Fig. 7. Below shows the brief trend of the three terms related to the topic which are "Artificial Intelligence", "Road Safety", and "Safety Management System". The analysis was conducted by the Google Ngram Viewer. The Google Ngram Viewer is a tool that exhibits a graph representing the frequency of user-selected words or phrases (ngrams) in a corpus of scanned books available in Google Books. The graph is generated with the publication year in the X axis with the frequency of the ngrams throughout the corpus



**Fig. 6.** Keyword analysis result using CiteSpace. Clusters are color-coded and titled.

in the Y axis. Researchers can enter the terms in ngrams and modify the case sensitivity, language, date range, and smoothing. [32] Our designated timeline for search was 1960 to current that the trend of the publications were easily visualized.

Using the Scopus database, various trend analyses were conducted. Figure 7 below shows the publication trends of the area of the journal. The top 6 highest appearances in the journal area were Computer Science (29.4%), Engineering (26.7%), Social Sciences (8.5%), Mathematics (8.0%), Physics and Astronomy (4.6%), and Decision Science (4.2%).



**Fig. 7.** Bigrams for artificial intelligence, road safety, and safety management system.

The annual trend of publications in three databases (Scopus, Web of Science, ProQuest) is described in Table 3. The highest publication count year was 2022 in all three databases. Furthermore, the lowest publication count year was 2004–2007 in Scopus, 2008 in Web of Science, and 2004 in ProQuest. The annual trend of the number of publications in all databases is growing recently. The annual publication trends in the area of “Artificial Intelligence” and “Road Safety” tracked from the year 1988 to 2023. The yearly publication trends of the research area have been arousing from 2014 to 2022, which is shown in Fig. 1, It can be interpreted as the topic has emerged. As shown in Fig. 8, the most frequent academic journal author of the publications in this area are Zhang J., Taddeo M., Qi D., Szolovits P., Xu W., Yudkowsky E., and Bostrom N using Bibexcel and Harzing software. The top 10 countries in the most frequent publications

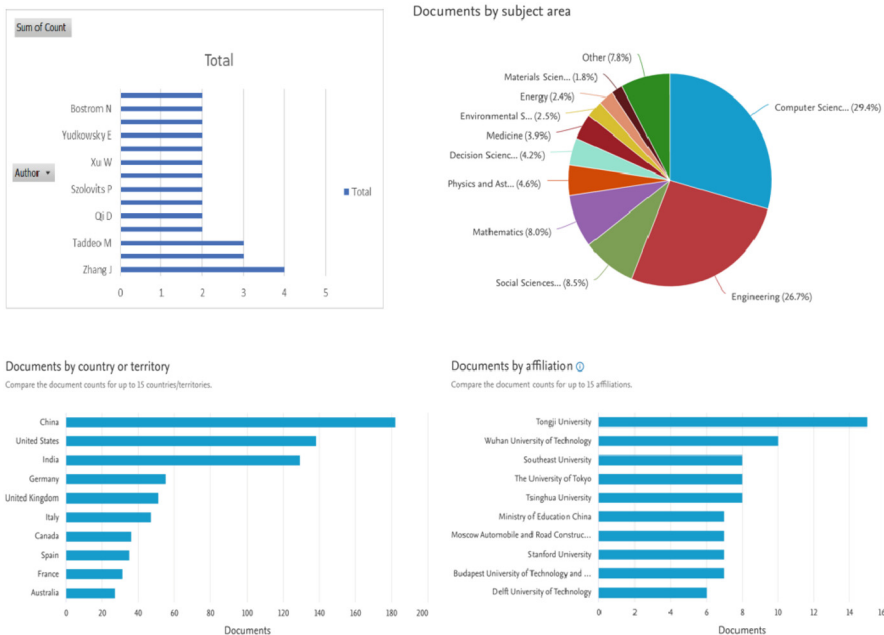


presented in this field were China (182), the United States (138), India (129), Germany (55), the United Kingdom (51), Italy (47), Canada (36), Spain (35), France (31), and Australia (27) as in Fig. 8. Furthermore, the highest publication count affiliations were Tongji University, Wuhan University of Technology, Southeast University, etc.

**Table 3.** Annual trend of publications from 2010 to 2023 per database.

| Database       | Year (20xx) |    |    |    |    |    |    |    |    |     |     |     |     |    |
|----------------|-------------|----|----|----|----|----|----|----|----|-----|-----|-----|-----|----|
|                | 10          | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19  | 20  | 21  | 22  | 23 |
| SCOPUS         | 6           | 7  | 3  | 6  | 4  | 10 | 13 | 19 | 31 | 24  | 31  | 41  | 61  | 22 |
| Web of Science | 7           | 7  | 13 | 7  | 6  | 14 | 16 | 23 | 32 | 137 | 208 | 256 | 357 | 47 |
| ProQuest       | 3           | 4  | 1  | 13 | 1  | 7  | 10 | 26 | 53 | 54  | 52  | 110 | 114 | 37 |

To track the hashtags and keywords in social media, the Vicinitas free software was applied. The keyword that we investigated was artificial intelligence and transportation which includes the topic of road safety. The analysis conducted shows word cloud, engagement timeline, posts timeline, types of posts, and the types of rich media in the social media as in Fig. 9.



**Fig. 8.** Frequency analyses of published articles by authors, subject area, country/territory, and affiliation, respectively.

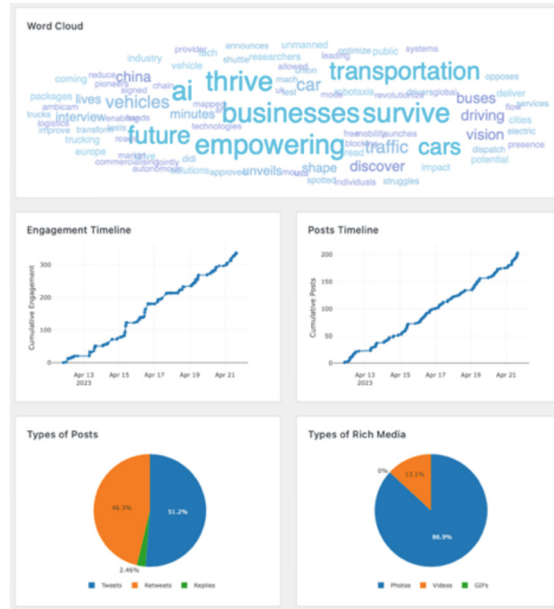


Fig. 9. Vicinitas social media trend analysis

## 2.6 Statistical Analysis

Statistical analysis was performed by the Minitab software. The analysis was based on the linear regression model. To figure out which predictors are working as a key feature affecting response predictor, the number of articles. The method of the statistical analysis conducted was categorical predictor coding. The linear regression equation of the model is as the following:

$$(\#articles) = 5.4 + 0.0 * DB_{PQ} - 29.3 * DB_{SCOPUS} + 44.0 * DB_{WoS} + 0.0 * Y_{15} + 28.3 * Y_{18} + 125.3 * Y_{21}$$

where DB stands for database and subscripts PQ, SCOPUS and WoS stands for the three databases respectively; Y stands for year and each subscript is for each year.

According to the coefficient table, which is shown in Fig. 10, the year 2021 is the most significant predictor among others by the p-value in the analysis of the coefficients. The p-value is used to determine the significance of the predictors; if the p-value is less than or close to 0.1, the predictor is relatively significant. Additionally, the R-squared value of the linear regression model shown in Fig. 10 is 67.71%, which could interpret the amount of the observed variables in the model. Since the R-squared value is relatively high in this model, it can be defined that the linear regression model did fit well.

Furthermore, the analysis of variance (ANOVA) result also reveals the analysis of the linear regression model, which is shown in Fig. 11. According to the p-value of the ANOVA table, the only significance feature is the Year, whose p-value is 0.149, which is relatively low compared to other features. The four residual plots for the number of

**Coefficients**

| Term     | Coef  | SE Coef | T-Value | P-Value | VIF  |
|----------|-------|---------|---------|---------|------|
| Constant | 5.4   | 47.5    | 0.11    | 0.914   |      |
| Database |       |         |         |         |      |
| Scopus   | -29.3 | 52.1    | -0.56   | 0.603   | 1.33 |
| WoS      | 44.0  | 52.1    | 0.85    | 0.446   | 1.33 |
| Year     |       |         |         |         |      |
| 2018     | 28.3  | 52.1    | 0.54    | 0.615   | 1.33 |
| 2021     | 125.3 | 52.1    | 2.41    | 0.074   | 1.33 |

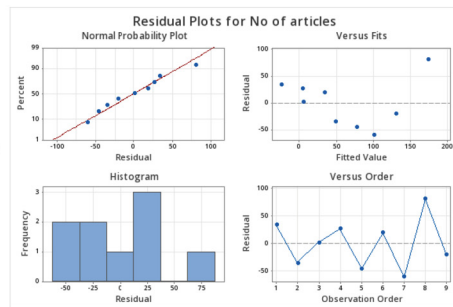
**Model Summary**

| S      | R-sq  | R-sq(adj) | R-sq(pred) |
|--------|-------|-----------|------------|
| 63.756 | 67.71 | 35.42%    | 0.00%      |
| 9      | %     |           |            |

**Fig. 10.** Summaries of the regression analysis result.

**Analysis of Variance**

| Source     | DF | Adj SS | Adj MS | F-Value | P-Value |
|------------|----|--------|--------|---------|---------|
| Regression | 4  | 34094  | 8524   | 2.10    | 0.245   |
| Error      | 4  | 16260  | 4065   |         |         |
| Total      | 8  | 50354  |        |         |         |



**Fig. 11.** The summary table of the ANOVA result.

articles are shown in Fig. 11. In a normal probability plot, the data points are aligned with the fitted linear line, which means that the residual number of articles fits well in the probability plot. The versus fits and versus order plot show that those data points are randomly scattered. Lastly, the histogram of the residual is skewed left, and most of the frequency is concentrated on 25 residuals.

### 3 Discussion

Transportation is an important factor in our daily life everywhere on earth. This, however, also means that we are exposed to the risk of accidents on the roads every day. Due to the expansion of the population on the globe, more vehicles are produced and driven by humans. It directly increases the rate of road accidents and the rate of mortality by accident. Furthermore, when the system of transportation infrastructure grows and becomes more complex, more regulation rules needs to be added to control the transportation system. Thus, it is important for modern society to run the best practices to keep the road safe from fatal accidents. Utilizing Artificial Intelligence technologies that have advanced dramatically over recent decades, we can keep individuals safe on the roads from critical accidents more effectively since the AI is able to model complex non-linear systems such as road transportation infrastructure networks and conditions.

Related to artificial intelligence and road safety, there are various research works conducted in the field. We emphasize the trend of the publications in the area by the bibliometric analysis in multiple resources. Before performing the analysis, we derived the data sources from three databases; Scopus, ProQuest, and Web of Science. We set up the timeline as 2004 to 2023, which includes the recent 20 years period. By comparing the acquired publication counts, the highest number of articles appeared in the Web of Science, followed by ProQuest and Scopus. The publication trends are aroused from the year 2016 to recent years.

The content analysis was performed by the MaxQDA software by word cloud and frequent term search. The word cloud was utilized to visualize relevant words used in the research articles on the topic of the research area. And the top 10 frequent content terminologies are also queried. The most frequent terms in the area were vehicles, drivers, systems, detection, driving, road, image, data, traffic, and safety.

To track the publication trends in various areas, we conducted a trend analysis. Google Ngram Viewer was used to compare the trends of our topic with related topics; “Artificial Intelligence”, “Road Safety”, and “Safety Management Systems”. The artificial intelligence topic has been aroused recently in the research field. Furthermore, we also tracked the leading factors in publication, such as subject areas, authors, countries, and affiliations. Social media hashtags and keywords were also investigated by the Vicinitas software to analyze the trend in public.

Moreover, we analyzed the relationships between articles, using co-citation analysis and co-occurrence analysis of keywords through VOS Viewer and CiteSpace. Through those cross relational analyses we could find the clusters and temporal patterns in publications on AI and Road Safety. The major clusters are related to road environments evaluation/prediction, road artifacts (e.g. traffic signs), transportation systems analysis (e.g. vehicles network), and machine learning and artificial intelligence methodologies frequently used in the field (e.g. computer vision related). We also found that the field of AI and Road Safety is moving toward tackling the problem from a systemic point of view from focusing on smaller tasks, such as road sign detection or accident hotspot detection, which was more popular a decade ago.

Lastly, we conducted statistical analyses using Minitab software to identify the important predictors in the publication trend and to understand the relationships between the predictor(s) and the dependent variable. As a result, the year predictor is the only significant factor among the variables in the search for publications.

## 4 Conclusion

Artificial intelligence is rapidly grown in the field of research and industry to solve current social problems. Transportation area is also evolving due to expansion of population and vehicles. Specifically, safety issue has been arouse concurrently with the transportation field of study. By utilizing the co-citation analysis results, artificial intelligence and road safety area of research shares the common idea. Furthermore, the trend of both research area continually grows since the leading researchers are publishing research articles actively.

As the research grows in this field, there are several funded works from the National Science Foundation grant research on-going. One research award is titled as “Acquisition of Connected Autonomous Vehicles(CAV) Infrastructure to Support Cooperative Human-Robot Driving and Pedestrian Safety”. The research grant #2216489 was awarded to Deepankar Medhi of UNLV Computer and Network Systems department. This project aims to create a “living laboratory” at the UNLV to facilitate research on connected and autonomous vehicles (CAVs) by deploying advanced sensors and vehicle-to-everything(V2X) communication equipment at three intersections adjacent to campus. The project seeks to investigate the cooperative and collaborative aspects of V2X connectivity and to develop AI algorithms that can adapt to different driving scenarios.

In this paper, we employed computer-aided software to systematically analyze the vast amount of academic publications in the field of AI and Road Safety. By utilizing various software tools – MaxQDA, VOS Viewer, CiteSpace, and Minitab –, we were able to identify the research history and trends in this field. Our study provides researchers interested in the field of AI and Road Safety with a comprehensive understanding of the research landscape as well as valuable insights into the future direction of this field.

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